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A CONSUMERS DEMAND MODEL FOR SUSTAINABLE DEVELOPMENT

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Abstract:
This paper sets up a model of private consumption for selected OECD countries with special emphasis on sustainability for 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 "commodities" (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).

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1. Introduction

Consumption patterns are increasingly seen as being central for a change in economic activities towards more sustainable structures. Consumer behaviour and lifestyles are recognised as determining factors for sustainable development, as they affect production processes and involve resource use.

Aside from the theoretical research on sustainable consumption, a number of research projects and initiatives have been carried out by international organisations or within countries. The research is mainly focused on the empirical analysis and assessment of consumption patterns and the related environmental effects (Brand, 2000 and Brown, Cameron, 2000). The integration of the above mentioned research into economic modelling is still missing to a large extent. In the economic literature we find different approaches, which might be helpful to bridge this gap and can be used for developing adequate consumer demand models for sustainability (see Conrad – Schröder, 1991, Becker, 1965, Lancaster, 1966, Deaton – Muellbauer, 1980).

The modelling of consumption so as to allow for the simulation of sustainable consumer behaviour must consider other than purely economic factors. A starting point of the analysis of decoupling resource use from consumption could be the observation that households derive utility not only from goods 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 (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. The goal of our study is to overcome these shortcomings in other studies and derive an operational model, which can be estimated econometrically.

The purpose of this paper is the construction of a general model of sustainable consumption. The major components of this model are: 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). That represents an important link between capital and consumers demand.

At an aggregate level utility is determined by the bundle of non-energy goods and the level of services for transport and heating. Using an indirect cost function at this allocation level our approach allows for deriving an utility or welfare measure for certain circumstances.

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. In section 4 the overall model, which is a combination of the aggragte consumption model with the two household production models is derived. In section 5 we describe the data base for the model and present some estimation results for selected countries. Section 6 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:

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

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

That is, $\log[a(\mathbf{p})]$ is a translog-function and $\log[b(\mathbf{p})]-\log[a(\mathbf{p})]$ 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:

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

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):

$$p_S = \mathrm{MC}[p_E,p_K] \qquad (6)$$

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:

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

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

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

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 $\delta_{ij} = 1$ for $i = j$ and $\delta_{ij} = 0$ for $i \neq j$.

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:

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

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:

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

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):

$$\begin{aligned}
\log CS_T = {} & \alpha_0 + \alpha_\mathrm{S} \log S_T + \alpha_\mathrm{F} \log p_F + \alpha_\mathrm{O} \log p_O + \beta_\mathrm{V} \log K_V + \beta_\mathrm{T} \log K_T + \\
& + 0.5\, \gamma_\mathrm{SS} (\log S_T)^2 + 0.5\, \gamma_\mathrm{FF} (\log p_F)^2 + \gamma_\mathrm{FO} (\log p_F \log p_O) + 0.5\, \gamma_\mathrm{OO} (\log p_O)^2 + \\
& + 0.5\, \gamma_\mathrm{K,VV} (\log K_V)^2 + 0.5\, \gamma_\mathrm{K,TT} (\log K_T)^2 + \\
& + \rho_\mathrm{FS} (\log p_F \log S_T) + \rho_\mathrm{OS} (\log p_O \log S_T) + \rho_\mathrm{VS} (\log K_V \log S_T) + \rho_\mathrm{TS} (\log K_T \log S_T) + \\
& + \rho_\mathrm{K,FV} (\log p_F \log K_V) + \rho_\mathrm{K,FT} (\log p_F \log K_T) + \rho_\mathrm{K,OV} (\log p_O \log K_V) + \rho_\mathrm{K,OT} (\log p_O \log K_T)
\end{aligned} \tag{11}$$

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) :

$$\begin{aligned}\log CS_H &= \alpha_0 + \alpha_S \log S_H + \alpha_E \log p_E + \alpha_{KH} \log p_{K_H} + \\ &+ 0.5\,\gamma_{SS} (\log S_H)^2 + 0.5\,\gamma_{EE} (\log p_E)^2 + \gamma_{EK} (\log p_E \log p_{K_H}) + 0.5\,\gamma_{KK} (\log p_{K_H})^2 + \\ &+ \rho_{ES} (\log p_E \log S_H) + \rho_{KS} (\log p_{K_H} \log S_H)\end{aligned} \tag{15}$$

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):

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

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

4. The overall model of consumption

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:

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

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

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

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: $\alpha_{S_T} + \gamma_{S_T,S_T}\log\left(\frac{p_{S_T}}{p_{S_H}}\right) + \gamma_{CN,S_T}\log\left(\frac{p_{CN}}{p_{S_H}}\right) + \beta_{S_T}\log\left(\frac{\mathrm{C}}{P_1}\right)$) 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)). 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 (equation (7)) in order to derive the follwing parameters: α_i , β_i and γ_{ij}. Then these parameters could be inserted into the system of equation (21) for estimating the other parameters. For estimation the system of equation (21) was rearranged for $\frac{p_F F}{C}$ and $\frac{p_E E}{C}$ describing each of these equation consisting of the terms

α_i x α_{Si} + α_i x AIDS-Term + α_{Si} x Translog-Term + AIDS-Term x Translog-Term:

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

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

$$
\begin{aligned}
\frac{p_E E}{C} &= \alpha_E \alpha_{S_H} + \alpha_{S_H}\left[\gamma_{EE}\log\left(\frac{p_E}{p_K}\right) + \rho_{ES}\log S_H\right] + \\
&+ \alpha_E\left[\gamma_{CN,S_H}\log\left(\frac{p_{CN}}{p_{S_H}}\right) + \gamma_{S_T,S_H}\log\left(\frac{p_{S_T}}{p_{S_H}}\right)p_{S_T} + \beta_{S_H}\log\left(\frac{\mathrm{C}}{P_1}\right)\right] + \\
&+ \left[\gamma_{CN,S_H}\log\left(\frac{p_{CN}}{p_{S_H}}\right) + \gamma_{S_T,S_H}\log\left(\frac{p_{S_T}}{p_{S_H}}\right)p_{S_T} + \beta_{S_H}\log\left(\frac{\mathrm{C}}{P_1}\right)\right] * \\
&* \left[\gamma_{EE}\log\left(\frac{p_E}{p_K}\right) + \rho_{ES}\log S_H\right]
\end{aligned}
\tag{22}
$$

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:

$$I_V = I_V\,[p_{KV}, z_{KV}, C] \tag{23}$$

The capital stock K_V then finally follows an accumulation path in time t determined by household investment $I_{V,t}$ and the (fixed) depreciation rate d :

$$K_{V,t} = I_t + (1\text{-}d)K_{t\text{-}1} \tag{24}$$

The overall budget constraint of households is given by:

$$C = YD - p_{IV}I_V - S \tag{25}$$

Total nominal consumption for non-durables C is determined by disposable income YD, the expenditure for investment in cars, $p_{IV}I_V$ 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 themselves but incorporates important infrastructure components.

5. Empirical Results

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 demand system described in (22) has been estimated for some European countries, where large time series for disaggregated consumption (OECD National Accounts Database) as well as infrastructure stock data were available: Austria, Italy and the UK. 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 and investment in dwellings). These flow data had to be converted into capital stock data for K_V and K_H. 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 in (24).

These data had to be complemented by data of the infrastructure on the public transport system K_T. Again the capital stock of this infrastructure category has been calculated from investment data. The relevant investment data were approximated by data from EUROCONSTRUCT about the production value of construction in transport infrastructure excluding roads.

As has been described above a two step-procedure has been applied for estimation. Estimating in a first step the model of aggregate consumption (the AIDS model) with the SUR estimator delivers the parameters to be inserted in the second step into the full model. At this first stage price elasticities can be calculated following (8) and it can be checked, if the underlying expenditure function is well behaved. Table 1 shows the parameter values that guarantee negative own price elasticities. We find significant differences in the parameter values that determine price reactions (the γ_{ij}) between countries. 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. The parameters from Table 1 have then been inserted into the full model, which has also been estimated using the SUR estimator. At this stage it is not straightforward to derive price elasticities, because considerable feedback mechanisms from services to input demand as well as between services and non-energy consumption are at work. The resulting model is well suited to take all these interdependencies 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 attempted to test the reactions of these variables to changes in prices and to changes in (quasi-fixed) capital stocks in three different model simulations for each country:

(1) A rise in the price of transport fuels by 20% (an *ad valorem* tax)

(2) A rise in the transport infrastructure capital stock by 5% (public investment)

(3) A rise in the price of transport fuels by 20%, where the revenues from the *ad valorem* tax are recycled by investment in the transport infrastructure capital stock.

Obviously the simulation exercises (1) and (2) are of exemplary nature and do not describe a consistent sustainability policy measure. The simulation (3) should reveal important interdependencies in the model between non-energy consumption and service demand as well as between costs of service demand and inputs in household production.

For the UK we observe (Table 2) that higher fuel prices lead to substitution within the transport service demand and to higher costs for the bundle of transport services (+ 0.12 percent). The difference between the cost increase and the price increase (in p_{ST}) determines the change in service demand induced by this measure, which is very small (not shown in Table 2). As nominal expenditure is not affected by this measure, real disposable income is reduced and non-energy consumption also declines. The bundle of heating demand is also changed due to the change in service prices and in real disposable income. An increase in public transport infrastructure in the UK (Table 3) induces substitution effects within the bundle of transport service demand and also slightly reduces the costs of the service, again without changing the level of service demand. The cost reducing impact of higher infrastructure is very small and does not induce further feedbacks on consumption of other goods. Therefore the scenario with revenue recycling of taxes into higher public transport infrastructure investment mainly leads to higher substitution effects within transport demand but only slightly reduces the cost impact of higher fuel prices (the increase in the transport service price is 0.11 instead of 0.12). On the other hand in the revenue recycling – scenario one needs lower tax rates in order to achieve the same target (in terms of reduction in fuel use) as in the price increase – scenario. This lower tax rate would lead to lower impact on the service price and induce lower impacts on non-energy consumption. Therefore for a given target of reduction in energy flows the combined scenario has lower costs on service prices and total consumer prices.

Simulation results are completely different for Italy (Table 5,6 and 7). High substitution effects within the bundle of transport service demand are combined with a relatively high negative impact on non-energy consumption and a similar impact on the costs for the bundle of transport services (+ 0.14 percent). In Italy the infrastructure stock turns out to have a negative influence on public transport and a positive impact on fuels. It must be emphasized here however that we encounter serious measurement problems with this variable (K_T). For the purpose of this model we would need a variable that exactly measures all investment in public transport infrastructure, but in practice we can only approach to that by subtracting roads from a general infrastructure variable, which still might contain other investment. Therefore in the case of Italy the combined scenario with revenue recycling neither shows higher substitution effects in transport nor lower costs for transport services than the scenario of the price increase.

For Austria (Table 8, 9 and 10) we find similar substitution effects within the transport bundle in the scenario of a price increase, but larger substitution effects between the two service categories and non-energy consumption. The impact on the costs for the bundle of transport services is also similar to the other two countries (+ 0.14 percent). Concerning the influence of a 5 percent increase in the infrastructure stock we find much more pronounced effects with a 0.01 percentage points feedback on the transport service price, which is higher than in the other two countries. The scenario with revenue recycling therefore leads to a substantial increase in substitution effects within the transport bundle, but – as in the case of the UK- to only small feedback at the level of transport service prices. But again we can conclude – as in the UK case – that for achieving the same fuel use reduction we needed a much smaller tax rate which would give us much smaller impacts on costs for services as well as on total consumer prices.

6. 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 for utility maximization. The utlity relevant services are therefore separated from energy flows, which are treated as inputs in a household production process. Energy demand for heating and transport can be decomposed into a factor demand component for energy inputs and into a services demand component as proposed by household production theory. This overall model can be formulated by inserting factor demand into service demand and can be estimated econometrically in a two step procedure.

The model captures a series of feedbacks between non-energy consumption, capital expenditure and prices, which are not described explicitly in standard models of private consumption for energy.

The model has been estimated econometrically for three selected OECD countries (UK, Italy and Austria). Three different scenarios have been simulated in order to test the properties of the model: (i) an *ad valorem* tax scenario on transport fuels, (ii) a transport infrastructure scenario (+ 5%) and a combined scenario of an *ad valorem* tax with revenue recycling into investment in transport infrastructure. With the exception of Italy the simulations show that an increase in public transport infrastructure can lead to considerable substitution effects within the bundle of transport services. This is especially relevant for the combined scenario (iii) and leads to feedbacks on consumption for other goods and services. The feedback of these increased substitution effects on the price for transport services is rather small in absolute terms. The feedback becomes more relevant, if the simulations are normalized for a certain target of fuel use reduction. Then we get the result that a much smaller tax rate is needed for the same impact on fuel use leading to much smaller impacts on costs for services as well as on total consumer prices.

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Table 1: Empirical Results for UK, Italy and Austria
Parameters of the Aggregate Consumption Model (AIDS)

	UK	Italy	Austria
α(CN)	0,9566	-0,1181	-0,4202
α(ST)	-0,0528	0,5454	-0,1035
α(SH)	0,0962	0,5727	1,5237
γ(CN,CN)	0,0692	0,1625	-0,0520
γ(CN,ST)	-0,0376	-0,0290	-0,1584
β(CN)	-0,0183	0,0628	0,0992
γ(ST,ST)	0,0731	0,0287	0,0900
β(ST)	0,0111	-0,0344	0,0164
γ(CN,SH)	-0,0316	-0,1335	0,2104
γ(ST,SH)	-0,0355	0,0003	0,0684
β(SH)	0,0072	-0,0284	-0,1156

CN	Non-energy Consumption
ST	Transport Services
SH	Heating Services

Table 2: Simulation Results for UK, 20% rise in p_F

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
				Difference to Baseline			
Non-Energy	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6
Fuels	-2,9	-3,0	-3,5	-3,6	-3,4	-3,2	-3,3
Transport Services	5,6	5,8	6,6	6,6	6,6	6,5	6,7
Electricity, Gas and Other	-3,0	-2,8	-2,5	-2,3	-2,4	-2,0	-2,1
Housing	0,7	0,7	0,6	0,5	0,5	0,4	0,5
Service Prices							
Transport		0,12	0,12	0,11	0,11	0,12	0,12
Heating		0,00	0,00	0,00	0,00	0,00	0,00
Total consumer price	0,01	0,01	0,01	0,01	0,01	0,02	0,02

Table 3: Simulation Results for UK, 5% rise in K_T

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
			Difference to Baseline				
Non-Energy	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Fuels	-1,6	-1,6	-1,6	-1,6	-1,7	-1,8	-1,8
Transport Services	2,5	2,5	2,5	2,4	2,3	2,3	2,3
Electricity, Gas and Other	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Housing	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Service Prices							
Transport		0,000	0,000	0,000	-0,001	-0,002	-0,002
Heating		0,00	0,00	0,00	0,00	0,00	0,00
Total consumer price	0	0,00	0,00	0,00	0,00	0,00	0,00

Table 4: Simulation Results for UK, 20% rise in p_F plus rise in K_T (revenue recycling)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
			Difference to Baseline				
Non-Energy	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6	-0,6
Fuels	-4,0	-4,1	-4,9	-5,1	-5,1	-5,1	-5,3
Transport Services	7,2	7,5	8,7	8,8	8,9	9,1	9,3
Electricity, Gas and Other	-2,9	-2,8	-2,4	-2,3	-2,3	-2,0	-2,1
Housing	0,7	0,7	0,6	0,5	0,5	0,4	0,4
Service Prices							
Transport		0,11	0,11	0,11	0,11	0,11	0,11
Heating		0,00	0,00	0,00	0,00	0,00	0,00
Total consumer price	0,01	0,01	0,01	0,01	0,01	0,02	0,02

Table 5: Simulation Results for Italy, 20% rise in p_F

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
			Difference to Baseline				
Non-Energy	-5,9	-5,9	-5,9	-5,9	-5,9	-5,8	-5,8
Fuels	-6,2	-6,3	-6,2	-6,2	-6,2	-6,1	-6,0
Transport Services	24,7	25,3	24,7	24,6	24,1	23,4	22,9
Electricity, Gas and Other	0,2	0,2	0,2	0,2	0,2	0,2	0,2
Housing	-0,1	-0,1	0,0	0,0	0,0	0,0	0,0
Service Prices							
Transport		0,14	0,14	0,14	0,14	0,14	0,14
Heating		0,00	0,00	0,00	0,00	0,00	0,00
Total consumer price	0,02	0,01	0,01	0,01	0,01	0,01	0,01

Table 6: Simulation Results for Italy, 5% rise in K_T

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
			Difference to Baseline				
Non-Energy	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Fuels	0,6	0,6	0,6	0,6	0,6	0,6	0,6
Transport Services	-2,3	-2,2	-2,2	-2,2	-2,2	-2,1	-2,1
Electricity, Gas and Other	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Housing	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Service Prices							
Transport		0,000	0,000	0,000	0,000	0,000	0,000
Heating		0,00	0,00	0,00	0,00	0,00	0,00
Total consumer price	0	0,00	0,00	0,00	0,00	0,00	0,00

Table 7: Simulation Results for Italy, 20% rise in p_F plus rise in K_T (revenue recycling)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
				Difference to Baseline			
Non-Energy	-5,9	-6,0	-5,9	-5,9	-5,9	-5,8	-5,8
Fuels	-6,0	-6,0	-6,0	-5,9	-5,9	-5,8	-5,6
Transport Services	23,7	24,3	23,7	23,6	23,0	22,3	21,8
Electricity, Gas and Other	0,2	0,2	0,2	0,2	0,2	0,2	0,2
Housing	-0,1	-0,1	0,0	0,0	0,0	0,0	0,0
Service Prices							
Transport		0,14	0,14	0,14	0,14	0,14	0,14
Heating		0,00	0,00	0,00	0,00	0,00	0,00
Total consumer price	0,02	0,01	0,01	0,01	0,01	0,01	0,01

Table 8: Simulation Results for Austria, 20% rise in p_F

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
				Difference to Baseline			
Non-Energy	-3,4	-3,5	-3,5	-3,4	-3,3	-3,4	-3,4
Fuels	-2,0	-1,8	-2,1	-2,1	-2,2	-2,7	-2,6
Transport Services	5,1	5,4	5,4	5,8	6,0	5,7	5,6
Electricity, Gas and Other	5,5	5,2	5,2	5,2	5,1	5,2	5,1
Housing	6,1	5,8	5,8	5,8	5,7	5,8	5,7
Service Prices							
Transport		0,15	0,15	0,14	0,14	0,14	0,14
Heating		0,00	0,00	0,00	0,00	0,00	0,00
Total consumer price	0,01	0,01	0,02	0,01	0,01	0,02	0,02

Table 9: Simulation Results for Austria, 5% rise in K_T

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
	Difference to Baseline						
Non-Energy	0,0	0,2	0,3	0,2	0,2	0,4	0,2
Fuels	-19,4	-20,1	-20,6	-20,8	-21,0	-21,3	-20,6
Transport Services	70,1	67,2	65,5	61,3	59,1	59,8	61,9
Electricity, Gas and Other	0,0	-0,2	-0,4	-0,3	-0,3	-0,5	-0,3
Housing	0,0	-0,3	-0,4	-0,4	-0,3	-0,6	-0,3
Service Prices							
Transport		-0,01	-0,01	-0,01	-0,01	-0,02	-0,01
Heating		0,00	0,00	0,00	0,00	0,00	0,00
Total consumer price	0	0,00	0,00	0,00	0,00	0,00	0,00

Table 10: Simulation Results for Austria, 20% rise in p_F *plus rise in* K_T *(revenue recycling)*

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
	Difference to Baseline						
Non-Energy	-3,4	-3,4	-3,4	-3,3	-3,2	-3,3	-3,3
Fuels	-4,2	-4,1	-4,4	-4,5	-4,6	-5,3	-5,3
Transport Services	13,2	13,2	13,3	13,1	13,1	13,6	14,0
Electricity, Gas and Other	5,3	5,1	5,1	5,0	4,9	5,0	5,0
Housing	6,0	5,7	5,6	5,6	5,5	5,6	5,5
Service Prices							
Transport		0,14	0,14	0,14	0,14	0,14	0,14
Heating		0,00	0,00	0,00	0,00	0,00	0,00
Total consumer price	0,01	0,01	0,01	0,01	0,01	0,02	0,02