WIFO
ÖSTERREICHISCHES INSTITUT
FÜR WIRTSCHAFTSFORSCHUNG

WORKING PAPERS

Combining a Demand System with the Household Production Approach

Modelling Energy Demand in Selected European Countries

Kurt Kratena, Michael Wüger

311/2008

Combining a Demand System with the Household Production Approach

Modelling Energy Demand in Selected European Countries

Kurt Kratena, Michael Wüger

WIFO Working Papers, No. 311
February 2008

E-mail addresses: Kurt.Kratena@wifo.ac.at, Michael.Wueger@wifo.ac.at
2008/038/W/0

COMBINING A DEMAND SYSTEM WITH THE HOUSEHOLD PRODUCTION APPROACH: MODELLING ENERGY DEMAND IN SELECTED EUROPEAN COUNTRIES

Kurt Kratena, Michael Wueger
Austrian Institute of Economic Research
P.O. Box 91 , A-1103 Vienna, AUSTRIA
Tel.: +43 1 7982601 246
Fax: +43 1 7989386
e-mail: Kurt.Kratena@wifo.ac.at

Abstract:
This paper sets up a model of private consumption for selected EU countries with special emphasis on the impact of energy efficiency on energy demand. Starting point for the analysis is the idea that consumers' demand is a combination of a demand for 'services' with a technological component. Demand for services is derived from utility maximization or cost minimization and actual energy (commodity) demand stems from a household production process. The model indirectly takes into account the impact of capital stocks and technology on energy demand and all the different links between services and goods demand. That allows for describing more channels of impacts on consumption expenditure for energy and non-energy than in traditional consumption models.Exogenous key variables that can be modified in order to calculate different scenarios are: (i) prices of energy and non-energy goods and (ii) the exogenous capital stock (infrastructure) or user costs of capital. Simulations of revenue neutral energy taxation with changes in capital stocks for heating and transport are carried out.
JEL Code: D11, D13, Q53

1. Introduction

Economic modelling of household energy demand can be seen as an important part of research in energy as well as environmental economics. Consumption patterns are increasingly seen as being central for a change in economic activities towards less energy and emission intensive structures. The existing research on this issue is mainly focused on the empirical analysis and assessment of consumption patterns and the related environmental effects (Brand, 2000 and Brown, Cameron, 2000). If we accept environmental targets as binding resource constraints for the potential of welfare maximization of consumers, ’decoupling’ of undesired emissions or resource flows from the desired and increasing flow of total consumer income and welfare is needed. Starting point for this analysis is the idea that households demand an output of a production process, where the input of market goods and capital are combined to deliver ’services’. This idea has been formulated in the theory of household production. The original approach of the household production function put forward by Lancaster (1966) has been taken up by various authors to show the differences to traditional consumption theory (Becker, 1965, Stigler, Becker, 1977). A very interesting application to energy consumption including investment decisions in energy efficiency has already been established by Willett, Naghspour (1987). Nevertheless all these studies do not include empirical applications of the household production function and do not deduce explicit demand functions.

On the other hand we find several attempts in energy economics to capture the role of prices as well as technology embodied in capital goods (appliances) on energy demand (e.g. Conrad, Schröder, 1991). This is often labelled as the synthesis between economic and engineering models (s.: Larsen, Nesbakken, 2004) or as a combination of bottom-up and top-down modelling (Rivers, Jaccard, 2005). If the aspect of overall welfare maximization has to be considered a model of total consumption must be formulated. Models of energy and non-energy consumption are usually incorporated into CGE models (s.: Boehringer, Loeschel, 2004). The role of capital or appliances is not incorporated in most of these models and welfare is linked to the commodity flows. Therefore 'decoupling' of energy flows from total consumption can only occur by reducing energy flows with the corresponding negative consequences for welfare, which can only be compensated, if non-energy consumption increases in a sufficient magnitude. This in the end depends on the price (substitution) elasticities.

Another extension to deal with the impact of technology on energy demand is describing the link between energy efficiency and capital stocks. One approach is to simply use the technical efficiency of the aggregate stock which changes by new investments (Khazzoom (1980), (1989)). An important aspect in these approaches is a feedback-loop from technological change (= changes in the efficiency of the stock) to the price of 'services'. This induces substitution reactions at the level of services with a feedback to energy demand. In the studies of Khazzoom the main consequence of this mechanism is the 'rebound effect': Improvements in the efficiency of the stock are partly compensated by increasing demand for 'services' due to lower 'service' prices. In our approach this will be done by using a 'household production function' where demand for energy commodities is a derived demand from the cost function of household production. Implementing the Khazzoom approach would have as a prerequisite data availability on the energy efficiency of different household appliancers and vehicles.

The purpose of this paper is to set up an empirical model of overall consumption, where household production for 'energy services' (heating, mobility) and demand functions for 'energy services' are integrated in a consistent way together with non-energy consumption.. Demand for energy commodities in such a model is a derived demand from the cost functions of household production. Capital is accumulated and financed out of household income, but does not directly contribute to the utility from consumption as is the case for non-durable goods. Capital serves as an input that together with other inputs produces a certain flow of services (commodities).

The analytical potential of our approach lies in the explicit formulation of all the different links between services and goods demand. That allows for describing more channels of impacts on consumption expenditure for energy and non-energy than in traditional consumption models. For example not only goods prices but also capital stocks play an important role in explaining consumption patterns. Service prices are also influenced by changes in capital stocks without changes in goods prices. Therefore a similar rebound effect as in the work of Khazzoom (1980, 1989) is implemented in our model without explicit information about the energy efficiency of appliances. An additional advantage of our model is that we are able to calculate welfare impacts based on the equivalent variation criterion.

The paper is organized as follows. In section 2 the main building blocks of an aggregate model of consumption are presented. Section 3 describes the detailed household production model for transport and for heating demand used to derive the overall model. In section 4 we describe the data base for the model, present estimation results and two taxation scenarios with narrowly targeted revenue recycling for several EU countries. Section 5 summarizes the main results and concludes.

2. The aggregate model of consumption

The structure of the model distinguishes between aggregate household consumption, capital expenditure of households, energy and other flows for heating and transport as well as other goods and services.

The overall model of private consumption starts from the indirect utility function of the Almost Ideal Demand System (AIDS, s.: Deaton and Muellbauer, 1980):

$$V = (\log C(U,\mathbf{p}) - \log(P_1))*(P_2)^{-1} \qquad (1)$$

The level of utility U and the vector of commodity prices **p** are the arguments of the expenditure function C. The two price aggregator functions P_1 and P_2, are defined by the following expressions:

$$\log P_1 = \log a(\mathbf{p}) = a_0 + \sum_{i=1}^{n} \alpha_i \log p_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{m} \gamma_{ij}^{*} \log p_i \log p_j \qquad (2)$$

$$P_2 = \log b(\mathbf{p}) - \log a(\mathbf{p}) \qquad ; \qquad \log b(\mathbf{p}) = \log a(\mathbf{p}) + b_0 \prod_{i=1}^{n} p_i^{\beta_i} \qquad (3)$$

That is, $\log(P_1)$ is a translog-function and (P_2) is a Cobb-Douglas type function. The indirect utility function corresponds to the PIGLOG-specification of the expenditure function C in the AIDS which is usually written as:

$$\log C(u,\mathbf{p}) = (1-u) \log[a(\mathbf{p})] + u \log[b(\mathbf{p})], \qquad (4)$$

A measure of utility in AIDS is therefore given by the indirect utility function $U = \dfrac{\log(C(U,p)/P_1)}{b_0 \prod_{i=1}^{n} p_i^{\beta_i}}$, with the level of utilitiy (U) $0 < U < 1$ (for exceptions see the

Appendix of Deaton, Muellbauer, 1980). This measure can be used to calculate welfare impacts applying Hick's equivalent variation criterion.

The commodity classification *i* in this model includes:

(i) services for transport, S_T

(ii) services for heating, S_H

(iii) other (non-energy goods) goods, *CN*

We find that the household production approach is an adequate treatment with respect to the generation of certain service flows in private consumption. This approach focuses specifically on the conversion of goods into so-called services. While in traditional economic theory consumption analysis focuses on the demand for goods, in the theory of household production it is services which are demanded and provide utility. The services S_T and S_H are produced in line with household production theory with inputs of energy flows, *E* and capital, *K* within a certain production function:

$$S_i = S_i[E_i , K_i] \qquad i = T, H \qquad (5)$$

Describing the household production process in the dual cost model, we derive marginal costs of services, which we can set equal to the consumer price of these services (p_S):

$$p_{S_i} = \mathrm{MC_i}[p_E, p_K] \qquad i = T, H \qquad (6)$$

These prices of services (p_S) become arguments of the vector of commodity prices **p** in the AIDS Model. By virtue of Shephard's Lemma and the indirect utility function we get the demands stated in terms of budget share equations for the AIDS:

$$\frac{p_{CN}CN}{C} = \alpha_{CN} + \gamma_{CN,CN} \log\left(\frac{p_{CN}}{p_{S_H}}\right) + \gamma_{CN,S_T} \log\left(\frac{p_{S_T}}{p_{S_H}}\right) + \beta_{CN} \log\left(\frac{\mathrm{C}}{P_1}\right)$$

$$\frac{p_{S_T} S_T}{C} = \alpha_{S_T} + \gamma_{CN,S_T} \log\left(\frac{p_{CN}}{p_{S_H}}\right) + \gamma_{S_T,S_T} \log\left(\frac{p_{S_T}}{p_{S_H}}\right) + \beta_{S_T} \log\left(\frac{\mathrm{C}}{P_1}\right)$$

$$\frac{p_{S_H} S_H}{C} = \alpha_{S_H} + \gamma_{CN,S_H} \log\left(\frac{p_{CN}}{p_{S_H}}\right) + \gamma_{S_T,S_H} \log\left(\frac{p_{S_T}}{p_{S_H}}\right) p_{S_T} + \beta_{S_H} \log\left(\frac{\mathrm{C}}{P_1}\right) \tag{7}$$

with $\gamma_{ij} = ½(\gamma_{ij}^* + \gamma_{ji}^*) = \gamma_{ji}$ and C as the level of total consumption expenditure for non-durables. The budget share equations satisfy the standard properties of demand functions given by three sets of restrictions, namely adding-up, homogeneity in prices and total expenditure and symmetry of the Slutsky equation.

$$\sum_{i=1}^{n} \alpha_i = 1; \ \sum_{i=1}^{n} \gamma_{ij} = 0; \ \sum_{i=1}^{n} \beta_i = 0; \sum_{j=1}^{n} \gamma_{ij} = 0; \gamma_{ij} = \gamma_{ji} \qquad ; \qquad i,j = CN, S_H, S_T$$

Homogeneity and symmetry have been already implied in (7) by inserting parameters.

The substitution potential between the commodities is condensed in the parameters γ_{ij} that can be used to define the price elasticities. An approximation to the uncompensated price elasticity in AIDS can be derived as (s.: Greene and Alston, 1990):

$$\eta_{ij} = \frac{\partial \log C_i}{\partial \log p_j} = \frac{\gamma_{ij} - \beta_i w_j}{w_i} - \delta_{ij}\,. \tag{8}$$

where δ_{ij} is the Kronecker delta and $\delta_{ij} = 1$ for $i = j$ and $\delta_{ij} = 0$ for $i \neq j$.

3. The model of household production of energy services

This overall model can be combined with the models for services assuming explicit forms for production or cost functions. As services are not directly observable we use the cost function approach, i.e. the level of (necessary) expenditure to derive a certain level of services. In the general case of variable factors and a quasi-fixed capital stock, these costs are given by the following cost functions:

$CS_i = CS_i\,[p_{ji}, K_{ji}]$ $\quad j = E$(energy), O(other flows) $\quad , \quad i = T, H \quad$ (9)

The cost functions must then be used to derive factor demand functions in the form of factor shares for E and O: $\frac{p_{ji} X_j}{CS_i}$.

The next step consists of linking the budget share equations (7) derived from the overall consumption model with these factor share equations derived from the household production process for services. That yields the follwing budget shares of inputs in household production:

$$\frac{p_{jT} X_j}{C} = \frac{p_{jT} X_j}{CS_T} \frac{p_{S_T} S_T}{C} \quad ; \quad \frac{p_{jH} X_j}{C} = \frac{p_{jH} X_j}{CS_H} \frac{p_{S_H} S_H}{C} \qquad (10)$$

Costs of services are given by $CS_T = p_{ST}S_T$ and $CS_H = p_{SH}S_H$.

3.1 Stocks and energy flows in transport demand

The demand for the services (S_T and S_H) is not directly observed, but is the result of household production. Specifying a certain functional form for household production or costs, where some inputs (capital stock) are partially exogenous, we arrive at factor demand equations for these inputs, especially energy flows. Transport (mobility) is treated in this way as a service produced by energy flows and capital stocks. Therefore not only relative prices as proposed by neoclassical economic theory, but also the nature of the infrastructure, for instance public transport systems, have a significant impact on the demand for energy flows. This leads to the substitution of technologies with specific inputs of capital and energy (public transport, private transport). Conrad - Schröder (1991) deal with these stock-flow relations in a narrow neo-classical sense, i.e. the capital stock is optimised in strictly economic terms (cost minimisation). In this model we consider different possible adjustment costs in the capital stock.

Starting from the household cost function (9) factor demand functions for energy and other flows can be derived. For transport services the cost function specified is a Translog function with fuels (F) and other flows (O = expenditure for public transport) as variable inputs and two relevant capital stocks as quasi-fixed inputs, namely the stock of private cars (K_V) and the infrastructure of the public transport system (K_T):

$$\log CS_T = \alpha_0 + \alpha_S \log S_T + \alpha_F \log p_F + \alpha_O \log p_O + \beta_V \log K_V + \beta_T \log K_T +$$

$$+ 0.5\,\gamma_{SS} (\log S_T)^2 + 0.5\,\gamma_{FF} (\log p_F)^2 + \gamma_{FO} (\log p_F \log p_O) + 0.5\,\gamma_{OO} (\log p_O)^2 +$$

$$+ 0.5\,\gamma_{K,VV} (\log K_V)^2 + 0.5\,\gamma_{K,TT} (\log K_T)^2 +$$

$$+ \rho_{FS} (\log p_F \log S_T) + \rho_{OS} (\log p_O \log S_T) + \rho_{VS} (\log K_V \log S_T) + \rho_{TS} (\log K_T \log S_T) +$$

$$+ \rho_{K,FV} (\log p_F \log K_V) + \rho_{K,FT} (\log p_F \log K_T) + \rho_{K,OV} (\log p_O \log K_V) + \rho_{K,OT} (\log p_O \log K_T) \tag{11}$$

Factor demand functions of household production are derived from this cost function in the usual way by applying Shephard's Lemma:

$$\frac{p_F F}{CS_T} = \alpha_F + \gamma_{FF} \log\left(\frac{p_F}{p_O}\right) + \rho_{K,FV} \log K_V + \rho_{K,FT} \log K_T + \rho_{FS} \log S_T \tag{12}$$

Again in (12) homogeneity in prices has already been applied. One equation can be skipped, as due to the application of additivity, symmetry and homogeneity restrictions all parameters are determined.

As the service demand (S_T) is not observable, it has to be approximated by using the variables of the cost function approach. An efficient way is to start from the underlying marginal costs of services (p_S), which in the case of the Translog function can be approximated by the Divisia index (s.: Harvey and Marshall, 1991):

$$\log p_{S_T} = \left(\frac{p_F F}{CS_T}\right)\log p_F + \left(\frac{p_O O}{CS_T}\right)\log p_O \tag{13}$$

This marginal cost index also serves as the consumer price of this service in the aggregate demand model (equation (7)). Furthermore the cost index can also be used to calculate an approximation of the non-observable services:

$$\log S_T = \log CS_T - \log p_{S_T} \tag{14}$$

3.2 Stocks and energy flows in heating demand

For the service of room heating we also specify a Translog type cost function, but with the capital stock of housing as a variable factor. This real capital stock in value terms also contains the real value of investment and repair, which increases energy efficiency of the housing stock (e.g. thermal insulation). The variable factors in this model therefore are:

energy (E) and the capital stocks of private housing (K_H) :

$$\log CS_H = \alpha_0 + \alpha_S \log S_H + \alpha_E \log p_E + \alpha_{KH} \log p_{K_H} +$$

$$+ 0.5\,\gamma_{SS} (\log S_H)^2 + 0.5\,\gamma_{EE} (\log p_E)^2 + \gamma_{EK} (\log p_E \log p_{K_H}) + 0.5\,\gamma_{KK} (\log p_{K_H})^2 +$$

$$+ \rho_{ES} (\log p_E \log S_H) + \rho_{KS} (\log p_{K_H} \log S_H) \tag{15}$$

Factor demand functions of household production are again derived by virtue of Shephard's Lemma:

$$\frac{p_E E}{CS_H} = \alpha_E + \gamma_{EE} \log\left(\frac{p_E}{p_{K_H}}\right) + \rho_{ES} \log S_H \tag{16}$$

Contrary to the model for transport services the capital stock represents a variable factor and information about the capital price (p_{K_H}) is needed.

Again service demand (S_H) is not observable and approximated by using the cost function and the Divisia index (s.: Harvey and Marshall, 1991):

$$\log p_{S_H} = \left(\frac{p_E E}{CS_H}\right)\log p_E + \left(\frac{p_{K_H} K_H}{CS_H}\right)\log p_{K_H} \tag{17}$$

$$\log S_H = \log CS_H - \log p_{S_H} \tag{18}$$

The two building blocks of our model can now be concentrated into one step. This is done by inserting the factor demand functions from the two household production models into the AIDS model at the aggregate level. By definition we get the follwing budget shares of factor inputs in total consumption:

$$\frac{p_F F}{C} = \frac{p_F F}{CS_T} \frac{p_{S_T} S_T}{C} \tag{19}$$

$$\frac{p_E E}{C} = \frac{p_E E}{CS_H} \frac{p_{S_H} S_H}{C} \tag{20}$$

From (19) and (20) the total demand can be clearly decomposed into two components:

(i) goods demand (in our case: factor demand for energy inputs) and (ii) services demand for services produced with these energy inputs as proposed by household production theory (Becker, 1965 and especially Lancaster, 1966).

Inserting of the factor demand equations yields the following overall demand system:

$$
\begin{aligned}
&\frac{p_{CN}CN}{C} = \alpha_{CN} + \gamma_{CN,CN}\log\left(\frac{p_{CN}}{p_{S_H}}\right) + \gamma_{CN,S_T}\log\left(\frac{p_{S_T}}{p_{S_H}}\right) + \beta_{CN}\log\left(\frac{\mathrm{C}}{P_1}\right) \\
&\frac{p_F F}{C} = \left[\alpha_F + \gamma_{FF}\log\left(\frac{p_F}{p_O}\right) + \rho_{K,FV}\log K_V + \rho_{K,FT}\log K_T + \rho_{FS}\log S_T\right] \\
&\left[\alpha_{S_T} + \gamma_{S_T,S_T}\log\left(\frac{p_{S_T}}{p_{S_H}}\right) + \gamma_{CN,S_T}\log\left(\frac{p_{CN}}{p_{S_H}}\right) + \beta_{S_T}\log\left(\frac{\mathrm{C}}{P_1}\right)\right] \\
&\frac{p_E E}{C} = \left[\alpha_E + \gamma_{EE}\log\left(\frac{p_E}{p_{KH}}\right) + \rho_{ES}\log S_H\right] \\
&\left[\alpha_{S_H} + \gamma_{CN,S_H}\log\left(\frac{p_{CN}}{p_{S_H}}\right) + \gamma_{S_T,S_H}\log\left(\frac{p_{S_T}}{p_{S_H}}\right) p_{S_T} + \beta_{S_H}\log\left(\frac{\mathrm{C}}{P_1}\right)\right]
\end{aligned}
\tag{21}
$$

Equation (21) reveals that the overall model is a combination of the Translog term (for transport: $\alpha_F + \gamma_{FF}\log\left(\frac{p_F}{p_O}\right) + \rho_{K,FV}\log K_V + \rho_{K,FT}\log K_T + \rho_{FS}\log S_T$) from factor demand with the AIDS term (for transport: $\alpha_{S_T} + \gamma_{S_T,S_T}\log\left(\frac{p_{S_T}}{p_{S_H}}\right) + \gamma_{CN,S_T}\log\left(\frac{p_{CN}}{p_{S_H}}\right) + \beta_{S_T}\log\left(\frac{\mathrm{C}}{P_1}\right)$) from the aggregate consumption model.

Note that applying the model for simulations the service prices (p_{S_T} , p_{S_H}) on the right hand side are endogenous as they depend on the shares via the Divisia price indices (equation (13) and (17)). In the Translog model for transport investment I in new capital goods (K_V and K_T) introduces technical change accompanied by lower short run variable costs. This negative impact of the capital stock on variable costs allows us to calculate a 'shadow' price z_K for each capital service

($j = V, T$): $z_{K,j} = - \frac{\partial CS_T}{\partial K_j}$. The model is usually closed by assuming that the actual capital stock adjusts to the 'optimal' stock given by the identity of the market price $p_{K,j}$ and the 'shadow' price $z_{K,j}$ for each capital stock. In our model K_T represents the exogenous public transport infrastructure and K_V the stock of private cars. We assume that consumers demand for cars is not only influenced by this adjustment of the actual to the 'optimal' capital stock, but also by other economic variables. Therefore we derive an investment function incorporating price and income elements for cars. We apply stock adjustment models of order two (Egebo, et.al., 1990):

$$\log(K_{\mathrm{Vt}}) - \log(K_{\mathrm{Vt-1}}) = \alpha_{\mathrm{KV}} + \gamma_{\mathrm{KV}} \log(p_{\mathrm{Vt}}/p_{\mathrm{Ft}}) + \beta_{\mathrm{KV}} \log(C_{\mathrm{t}}/P_{\mathrm{t}}) -$$
$$- \tau_1 \log(K_{\mathrm{Vt-1}}) + \tau_2 (\log(K_{\mathrm{Vt-1}}) - \log(K_{\mathrm{Vt-2}})) \qquad (22)$$

The capital stock K_V follows an adjustment path in time t to the 'optimal' stock, which is a function of the income variable C_t/P_t and the relative price variable p_{Vt}/p_{Ft}. The adjustment path towards equilibrium is guaranteed by the parameter restriction for $\tau_1 > 0$, whereas the second order adjustment parameter τ_2 might be negative or positive (see: Egebo, et.al., 1990). The argument to include the relative price variable is that an increase in the fuel price might represent an incentive to buy new fuel efficient cars. Given an assumed linear depreciation rate for cars of 20 percent we can derive annual car purchases (I_V) from equation (22). The overall model comprises the demand system described in (21) and the capital stock equation (22).

The relevant capital stock in heating is the stock of dwellings. The investment in dwellings depends on the user cost of capital (p_{KH}), defined by the ex post return to dwellings capital which is given by the rents (including imputations for ownership) in current prices.

The investment data had to be converted into capital stock data. This has been carried out by estimating a starting value of the capital stock in the first period (K_0) using the following formula, developed by Griliches (1980) and Coe, Helpman (1995):

$K_0 = I_0 /(g + d)$,

where g = the average growth rate of investment over the whole period and d the depreciation rate. Starting with K_0 the development of the capital stock follows the path described by the defintion:

$K_t = I_t + (1- d)K_{t-1}$.

The total budget constraint of households is then given by:

$$C = YD - p_V I_V - S \qquad (23)$$

Total nominal consumption for non-durables C is determined by disposable income YD, the expenditure for investment in cars, $p_V I_V$ and households savings S.

Other studies of household production incorporate a long run budget constraint where total household investment must equal total household savings (Willett and Naghspour, 1987). In our model this budget constraint is obsolete as the relevant capital stock for energy consumption of households is not fully financed by households themselves but incorporates important infrastructure components.

4. Data and simulation results

4.1 Data

Our overall model consists of (i) the demand system, (ii) factor demand equations for household production and (iii) capital stock equations. This model has been estimated for those EU 15 countries, where the needed long run time series (at least 1990 – 2003, for most data range is from 1975 – 2003) for disaggregated consumption (OECD National Accounts Database) as well as infrastructure stock data were available: Austria, France, UK, Finland, Netherlands, Portugal, Irland and Germany. For Greece, Spain and Sweden only time series from 1995 on are available and important data for Belgium, Italy, Denmark and Luxemburg are completely missing or inadequate. The OECD data base contains information about the goods categories of our model (C, CN, F, O, E) as well as about expenditure on durables (vehicles, I_V , investment in dwellings and total construction investment). Infrastructure investment has been approximated by construction investment exclusive of dwellings. We are aware of the fact that this variable is only a broad proxy variable for the needed measure of infrastructure in public transport. The results of our estimations and simulations are therefore heravily influenced by this measurement problem. The investment data had to be converted into capital stock data by first calcultaing starting values and using the defintion for the capital accumulation path described above.

The econometric estimation of the model had to be carried out in two steps. First the AIDS model of aggregate consumption (equation (7)) had to be estimated. Then there are two different ways to proceed with the estimation. One consists of inserting the parameter values for α_i , β_i and γ_{ij} from the AIDS model into the system of equation (21) to derive the other parameters. The other possibility is to estimate the two Translog models (equations (12) and (16)) separately. The overall model is then derived as the equation system combining the

AIDS model with the Translog models.We proceeded by applying the latter of the two methodologies. Estimating in a first step the model of aggregate consumption (the AIDS model (7)) with the SUR estimator allows us to calculate cross and own price elasticities following (8) and it can be checked, if the underlying expenditure function is well behaved. In a second step the two Translog models (equations (12) and (16)) have been estimated and also the corresponding elasticities have been derived.

Table 1: Own price elasticities

Table 1 shows the own price elasticities of these models for all countries. Parameter values for Greece, Spain and Sweden have been derived by a calibration procedure. Starting point is that we find significant differences in the parameter values that determine price reactions (the γ_{ij}) between countries[1] . From our estimated parameters for 8 countries we calculate the distribution of elasticities and thereby derive a stastical relevant space of elasticities. In order to calibrate the missing paramters we started with average parameter estimates from the 8 countries and adjusted them until the resulting elasticities came to lie in this stastical relevant space. This calibration procedure combines econometric estimation methods with theoretical restrictions on elasticities. For estimating the capital stock equation for vehicles we started from the specification in (22) and finally included only significant parameter values.

[1] These differences are based on the application of econometric methods on historical data and are an indication that calibrating a European model with identical parameters for each region would be clearly misleading.

4.2 Simulations of changes in prices and capital stocks

In general we think that one important advantage of our approach is the implementation of interdependencies between commodity prices, 'service' prices and commodity stocks. The main idea behind this model is that service demand can be satisfied with different bundles of energy/capital inputs and that there are repercussions on non-energy consumption. We attempted to test the reactions of these variables to changes in prices and to changes in (quasi-fixed) capital stocks in two different *ex post* model simulations for each country covering the period 1999 to 2003:

(I) A rise in the price of transport fuels by 30%, where the revenues from the *ad valorem* tax are recycled by lowering the user costs of the transport infrastructure capital stock.

(II) A rise in the price of heating fuels by 30%, where the revenues from the *ad valorem* tax are recycled by lowering the user costs of the dwellings capital stock.

The simulations should reveal important interdependencies in the model between non-energy consumption and service demand as well as between costs of service demand and capital inputs in household production.

Table 2: Simulation – Tax on p_F of 30% (ad valorem), revenue recycling via 'user costs' of K_T

(I) *Transport fuel tax with revenue recycling (user costs of transport infrastructure)*

In Table 2 we observe for the 5th year of the simulation period that a fuel price increase combined with revenue recycling reduces purchases of vehicles in all countries. We observe that higher fuel prices lead to substitution within the transport service demand and to higher costs for the bundle of transport services of about 20 percent in all countries. Revenue recycling via lower user costs of K_T leads to an increase of this stock, which enhances the substitution effect. This in turn must also reduce the costs for transport services, which would raise more in a pure tax increase scenario (without revenue recycling). This cost reducing impact of higher infrastructure is very small perhaps due to the above mentioned data problems in our measure of public transport infrastructure. Therefore the increase in the substitution effect (brought about by a higher capital stock) is too low to compensate for the negative 'income' effect. In general there is a small but not unambiguous feedback on consumption of other goods. This might be seen as an important feature of the model framework developed here, which takes into account links between different categories of energy and non-energy consumption. In some cases (e.g. Portugal) the impact on the non-taxed consumption categories is rather high and is a result of changes in the commodity structutre at the aggregate level (non-energy, transport, heating) described within the AIDS model. Anyway the magnitude of changes in quantities must be seen in relation to the 30% price shock.

In most countries the substitution effect leads to higher real demand for public transport. Only in Netherlands and Portugal the 'income' effect of lower total real transport service demand outweighs this substitution effect. The impact on transport service demand is negative in all countries with a reduction of about 3 to 14 percent. As nominal expenditure is not affected by this price increase, real disposable income is reduced and non-energy consumption also declines in nearly all countries. This 'income' effect is accompanied by a substitution effect between energy services and non-energy commodities, which in Germany and Netherlands is important enough to lead to a small increase in real non-energy demand. The bundle of heating service demand is also negatively affected in nearly all countries due to this 'income' effect. Our welfare measure shows a small decrease in all countries with the exception of Finland and Austria. Therefore the substitution effect enforced by the higher infrastructure capital stock is not large enough to compensate households for the price increase of transport fuels in this scenario.

Table 3: Simulation – Tax on p_E of 30% (ad valorem), revenue recycling via p_{KH}

(II) *Energy tax with revenue recycling (user costs of dwellings)*

The scenario of a higher energy price for heating together with revenue recycling (Table 3) even leads to an average decrease in the heating services price between 5 and 12 percent across countries and to an average decrease in the total consumer price between 0.5 and 2 percent. Revenue recycling via lower user costs of K_H again leads to an increase of this stock, which enhances the substitution effect and thereby reduces the costs for heating services. Obviously this cost decreasing effect of lower user costs more than compensates households for the price increaese due to taxation. Compared to the transport scenario above there is an additional direct feedback on costs of living of consumers in this scenario. The increase in the substitution effect via revenue recycling is brought about directly by a relative price effect (on p_E / p_{K_H}). This in turn directly influences households' expenditures, whereas the higher infrastructure capital stock in the transport scenario had no direct link to households. [2]

[2] In a closed macroeconomic model where the public sector is included the link between households' income and infrasstructure financing had to be implemented.

As a consequence of revenue recycling in this scenario real demand reduction for electricity/gas is much more pronounced than price elasticities would lead us to suppose and real demand for housing increases considerably. The feedback on the service price of heating now even leads to a remarkable decrease in this price and therefore also to small increases in heating service demand in most countries (with the exception of Germany and Finland). This feedback represents the ’rebound effect’ of a more energy-efficient capital stock. Although we do not exactly quantify the magnitude of the rebound effect here, we draw the conclusion that it does not fully compensate the energy reducing impact of a more efficient capital stock. Therefore the service demand increase we observe is combined with a reduction of energy demand for heating. The enforcement of the substitution effect by revenue recycling results in the already mentioned reduction in the total consumer price and an increase in real income. Both non-energy consumption and purchases of vehicles therefore increase in all countries (except Netherlands). Again we observe feedbacks on all consumption categories. An important aspect is that energy demand for transport is influenced by taxation of energy demand for heating. The evidence is mixed for the different countries with considerable increases in some countries (e.g. Germany, Irland). This feedback mechanism could be qualified as an indirect ’rebound effect’ or ’cross rebound effect’ between different categories of energy use.

Our welfare measure is positively affected in nearly all countries, except Portugal. This scenario represents a situation, where sustainable consumption patterns (less energy flows) can be achieved without welfare losses

5. Conclusions

In this paper we set up a consistent model of private consumption, where demand for transport and heating services is combined with non-energy consumption at an aggregate level of utility maximization. The utility relevant services are therefore separated from energy flows, which are treated as inputs in a household production process. The indirect utility function applied at this aggregate level can be used to derive a welfare measure. The inputs of energy flows and capital can be substituted in order to produce the same level of energy services. In our approach this will be described via a 'household production function' where demand for energy commodities is a derived demand from the cost function of household production. Implementing the alternative approach of an explicit model of energy technologies would have as a prerequisite data availability on the energy efficiency of different household appliancers and vehicles.

Energy demand for heating and transport can be decomposed into a factor demand component for energy inputs as proposed by household production theory and into a services demand component. The model captures a series of feedbacks on the aggregate level between non-energy consumption and service demand for heating and transport. At the level of the household production models the relationships between capital expenditure and prices play an important role. Additionally we can capture different feedbacks between the energy demand for heating and transport as well as different 'rebound effects' and show that isolated policy measure in one category have impacts on the other. These features are not described explicitly in standard models of private consumption for energy.

The model has been econometrically estimated and applied to selected EU countries. Two different scenarios have been simulated for *ad valorem* taxes on energy with revenue recycling in lowering user costs of capital. The simulation results considerably differ for heating and transport due to different impacts of capital stocks (with embodied technology) on energy demand. For heating demand this effect is much more pronounced, as there is a direct impact channel via a relative price (energy/capital) term on energy demand. The low effect of a higher capital stock on energy demand in transport might also be due to a measurement problem in the relevant infrastructure stock for public transport. In the case of heating we can design a scenario, where revenue recycling via lower capital costs more than compensates for the negative impact of taxation on total consumer real income and welfare.

References

Becker, G. S., "A theory of the allocation of time", Economic Journal, 1965, 75, S 493-517.

Boehringer, C. and A. Loeschel (2004), Measuring Sustainable Development: The Use of Computable General Equilibrium Models, ZEW Discussion Paper No. 04-14.

Brand, I., "The Perspective Project Towards an energy-aware lifestyle", paper presented at the ProSus/CSTM Workshop on Sustainable Household Consumption: Impacts, Goals and Indicators for Energy-use, Transport and Food, University of Twente, November 17-19, 2000.

Brown, P. M., Cameron, L. D., "Survey: What can be done to reduce overconsumption?" Ecological Economics, 2000, 32 (1), 27 – 41.

Conrad, K., Schröder, M., "Demand for durable and nondurable goods, environmental policy and consumer welfare", Journal of Applied Econometrics, 6, 1991.

Coe, D.T., Helpman, E., "International R&D spillovers ", European Economic Review, 39, 1995, 859-887.

Deaton, A., Muellbauer, J., An Almost Ideal Demand System, American Economic Review, 1980, 312 – 326.

Egebo, T., Richardson, P. and Lienert, I., A Model of Housing Investment for the Major OECD Economies. *OECD Economic Studies*, 1990, 0(14), pp. 151 – 188.

Green , R. D. and Alston, J. M., Elasticities in AIDS Models. *American Journal of Agricultural Economics*, 72, 1990, 442 – 445.

Griliches, Z., "R&D and the productivity slowdown ", American Economic Review, 70, 1980, 343-348.

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

Khazzoom, J. D., 1980, Economic Implications of Mandated Efficiency in Standards for Household Appliances, *The Energy Journal*, 1, pp. 21-40.

Khazzoom, J. D., 1989, Energy Savings from More Efficient Appliances: A Rejoinder, *The Energy Journal*, 10, pp. 157-166.

Lancaster, K.J., "A new approach to consumer theory", Journal of Political Economy, 74, 1966, 132-57.

Larsen, B.M., Nesbakken, R., Household Electricity End-Use Consumption: Results from Econometric and Engineering Models, Energy Economics, 2004, 26, (2), 179 – 200.

Parsons, G. R., "An Almost Ideal Demand System for Housing Attributes", The Southern economic journal, 53, 1986, 47-63.

Rivers, N., Jaccard, M., Combining Top-Down and Bottom-Up Approaches to Energy-Economy Modeling Using Discrete Choice Models, *The Energy Journal*, 2005, 26 (1), 83 – 106.

Stigler, G. J., Becker, G. S., "De Gustibus Non Est Disputandum", The American Economic Review, 1977, 67(2),76-90.

Willet, K. D, Naghshpour, S., "Residential demand for energy commodities: A Household Production Function Approach", Energy Economics, Oktober 1987, 9(4), S 251-56.

Table 1: Own price elasticities

	AIDS-model			Translog-model			
				Transport		Heating	
	η_{NE}	η_{ST}	η_{SH}	η_{F}	η_{O}	η_{E}	η_{H}
Austria	–0.65	–0.09	–0.12	–0.03	–0.10	–0.26	–0.11
France	–0.56	–0.25	–0.13	–0.02	–0.71	–0.21	–0.06
UK	–0.89	–0.24	–0.62	–0.05	–0.46	–0.40	–0.15
Finland	–0.58	–0.19	–0.05	–0.15	–0.37	–0.54	–0.08
Netherlands	–0.99	–0.54	–1.38	–0.08	–0.37	–0.33	–0.07
Portugal	–0.66	–0.02	–0.40	–	–	–0.46	–0.16
Irland	–0.89	–0.46	–0.43	–0.24	–0.42	–0.40	–0.13
Greece	–0.76	–0.28	–0.30	–0.25	–0.38	–0.25	–0.04
Spain	–0.76	–0.30	–0.18	–0.14	–0.40	–0.29	–0.06
Sweden	–0.68	–0.27	–0.57	–0.09	–0.36	–0.34	–0.08
Germany	–0.72	–0.68	–0.51	–0.27	–0.97	–0.56	–0.12
Average	–0.73	–0.29	–0.38	–0.13	–0.42	–0.36	–0.10

Table 2: Simulation – Tax on p_F of 30% (ad valorem), revenue recycling via 'user costs' of K_T

	Austria	France	UK	Finland	Nether-lands	Portugal	Irland	Greece	Spain	Sweden	Germany
	Difference to Baseline in %, 5th year										
Private consumption (constant prices)											
Purchase of vehicles	–3.8	–1.8	–1.7	–3.6	–1.9	–5.8	–0.9	–1.8	–2.3	–1.3	–0.5
Non-energy	–2.5	–1.0	–0.7	–1.4	+0.6	–5.7	+0.1	–1.1	–1.2	–1.7	+2.7
Fuels	–4.7	–12.2	–15.0	–6.7	–11.7	–3.9	–10.8	–11.1	–10.0	–9.4	–18.5
Public transport	+6.2	+15.1	+12.4	+7.2	–9.5	–3.7	+2.4	+6.3	+6.9	+6.0	+8.3
Electricity, gas, and others	+0.5	–4.8	–1.2	+0.6	–3.1	±0.0	+2.3	+0.2	–0.2	–0.9	+1.6
Housing	+1.0	–3.8	–3.2	–1.8	–5.7	+27.7	–4.5	+0.3	–0.3	–1.2	–10.8
Service prices											
Transport	+20.9	+20.7	+15.6	+19.5	+22.4	+23.9	+17.2	+16.2	+19.6	+21.0	+20.6
Heating	±0.0	±0.0	–0.1	±0.0	+0.1	+0.3	–0.6	±0.0	±0.0	±0.0	+0.2
Total consumer price	+2.4	+2.7	+1.7	+2.0	+1.8	+3.5	+0.9	+1.2	+1.7	+2.4	+1.9
Private consumption (current prices)											
Non-energy	–2.5	–1.0	–0.7	–1.4	+0.6	–5.7	+0.1	–1.1	–1.2	–1.7	+2.7
Costs of transport services	+19.7	+14.4	+11.3	+17.3	+10.2	+21.9	+10.9	+11.9	+14.3	+15.2	+6.5
Costs of heating services	+0.9	–4.0	–2.9	–1.6	–5.2	+20.9	–3.6	+0.2	–0.3	–1.2	–8.8
Transport services demand	–3.0	–7.2	–4.9	–3.5	–12.7	–4.1	–6.9	–4.9	–6.2	–6.9	–14.3
Heating services demand	+0.9	–4.0	–2.9	–1.6	–5.4	+18.6	–3.1	+0.2	–0.3	–1.2	–9.4
Welfare	±0.0	–0.2	–0.2	±0.0	–0.3	–0.2	–0.2	–0.1	–0.1	–0.2	–0.6

Table 3: Simulation – Tax on p_E of 30% (ad valorem), revenue recycling via p_{KH}

	Austria	France	UK	Finland	Nether-lands	Portugal	Irland	Greece	Spain	Sweden	Germany
	Difference to Baseline in %, 5th year										
Private consumption (constant prices)											
Purchase of vehicles	+2.4	+1.1	+1.6	+4.5	+1.6	+1.1	+6.5	+1.9	+1.8	+0.3	+0.3
Non-energy	+1.7	+2.6	+0.3	+3.3	–1.3	+1.1	+0.6	+1.4	+1.3	+1.0	+1.6
Fuels	–2.5	+2.8	+3.7	+1.2	+3.3	–4.9	+6.3	–1.0	–0.3	+0.6	+9.4
Public transport	+3.4	+2.4	+3.1	+1.1	+7.3	–0.9	+11.4	–0.5	±0.0	+0.7	+13.3
Electricity, gas, and others	–18.6	–18.2	–19.5	–21.8	–18.3	–30.0	–28.2	–19.4	–20.2	–20.7	–26.8
Housing	+7.5	+3.8	+11.3	+2.3	+19.4	+16.4	+12.9	+7.1	+6.0	+12.9	+6.8
Service prices											
Transport	–0.1	±0.0	±0.0	±0.0	±0.0	±0.0	±0.0	±0.0	±0.0	±0.0	±0.0
Heating	–6.8	–7.1	–9.4	–9.7	–6.9	–5.8	–12.4	–9.0	–9.0	–5.4	–7.4
Total consumer price	–1.4	–1.5	–1.7	–2.4	–1.4	–0.7	–3.0	–1.3	–1.2	–1.5	–1.7
Private consumption (current prices)											
Non-energy	+1.7	+2.6	+0.3	+3.3	–1.3	+1.1	+0.6	+1.4	+1.3	+1.0	+1.6
Costs of transport services	–1.1	+2.7	+3.4	+1.2	+4.0	–4.5	+8.2	–0.8	–0.2	+0.6	+10.2
Costs of heating services	–6.1	–8.2	–3.4	–9.4	+2.4	–3.5	–5.9	–6.7	–7.5	–2.3	–7.7
Transport services demand	–1.1	+2.7	+3.4	+1.2	+4.0	–4.6	+8.0	–0.8	–0.2	+0.6	+9.8
Heating services demand	+0.5	–1.5	+6.0	–0.2	+9.3	+2.3	+6.2	+2.1	+1.3	+3.0	–0.6
Welfare	+0.1	+0.2	+0.1	+0.3	+0.4	–0.1	+0.3	+0.2	+0.1	+0.2	+0.3

Medieninhaber (Verleger), Hersteller: Österreichisches Institut für Wirtschaftsforschung • Wien 3, Arsenal, Objekt 20 • A-1103 Wien, Postfach 91 • Tel. (43 1) 798 26 01-0 • Fax (43 1) 798 93 86 • http://www.wifo.ac.at/ • Verlags- und Herstellungsort: Wien