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A CONSUMERS DEMAND MODEL WITH 'ENERGY FLOWS', STOCKS AND 'ENERGY SERVICES'

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Abstract:
This paper sets up a model of private consumption for selected EU countries with special emphasis on the consumption categories heating and transport. Sustainable consumption patterns require a 'decoupling' of energy or materials use from satisfaction of consumers' needs and demands. Starting point for the analysis is the observation that the ultimate goal of consumption is utility maximization and that utility is determined by the consumption of goods as well as the level of 'services', produced with inputs of other consumption goods. These other goods are energy flows and capital services. Exogenous key variables that can be modified in order to calculate different scenarios are:

(i) prices of energy and non-energy goods (ii) the exogenous capital stock (infrastructure) or user costs of capital.

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. More than a decade ago the concept of sustainable developmenmt introduced new aspects in the analysis of welfare environmental economics. This is laid down in the 'Brundtland definition' (WCED, 1987): " *..development, which meets the needs of the present without compromising the ability of future generations to meet their own needs*". This definition bears two direct links to welfare economics. One is covered by the intergenerational allocation problem and the other one refers to definition of 'needs' that might be approached by the microeconomic theory of utility maximization. Therefore consumption patterns are increasingly seen as being central for a change in economic activities towards more sustainable structures. The 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). Accepting the concept of 'strong' sustainabilty (s.: Neumayer, 2002) involves the existence of a binding resource constraint for the potential of welfare maximization of consumers. The solution to this dilemma can only be found in 'decoupling' of undesired emissions or resource flows from the desired and increasing flow of total consumer income and welfare.

A starting point of the analysis of decoupling resource use from consumption could be the observation that households derive utility not only from commodities demanded on the market but from commodities which the household itself produces with the input of market goods and capital. 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 can be found in Willett, Naghspour (1987). 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). If the aspect of overall welfare maximization has to be considered – as is suggested by the 'sustainable development' definition – 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 consumptioncan only occur by reducing energy flows with the corresponding negative consequences for welfare, which can only be compensated, if non-energy consumption increaes in a sufficient magnitude. This in the end depends on the price (substitution) elasticities, which are often taken from other studies without any additional empirical foundation by econometric analysis. The reduction of energy flows is in most model exercises brought about by an increase in prices (taxation) of energy with lump-sum recycling of revenues to households.

The purpose of this paper is the construction of a model of overall consumption, comprising cost functions of household production for 'energy services' (heating, mobility), capital accumulation functions (e.g. purchase of vehicles), and demand functions for 'energy services'. Demand functions for energy and fuels are derived from the cost functions of household production and expressed in terms of factor demand. The household production function concept emphazises the role of capital stocks in consumption. 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). At an aggregate level utility is determined by the bundle of non-energy goods and the level of services for transport and heating.

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 four taxation scenarios partly with narrowly targeted revenue recycling for EU 13 countries (without Belgium and Luxermburg). 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:

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

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

That is, log[a(**p**)] is a translog-function and log[b(**p**)]-log[a(**p**)] 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 $U = \frac{\log(C(U,p))/P_1}{b_0 \prod_{i=1}^{n} p_i^{\beta_i}}$, 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:

$$S_i = S_i[E_i\,,\,K_i] \qquad\qquad i = T, H \tag{5}$$

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):

$$p_S = \mathrm{MC}[p_E, p_K] \tag{6}$$

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):

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

where δ_{ij} is the Kronecker delta and δ_{ij} = 1 for $i = j$ and δ_{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:

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

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:

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

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):

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

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

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

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

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

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

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

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:

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

$$\frac{p_F F}{C} = \left[\alpha_F + \gamma_{FF} \log\left(\frac{p_F}{p_O}\right) + \rho_{K,FV} \log K_V + \rho_{K,FT} \log K_T + \rho_{FS} \log S_T\right]$$
$$\left[\alpha_{S_T} + \gamma_{S_T,S_T} \log\left(\frac{p_{S_T}}{p_{S_H}}\right) + \gamma_{CN,S_T} \log\left(\frac{p_{CN}}{p_{S_H}}\right) + \beta_{S_T} \log\left(\frac{C}{P_1}\right)\right]$$

$$\frac{p_E E}{C} = \left[\alpha_E + \gamma_{EE} \log\left(\frac{p_E}{p_K}\right) + \rho_{ES} \log S_H\right]$$
$$\left[\alpha_{S_H} + \gamma_{CN,S_H} \log\left(\frac{p_{CN}}{p_{S_H}}\right) + \gamma_{S_T,S_H} \log\left(\frac{p_{S_T}}{p_{S_H}}\right) p_{S_T} + \beta_{S_H} \log\left(\frac{C}{P_1}\right)\right] \qquad (21)$$

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: $\alpha_{S_T} + \gamma_{S_T,S_T} \log\left(\frac{p_{S_T}}{p_{S_H}}\right) + \gamma_{CN,S_T} \log\left(\frac{p_{CN}}{p_{S_H}}\right) + \beta_{S_T} \log\left(\frac{C}{P_1}\right)$) 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)). The econometric estimation of the model had to be carried out in two steps. First the AIDS model of aggregate consumption 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 seperately. The overall model is then derived as the equation system combining the AIDS model with the Translog models.

In the Translog model for transport investment I in new capital goods (K_V and K_T) induces technical change accompanied by lower short run variable costs. This negative impact of the capital stock on variable costs allows 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 the following type:

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

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. 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. Give 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 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 total capital stock used by households is not fully financed by households themselves but incorporates important infrastructure components. The analytical potential of this approach lies in the explicit formulation of the link 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 feedback from partly exogenous and partly endogenous capital stocks on the price system exists. The second advantage of our model is that we are able to calculate welfare impacts based on the equivalent variation criterion.

4. Data and empirical Results

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 for disaggregated consumption (OECD National Accounts Database) as well as infrastructure stock data were available: Austria, Denmark, France, Italy, UK, Finland, Netherlands, Portugal, Irland and Germany. For Greece, Spain and Sweden only time series from 1995 on are available and important data for both Belgium and Luxemburg are completely missing. 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. These 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.

Estimating in a first step the model of aggregate consumption (the AIDS model) 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 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 10 countries we calculate the distribution of elasticities. Figures 1 to 3 show the kernel esimation for the distribution of the AIDS model elasticities of the 10 countries. The other figures show similar distributions for the two Translog models. These figures again reveal that significant differences in elasticities between countries exist and that one can find a stastical relevant space of elasticities. In order to calibrate the missing paramters we started with average parameter estimates from the 10 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 included only significant parameter values. This is especially relevant for the relative price term, which only turned out significant for Denmark and Italy.

Our model is well suited to take all interdependencies between commodity prices, 'service' prices and commodity stocks into account, what can be shown in model simulations. 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

[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.

attempted to test the reactions of these variables to changes in prices and to changes in (quasi-fixed) capital stocks in four different model simulations for each country:

(I) A rise in the price of transport fuels by 30% (an *ad valorem* tax) without revenue recycling

(II) 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.

(III) A rise in the price of heating fuels by 30% (an *ad valorem* tax) without revenue recycling

(IV) 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.

Obviously these simulation exercises are of an exemplary nature and do not describe a consistent sustainability policy measure. The simulations (II) and (IV) 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)

In Table 2 we observe that a pure fuel price increase reduces purchases of vehicles in all countries with the exception of Denmark and Italy, where the relative price term is at work. 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. In most countries this substitution effect leads to higher real demand for public transport. Only in Italy, 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. In general in this simulation only a negative stimulus of a price increase is implemented with corresponding reduction of real income and welfare.

Table 3: Simulation – Tax on p_F of 30% (ad valorem), revenue recycling via 'user costs' of K_T

Revenue recycling via lower user costs of K_T leads to an increase of this stock, which enhances the substitution effect and thereby reduces the costs for transport services. This cost reducing impact of higher infrastructure is very small with exception of Denamrk, where the transport service price impact is reduced by 2.5 percentage points. Therefore we also observe only small differences in the real transport service demand impact (compared to the first scenario), again with the exception of Denmark, where we find a one percentage point lower reduction. This is due to the fact that the increase in the substitution effect (brought about by a higher capital stock) is too low to compensate for the negative 'income' effect. We also observe no relevant feedbacks on consumption of other goods and on our welfare measure.

Table 4: Simulation – Tax on p_E of 30% (ad valorem)

The scenario of a higher energy price for heating (Table 4) leads to an average increase in the heating services price of about 5 percent across countries and to an average increase in the total consumer price of about 1 percent. This impact is about 1 percentage point less of the total consumer price impact in scenario (I), which is mainly due to the different weights of the service categories (transport, heating). That means that the negative income as well as the (in nearly all countries negative) welfare effect are considerably smaller. That occurs although the substitution effects within the category (between electricity/gas and housing) are much smaller compared to the transport fuel price simulations (scenario (I) and (II)). Therefore the weights of commodities within a service category as well as the weight of service categories within total consumption are mainly responsible for the magnitude of the aggregate effects. Due to the lower weights for heating we also observe smaller reductions in non-energy consumption induced by a higher energy price in this scenario. An important aspect of our model are the feedbacks between heating and transport, which can be seen by reactions in the real transport service demand in a scenario, where the energy price for heating increases.

Table 5: Simulation – Tax on p_E of 30% (ad valorem), revenue recycling via p_{KH}

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 transport services. There is an additional direct feedback on costs of living of consumers in this scenario (IV) compared to scenario (II), where the lower (infrastructure) capital costs are not directly relevant for private households. The increase in the substitution effect via revenue recycling is brought about directly by a relative price effect (on p_E / p_{K_H}), which is another difference to scenario (II). This enhancement in the substitution effect between the scenarios with and without revenue recycling is much larger than between the two transport scenarios. As a consequence real demand reduction for electricity/gas is much more pronounced 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. This results in a reduction in the total consumer price and an increase in real income. Both non-energy consumption and purchases of vehicles therefore increase and the welfare impact changes from a negative to a positive number. This scenario represents a situation, where sustainable consumption patterns (less energy flows) can be achieved without welfare losses (same or higher service demand).

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 utlity 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.

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 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 feedbacks between the energy demand for heating and transport 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 EU 13 countries (without Belgium and Luxemburg). Four different scenarios have been simulated for *ad valorem* taxes on energy with and without revenue recycling in lowering user costs of capital. In the revenue recycling scenarios the simulation results are different for heating and transport due to different impacts of capital stocks (with embodied technology) on energy demand. For heating demand this impact 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 (public transport). Therefore we find only negligible differences in the impacts on total consumer real income and welfare between the two scenarios (with and without revenue recycling) for transport demand. 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. This scenario might be seen as compatible with the paradigm of sustainable development, as energy flows are reduced, whereas welfare is even increased and the same or higher real service demand is achieved with lower costs.

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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
Denmark	–0.69	–0.28	–0.09	–0.08	–0.30	–0.48	–0.14
France	–0.56	–0.25	–0.13	–0.02	–0.71	–0.21	–0.06
Italy	–0.71	–0.20	–0.14	–0.19	–0.17	–0.16	–0.05
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)

	Austria	Denmark	France	Italy	UK	Finland	Nether-lands	Portugal	Irland	Greece	Spain	Sweden	Germany
	Difference to Baseline in %, 5th year												
Private consumption (constant prices)													
Purchase of vehicles	–3.9	+9.1	–1.8	+35.0	– 1.7	– 3.6	–2.0	– 5.8	–0.9	– 1.8	–2.3	–1.3	–0.5
Non-energy	–2.5	–1.8	–1.0	– 3.6	– 0.7	– 1.4	+0.6	– 5.7	+0.1	– 1.1	–1.2	–1.7	+2.7
Fuels	–3.9	–8.4	–11.7	– 7.4	–12.1	– 6.4	–11.5	– 3.9	–10.4	–11.0	–9.7	–9.2	–18.2
Public transport	+3.5	+6.4	+13.1	– 2.6	+ 8.1	+ 6.5	–10.9	– 3.7	+1.7	+ 6.2	+6.1	+5.0	+7.1
Electricity, gas, and others	+0.5	–2.3	–4.8	– 1.4	– 1.3	+ 0.6	–3.2	± 0.0	+2.3	+ 0.2	–0.2	–0.9	+1.7
Housing	+1.1	–1.9	–3.8	– 0.7	– 3.3	– 1.8	–5.7	+27.7	–4.6	+ 0.3	–0.3	–1.2	–10.9
Service prices													
Transport	+21.1	+21.8	+20.8	+21.7	+16.3	+19.5	+22.4	+23.9	+17.3	+16.2	+19.7	+21.1	+20.6
Heating	±0.0	±0.0	±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	+2.1	+2.8	+ 2.2	+ 1.8	+ 2.0	+1.8	+ 3.5	+0.9	+ 1.2	+1.7	+2.4	+1.9
Private consumption (current prices)													
Non-energy	–2.5	–1.8	–1.0	– 3.6	– 0.7	– 1.4	+0.6	– 5.7	+0.1	– 1.1	–1.2	–1.7	+2.7
Costs of transport services	+19.9	+16.6	+14.5	+15.5	+11.8	+17.3	+10.2	+21.9	+10.9	+11.9	+14.4	+15.3	+6.5
Costs of heating services	+1.0	–2.0	–4.0	– 0.8	– 3.1	– 1.6	–5.2	+20.9	–3.6	+ 0.2	–0.3	–1.2	–8.8
Transport services demand	–3.0	–6.5	–7.3	– 7.3	– 5.1	– 3.5	–12.7	– 4.1	–6.9	– 4.9	–6.2	–6.9	–14.3
Heating services demand	+0.9	–2.0	–4.1	– 0.8	– 3.0	– 1.6	–5.5	+18.6	–3.1	+ 0.2	–0.3	–1.2	–9.4
Welfare	±0.0	±0.0	–0.2	– 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_F of 30% (ad valorem), revenue recycling via 'user costs' of K_T

	Austria	Denmark	France	Italy	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	+10.0	–1.8	+35.0	–1.7	–3.6	–1.9	–5.8	–0.9	–1.8	–2.3	–1.3	–0.5
Non-energy	–2.5	– 1.6	–1.0	–3.6	–0.7	–1.4	+0.6	–5.7	+0.1	–1.1	–1.2	–1.7	+2.7
Fuels	–4.7	–19.9	–12.2	–7.5	–15.0	–6.7	–11.7	–3.9	–10.8	–11.1	–10.0	–9.4	–18.5
Public transport	+6.2	+54.6	+15.1	–2.4	+12.4	+7.2	–9.5	–3.7	+2.4	+6.3	+6.9	+6.0	+8.3
Electricity, gas, and others	+0.5	– 2.1	–4.8	–1.4	–1.2	+0.6	–3.1	±0.0	+2.3	+0.2	–0.2	–0.9	+1.6
Housing	+1.0	– 1.7	–3.8	–0.7	–3.2	–1.8	–5.7	+27.7	–4.5	+0.3	–0.3	–1.2	–10.8
Service prices													
Transport	+20.9	+18.4	+20.7	+21.7	+15.6	+19.5	+22.4	+23.9	+17.2	+16.2	+19.6	+21.0	+20.6
Heating	±0.0	± 0.0	±0.0	±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	+ 1.7	+2.7	+2.2	+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	– 1.6	–1.0	–3.6	–0.7	–1.4	+0.6	–5.7	+0.1	–1.1	–1.2	–1.7	+2.7
Costs of transport services	+19.7	+13.9	+14.4	+15.4	+11.3	+17.3	+10.2	+21.9	+10.9	+11.9	+14.3	+15.2	+6.5
Costs of heating services	+0.9	– 1.8	–4.0	–0.8	–2.9	–1.6	–5.2	+20.9	–3.6	+0.2	–0.3	–1.2	–8.8
Transport services demand	–3.0	– 5.4	–7.2	–7.3	–4.9	–3.5	–12.7	–4.1	–6.9	–4.9	–6.2	–6.9	–14.3
Heating services demand	+0.9	– 1.8	–4.0	–0.8	–2.9	–1.6	–5.4	+18.6	–3.1	+0.2	–0.3	–1.2	–9.4
Welfare	±0.0	± 0.0	–0.2	–0.2	–0.2	±0.0	–0.3	–0.2	–0.2	–0.1	–0.1	–0.2	–0.6

Table 4: Simulation – Tax on p_E of 30% (ad valorem)

	Austria	Denmark	France	Italy	UK	Finland	Nether-lands	Portugal	Irland	Greece	Spain	Sweden	Germany
	Difference to Baseline in %, 5th year												
Private consumption (constant prices)													
Purchase of vehicles	–2.1	–4.0	–0.8	–0.8	–0.7	–1.2	–1.2	–1.3	–0.6	–0.9	–0.8	–1.1	–0.5
Non-energy	–1.4	–2.2	–1.8	–1.0	–0.1	–0.8	+1.1	–1.2	–0.2	–0.6	–0.6	–1.2	–1.0
Fuels	+2.2	–1.9	–2.0	+0.4	–1.4	–0.3	–3.0	+5.4	–1.4	+0.4	+0.1	–0.7	–6.2
Public transport	–3.1	+1.4	–1.7	+0.3	–1.1	–0.2	–6.1	+0.8	–2.4	+0.2	±0.0	–0.8	–8.6
Electricity, gas, and others	–5.2	–12.8	–2.9	–4.8	–9.2	–10.6	–13.1	–23.1	–8.0	–8.0	–8.2	–11.3	–13.5
Housing	+0.9	+3.1	+1.8	–0.9	–1.4	+1.0	–5.5	+5.1	–1.7	±0.0	+0.3	–0.4	+3.5
Service prices													
Transport	+0.1	–0.1	±0.0	±0.0	±0.0	±0.0	±0.0	±0.0	±0.0	±0.0	±0.0	±0.0	±0.0
Heating	+5.6	+6.5	+5.0	+4.8	+3.5	+2.2	+6.1	+6.3	+2.5	+4.0	+3.8	+6.5	+4.8
Total consumer price	+1.3	+2.1	+1.3	+1.1	+0.7	+0.6	+1.2	+0.8	+0.7	+0.6	+0.6	+2.0	+1.3
Private consumption (current prices)													
Non-energy	–1.4	–2.2	–1.8	–1.0	–0.1	–0.8	+1.1	–1.2	–0.2	–0.6	–0.6	–1.2	–1.0
Costs of transport services	+1.0	–1.3	–1.9	+0.4	–1.3	–0.3	–3.6	+4.9	–1.7	+0.4	+0.1	–0.7	–6.7
Costs of heating services	+5.0	+5.4	+5.8	+3.4	+1.2	+2.2	–2.1	+3.8	+1.2	+2.9	+3.2	+2.9	+5.0
Transport services demand	+0.9	–1.2	–2.0	+0.4	–1.3	–0.3	–3.7	+4.8	–1.8	+0.4	+0.1	–0.7	–7.0
Heating services demand	–0.7	–1.2	+0.6	–1.5	–2.3	–0.1	–8.3	–2.5	–1.4	–1.1	–0.7	–3.7	±0.0
Welfare	–0.1	–0.1	–0.1	–0.1	–0.1	–0.1	–0.4	+0.1	–0.1	–0.1	–0.1	–0.2	–0.2

Table 5: Simulation – Tax on p_E of 30% (ad valorem), revenue recycling via p_{KH}

	Austria	Denmark	France	Italy	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	+ 3.3	+1.1	+ 1.2	+1.6	+4.5	+1.6	+1.1	+6.5	+1.9	+1.8	+0.3	+0.3
Non-energy	+1.7	+ 2.0	+2.6	+ 1.6	+0.3	+3.3	−1.3	+1.1	+0.6	+1.4	+1.3	+1.0	+1.6
Fuels	−2.5	+ 1.8	+2.8	− 0.6	+3.7	+1.2	+3.3	−4.9	+6.3	−1.0	−0.3	+0.6	+9.4
Public transport	+3.4	− 1.3	+2.4	− 0.5	+3.1	+1.1	+7.3	−0.9	+11.4	−0.5	±0.0	+0.7	+13.3
Electricity, gas, and others	−18.6	−26.4	−18.2	−13.8	−19.5	−21.8	−18.3	−30.0	−28.2	−19.4	−20.2	−20.7	−26.8
Housing	+7.5	+12.6	+3.8	+ 7.1	+11.3	+2.3	+19.4	+16.4	+12.9	+7.1	+6.0	+12.9	+6.8
Service prices													
Transport	−0.1	+ 0.1	±0.0	± 0.0	±0.0	±0.0	±0.0	±0.0	±0.0	±0.0	±0.0	±0.0	±0.0
Heating	−6.8	− 6.0	−7.1	− 7.9	−9.4	−9.7	−6.9	−5.8	−12.4	−9.0	−9.0	−5.4	−7.4
Total consumer price	−1.4	− 1.8	−1.5	− 1.6	−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	+ 2.0	+2.6	+ 1.6	+0.3	+3.3	−1.3	+1.1	+0.6	+1.4	+1.3	+1.0	+1.6
Costs of transport services	−1.1	+ 1.2	+2.7	− 0.6	+3.4	+1.2	+4.0	−4.5	+8.2	−0.8	−0.2	+0.6	+10.2
Costs of heating services	−6.1	− 5.0	−8.2	− 5.5	−3.4	−9.4	+2.4	−3.5	−5.9	−6.7	−7.5	−2.3	−7.7
Transport services demand	−1.1	+ 1.2	+2.7	− 0.6	+3.4	+1.2	+4.0	−4.6	+8.0	−0.8	−0.2	+0.6	+9.8
Heating services demand	+0.5	+ 0.9	−1.5	+ 2.2	+6.0	−0.2	+9.3	+2.3	+6.2	+2.1	+1.3	+3.0	−0.6
Welfare	+0.1	+ 0.1	+0.2	+ 0.1	+0.1	+0.3	+0.4	−0.1	+0.3	+0.2	+0.1	+0.2	+0.3

Figure 1: Own price elasticity for non-energy demand (AIDS-model), Kernel estimates (normal distribution)

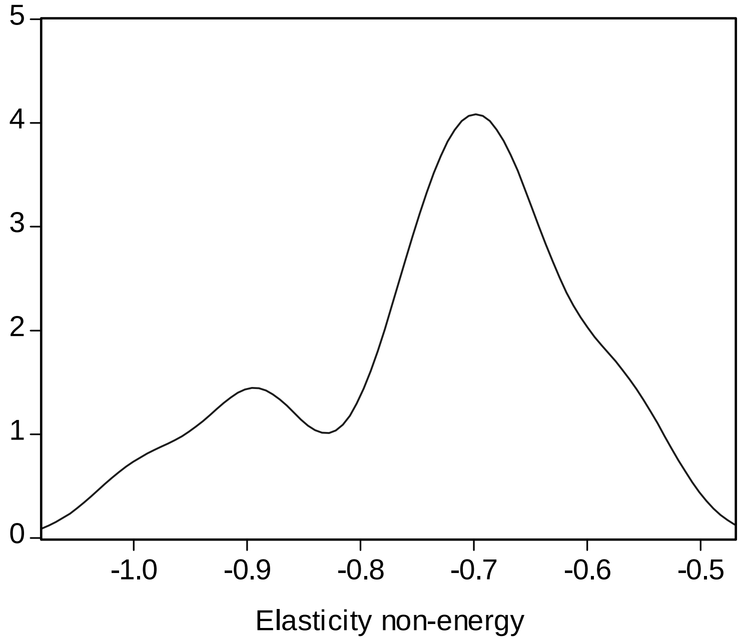


Figure 2: Own price elasticity for transport service demand (AIDS-model), Kernel estimates (normal distribution)

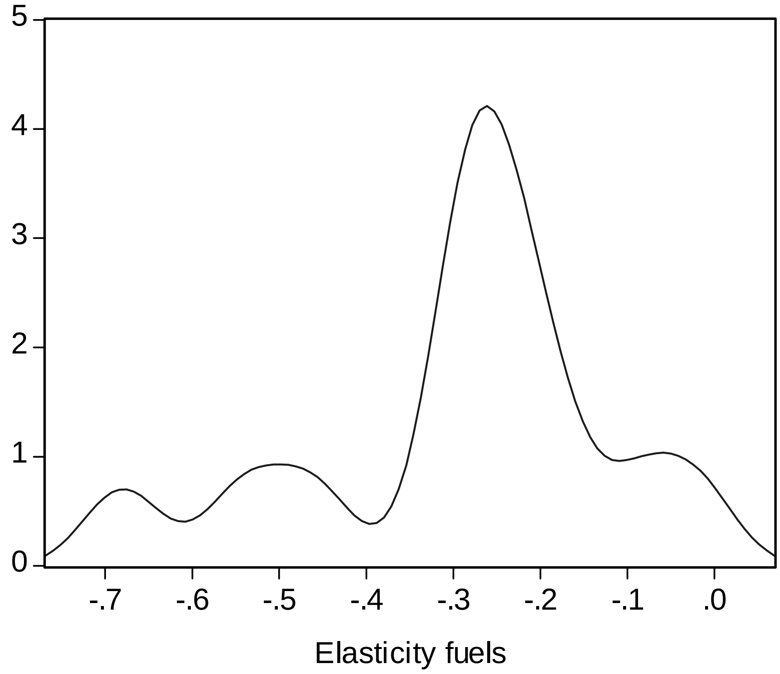


Figure 3: Own price elasticity for heating service demand (AIDS-model), Kernel estimates (normal distribution)

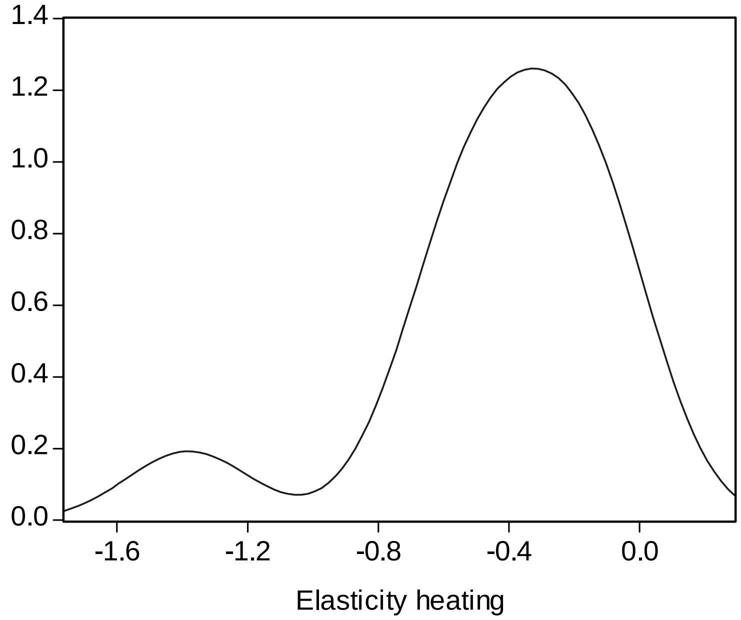


Figure 4: Own price elasticity for fuel demand (Translog model for transport), Kernel estimates (normal distribution)

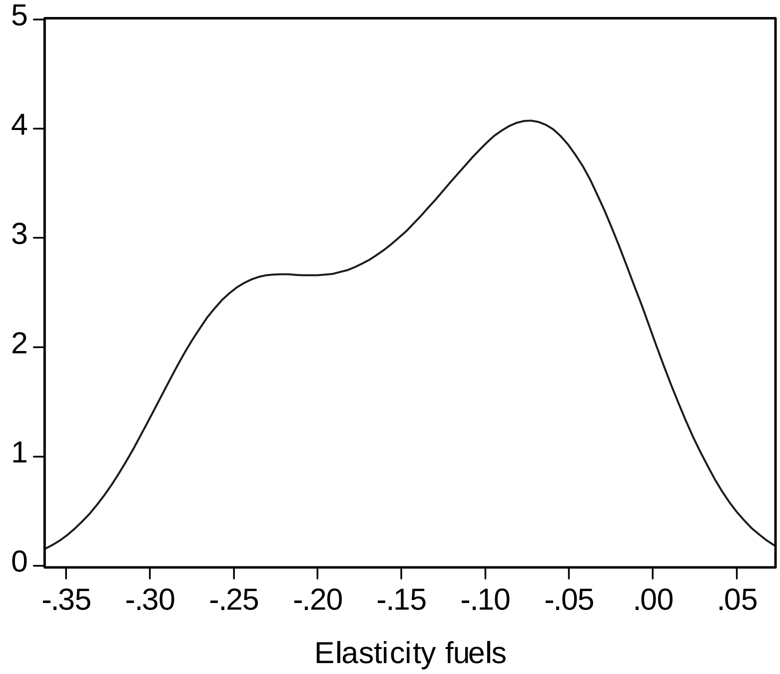


Figure 5: Own price elasticity for public transport demand (Translog model for transport), Kernel estimates (normal distribution)

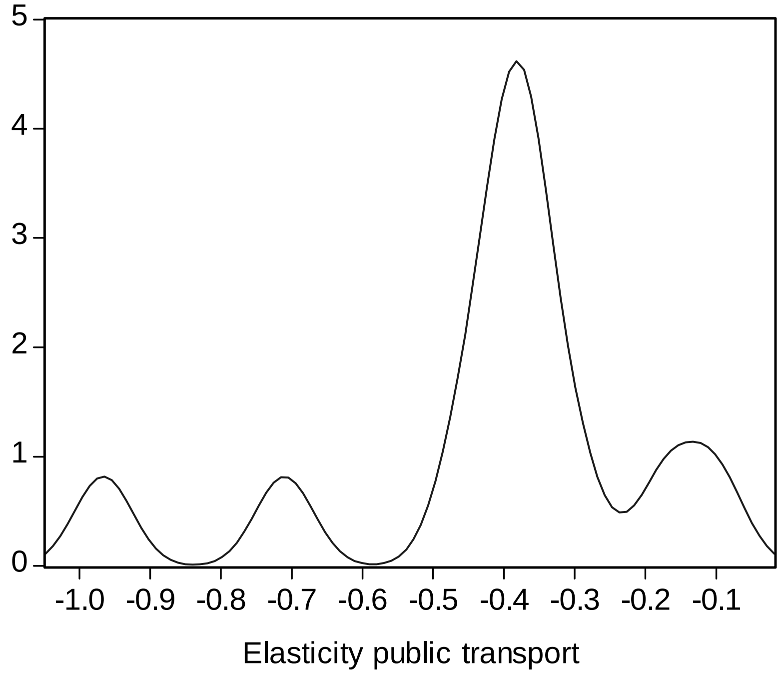


Figure 6: Own price elasticity for energy demand (Translog model for heating), Kernel estimates (normal distribution)

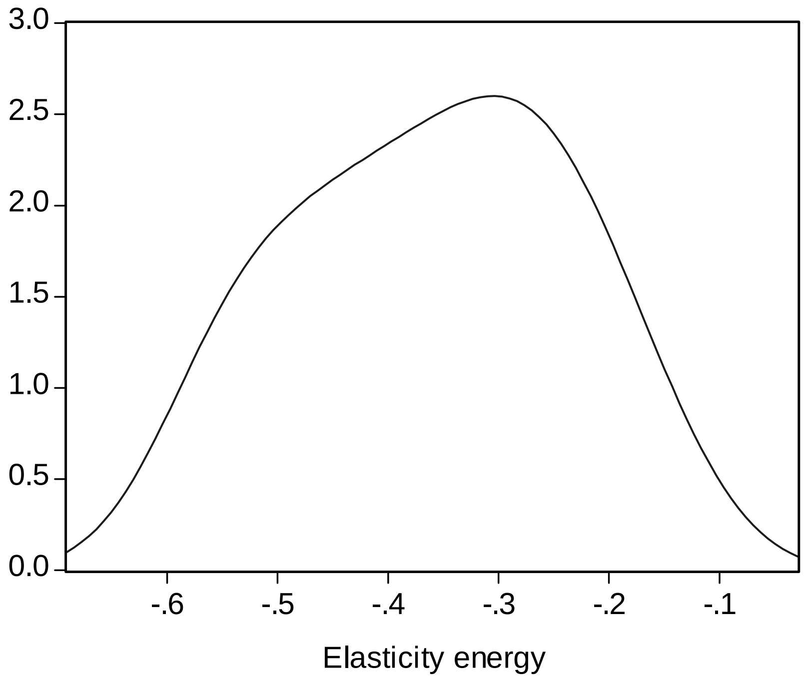
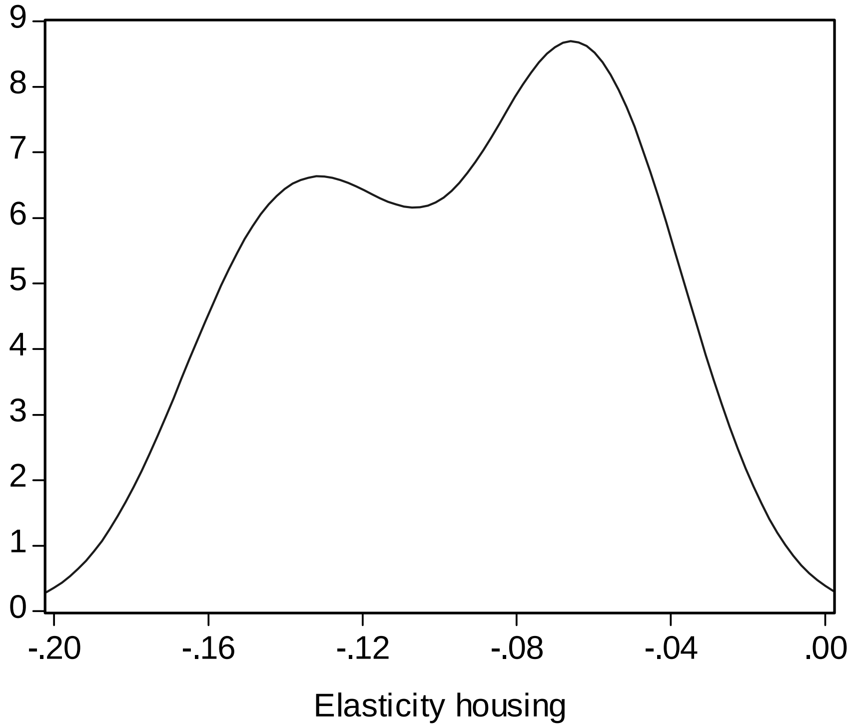


Figure 7: Own price elasticity for housing (Translog model for heating), Kernel estimates (normal distribution)



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