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An intertemporal optimisation model of households in an E3-model (economy/energy/environment) framework

Kurt Kratena, Michael Wüger *

Abstract:

This paper deals with the total CO_2 impact of households in a simple dynamic E3-model (economy/energy/environment), comprising a model block of private consumption and an input-output model. The consumption model describes the demand for different durables and nondurables, derived from intertemporal optimisation and has been estimated econometrically with Austrian time series data. Energy demand of households in addition to economic variables also depends on the energy-efficiency as well as the level of energy-using durables (electrical and non-electrical appliances, vehicles, video, audio, computer goods). Higher energy-efficiency also leads to the well known 'rebound effect', as the 'service' of energy becomes cheaper. Investment in new and potentially more energy-efficient durables is guided by intertemporal optimisation. Policies with incentives to switch towards a more energy-efficient durable stock have an impact on energy consumption, as well as on the demand for other nondurables and – due to the investment – on durables and therefore cause multiple effects on energy demand and emissions. Indirect energy demand and CO_2 emissions of production for households is also taken into account. An exemplary simulation of a scrappage policy scheme for private cars reveals that – though the direct 'rebound effect' lies within the range found in the literature - the direct and indirect feedback mechanisms on energy demand of the total economy might be completely different.

Key words: energy demand and environmental impact, durable goods, intertemporal optimisation with liquidity constraints, input-output modelling

JEL Code: D11, D13, Q53

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1. Introduction

During the last two decades issues of environmental policy pushed the development of CGE models like the GREEN model of OECD (Burniaux, et al., 1992; Lee, et al., 1994). The situation in Europe during the decade after 1990 was characterized by the parallel development and application of the CGE model GEM-E3 (Conrad, and Schmidt, 1998) and the econometric input-output (EIO) model E3ME (Barker, 1999; Barker, et al., 1999). Both models integrated energy and emissions in the economic model (E3) and have been used for evaluation of energy tax policies and emission trading at the EU level in standardized simulations (for comparison of results see: Barker, 1999). As a consequence of these parallel developments of very different models, there has been an ongoing discussion between the EIO- and the CGE-community focussing on the following issues: calibration vs. econometric estimation, the choice of functional forms in relation to the behavioural assumptions (degree of rationality of agents), the role of equilibrium mechanisms and the benchmark year, as well as the concept of time and the modelling of adjustment towards equilibrium. Some authors like Jorgenson (1998) and Siebe (1994) have attempted to reconcile the different methodologies of CGE and EIO models by supporting econometric techniques as a base for calibration.

We follow the latter approach in this paper and present a dynamic consumer optimisation model integrated into an input-output (IO) framework model. This can be seen as a first step towards the construction of a fully fledged Dynamic Econometric IO model (DEIO), following the modelling philosophy of Dynamic Stochastic General Equilibrium (DSGE) models (Christiano, Eichenbaum, and Evans, 2005; Smet, and Wouters, 2003; and Ratto, Roeger, and In't Veld, 2009). The simplest representation of private consumption within an IO framework is the SAM (social accounting matrix) multiplier model with fixed shares for the inter-linkages between value added, household income, and private consumption. It is worth noting, that the standard applied CGE model (Lofgren, et al., 2002; Hertel, and Tsigas, 1997) treats the expenditure side of household accounts in the same way.[1]

In contrast to that, the DSGE model and the recent U.S. dynamic CGE model IGEM (Goettle, et al., 2007) deal with private consumption within the framework of an intertemporal optimisation model of private households applying institutional rigidities and constraints. The standard DSGE model usually contains an intertemporal optimization model for households, where households derive utility from leisure and consumption. In this paper we set up a dynamic optimization model of households with liquidity constraints using data on the stock of durable goods and purchases of nondurables. We assume that households are forward looking and maximize expected life time utility subject to current assets, current income and expected future income. Borrowing by households does not allow for smoothing all consumption over time. Durable goods provide services which are relevant for utility and in some cases use energy input for the production of these services (appliances, vehicles). The average energy-efficiency of the durable stock is one important factor for energy demand in addition to income and prices. This demand is modelled as a service demand, depending on the price for the corresponding energy-using service (heating, electricity-using services, private transport). An important feedback effect from energy-efficiency to service prices is taken into account, which is responsible for the 'rebound effect' of energy-efficiency improvements. In line with the philosophy in IGEM (Goettle, et al., 2007), the model is specified in a way to yield specifications of the demand for total nondurables, that can be

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[1] Though, the linking of equilibrium conditions to household consumption behaviour in CGE models adds some dynamics to the relationship between household income and consumption expenditure.

directly estimated econometrically. For splitting up the total demand of nondurables across seven different consumption categories, the Almost Ideal Demand System (AIDS) is used. Total nondurable consumption consists of demand for commodities (non-energy items) and of service demand (energy items).

The demand for four different durables is modelled according to the optimal (S,s) model of households' durable purchases, where S and s represent upper and lower bounds of target durable stocks of households, so that actual stocks are adjusted in order to lie within these bounds. This type of model is usually applied at the individual level and explains changes in the distribution of durable stocks across households which in turn can explain the aggregate behaviour of households' durable purchases (Caballero, 1993; and Eberly, 1994). We approximate the aggregate of this demand by a model of stock adjustment, where the target stock is determined by aggregate variables measuring the wealth position of households and additionally take into account liquidity constraints. The demand for durables can be influenced by policies affecting the user costs of capital of durables at purchaser prices.

The private consumption model determines the vector of private consumption for 12 consumption categories (in COICOP classification) which is transformed into a vector of private consumption used in an input-output model by applying a bridge matrix. The link of the consumption model to the input-output model (in NACE 60 classifiaction) is similar to the one proposed in Mongelli, et al. (2010) and comprises three interfaces: (i) consumption demand by commodities derived from the consumption model, (ii) consumer prices by categories derived from the input-output price model, and (iii) value added and household income derived from the input-output model.

The consumption model block as well as the input-output model are complemented by an energy and environment-satellite based on NAMEA data. Actually it includes detailed energy accounts (in energy units for 19 types of energy) which are linked to consumption and production activities and are converted into CO_2 emissions. In the private consumption model a fully consistent link between energy demand in energy units and expenditure for energy commodities is in place, based on price links. For production, energy inputs in energy units by unit of output are used. The energy- and environment-satellite therefore allows for calculating direct CO_2 emissions of households as well as domestic indirect emissions, stemming from production induced by domestic household demand.

2. A consumers' optimization model with durable goods and purchases of nondurables

The structure of the consumers' optimization model distinguishes between different types of durable expenditure and stocks of households (including some expenditure for services of durables), total expenditure for nondurables and it's splitting up into seven categories of consumption (food, beverages, tobacco; clothing, and footwear; heating; electricity; fuel for private transport; public transport services; and other goods and services). The consumption model is based on the literature of dynamic consumer optimization with durable goods and liquidity constraints. The seminal paper in this literature is Hall (1978), where explicit demand functions are derived from the solution of the optimization problem. Large part of the literature on consumer optimization is purely theoretical and the empirical use of these models is limited to calibration of parameters (for example Luengo-Prado, 2006).

Some papers analyse consumer intertemporal optimization with econometric methods based on household level data from consumer surveys (Alessie, et al., 1997; Attanasio, and Weber, 1995). Both estimate an Euler equation as a solution to the intertemporal optimization problem and explain nondurable consumption; Alessie, et al. (1997) also include the demand for durables in the analysis. The approach chosen here is based on Chah, et al. (1995), where consumer demand functions can be derived directly from the intertemporal optimisation problem. That enables us to directly estimate these consumer demand functions based on time series econometrics. Like Chah, et al. (1995), we start with a representative consumer who maximizes the expected value E_0 of utility U in t = 0 over an infinite time horizon by chosing the level of C (nondurables consumption) and K (stock of durables), for given financial assets A:

$$\underset{C,K,A}{Max}\, E_0 \sum_{t=0}^{\infty} (1+\rho)^{-t} U(C_t, K_t) \tag{1}$$

$$A_t = (1+r)A_{t-1} + Y_t - C_t - p_D\left(K_t - (1-\delta)K_{t-1}\right) \tag{2}$$

$$A_t + \varphi p_D K_t \geq 0 \tag{3}$$

The rate of time preference of consumers is given by ρ, the market interest rate by r, and Y is labour income. Expenditures for durables are determined by the relative price of durables to nondurables, p_D, and the depreciation rate, δ. Equation (2) describes the path of the asset position of households and includes the expenditure for durables. Equation (3) is the nonnegativity constraint for households' asset position and comprises financial assets as well as the stock of durables. The parameter φ defines the part of durables that can be financed and takes values between 0 and 1, usually close to 1. The Lagrangean function L and the first order conditions for this problem are given with:

$$L = E_0 \sum_{t=0}^{\infty} (1+\rho)^{-t} \begin{Bmatrix} U\left[(1+r)A_{t-1} + Y_t - p_D\left(K_t - (1-\delta)K_{t-1}\right) - A_t, K_t\right] + \\ + \mu_t\left[A_t + \varphi p_D K_t\right] \end{Bmatrix} \tag{4}$$

$$E_t \frac{1+r_{t+1}}{1+\rho} U_C(1+t) = U_C(t) - \mu_t \tag{5}$$

$$U_K(t) = p_{Dt}\left[U_{Ct} - \frac{1-\delta}{1+\rho}E_t\left((1+\pi_{t+1})U_{Ct}(t+1)\right)\right] - \varphi p_D \mu_t \qquad (6)$$

In (5) and (6) U_C, and U_K denote the derivative of the utility function with respect to *C*, and to *K*. With liquidity constraints, the shadow price of the nonnegativity constraint for the asset position of households is positive ($\mu_t \geq 0$). The inflation rate of relative prices of durables is described with $1+\pi_{t+1} = p_{Dt+1}/p_{Dt}$. Combining (5) and (6), the optimisation problem can be solved, if at time *t* both r_{t+1} and p_{Dt+1} are known. That yields equation (7), where $R^k_{t+1} = 1 + r_{t+1} - (1-\delta)(1+\pi_{t+1})$. In absence of liquidity constraints ($\mu = 0$), the usual relationship between the marginal rate of substitution and relative prices of durables and nondurables is obtained.[2] Inserting (7) into (5) yields solutions for $U_C(t)$, and $U_C(t+1)$.

$$U_C(t) = \frac{1+r_{t+1}}{R^K_{t+1}}\frac{1}{p_{Dt}}U_K(t) + \frac{\varphi(1+r_{t+1}) - (1-\delta)(1+\pi_{t+1})}{R^K_{t+1}}\mu_t \qquad (7)$$

$$\begin{aligned} & U_C(t+1) - \frac{1+\rho}{1+r_{t+1}}\frac{1}{p_{Dt}}U_C(t) = \frac{1+\rho}{1+r_{t+1}}\mu_t + \varepsilon_{t+1} = \\ & = \frac{1+\rho}{1+r_{t+1}}\frac{R^K_{t+1}}{\varphi(1+r_{t+1}) - (1-\delta)(1+\pi_{t+1})}\left[U_C(t) - \frac{1+r_{t+1}}{R^K_{t+1}}\frac{1}{p_{dt}}U_K(t)\right] + \varepsilon_{t+1} \end{aligned} \qquad (8)$$

Equation (8) describes a relationship between the change in marginal utility from the consumption of nondurables and the difference between the marginal utility from durables and nondurables.

Applying a CES utility function of the form $U = \eta_t C_t^{1-1/\alpha} + v_t K_t^{1-1/\beta}$, where η and v are stochastic shocks to utility, allows calculating explicit values for U_C, and U_K. Taking

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[2] Note that in this model liquidity constraints are explicitly part of the decision problem of the representative household, and households are not divided into liquidity constrained on non-constrained household types as in the approach of Campbell, and Mankiw (1989).

logarithms and approximating log(1+x) = x for small x finally yields an explicit equation for C:

$$\log C_t = const + \alpha / \beta \log K_t + \alpha \log p_{Dt} + \alpha \log R^K_{t+1} - \alpha r_{t+1} + Z_t \tag{9}$$

$$\Delta \log C_{t+1} = \theta_0 + \alpha r_{t+1} + \theta_{2t+1} Z_t + \alpha \Delta \log \eta_{t+1} - \alpha \varepsilon_{t+1} \tag{10}$$

As Chah, et al. (1995) have noted already, this system reveals the form of an error correction model, where the error term in the cointegrating relationship, Z_t, is a function of stochastic shocks to utility (η_t, and ν_t), of the interest rate and of user costs: $Z_t = Z_t\left(\eta_t, \nu_t, r_{t+1}, R^K_{t+1}\right)$.

The error correction parameter, θ_{2t+1}, can be specified as a constant parameter or as a function of interest rates and rental costs. If it is specified as not constant, its value mainly depends on the magnitude of φ. If φ is close to unity, then θ_{2t+1} will be negative, for $\varphi = 1$, θ_{2t+1} will be a constant with magnitude -1. The statistical significance of θ_{2t+1} decides about the validity of this error correction model and of the liquidity constraints-hypothesis.

2.1 Demand for nondurables

The system consisting of (9) and (10) is the starting point for the empirical application of the model and allows us deriving a specification for the demand for nondurables. Following Chah, et al. (1995), we estimate as a first step the long-run equilibrium relationship (in logarithms) between the aggregate of nondurables expenditure, C_t, the current-cost stock of durables, K_t, and the relative price of durables (p_D):

$$\log C_t = a_0 + a_1 \log K_t + a_2 \log p_{Dt} + Z_t \tag{11}$$

The error term of this long-run relationship (Z_t) enters the estimation of the dynamic equation for the demand for nondurables:

$$\Delta \log C_t = b_0 + b_1 \Delta \log K_t + b_2 \Delta \log C_{t-1} + b_3 r_t + b_4 Z_{t-1} + \zeta_t \tag{12}$$

In (11) the expected signs on parameters are $a_1 > 0$ and $a_2 > -1$ (as p_D is the relative price of durables to non-durables and C is the expenditure in current price terms). The aggregate of total nondurables is the starting point of a demand system that describes the consistent splitting up across different consumption categories. This demand system can be linked directly to the expenditure, C, if we use an expenditure function with the level of utility, u, and the vector of prices of consumption categories, p_i. As Attanasio, and Weber (1995) have pointed out, this is consistent with a two step interpretation of the intertemporal optimization problem: in a first step the consumer decides how to allocate expenditure across time periods, and in a second step allocates the expenditure in each time period to different consumption categories. This second step allocation depends on the vector of prices of consumption categories, p_i, and the level of C. Therefore we proceed by applying the cost function of the Almost Ideal Demand System (AIDS) for $C(u, p_i)$. The AIDS model represents a flexible functional form consistent with restrictions on demand in microeconomic theory (Deaton, and Muellbauer, 1980).

$$\log C(u, p_i) = (1-u)\log(a(p_i)) + u \log(b(p_i)) \tag{13}$$

with the translog price index for $a(p_i)$:

$\log a(p_i) = \alpha_0 + \sum_k \alpha_k \log p_k + 0.5 \sum_k \sum_j \gamma_{ij} \log p_k \log p_j$, the Cobb-Douglas price index for $b(p_i)$:

$\log b(p_i) = \log a(p_i) + \beta_0 \prod_k p_k^{\beta_k}$ and the level of utility, u. As the level of utility u is an argument of the expenditure function, an indirect utility function can be derived:

$$U = \left[\frac{\log C(u,p) - \log a(p_i)}{\beta_0 \prod_k p_k^{\beta_k}} \right] \tag{14}$$

Applying Shephard's Lemma to the cost function (13) and inserting the indirect utility function (14) gives the well known budget share equations for the *i* nondurable goods in each period:

$$w_{it} = \alpha_i + \sum_j \gamma_{ij} \log p_{jt} + \beta_i \log\left(\frac{C_t}{P_t} \right) \tag{15}$$

with price index, P_t, defined by $\log P_t = \alpha_0 + \sum_k \alpha_k \log p_{kt} + 0.5 \sum_k \sum_j \gamma_{ij} \log p_{kt} \log p_{jt}$, often approached by the Stone price index: $\log P_t^* = \sum_k w_{kt} \log p_{kt}$.

As $\log C_t = \log C_{t-1} + \Delta \log C_t$, we could substitute log C_t in (15) by this term and use equation (12) for $\Delta \log C_t$. This link describes the two step allocation process comprising the allocation of expenditure across time periods and across commodities.

As mentioned above, for non-energy commodities the budget share, w_i, is given as in the traditional model, for energy commodities it is specified as the expenditure share of the service 'produced' with energy. Energy commodities are used by consumers for the 'production' of services (heating, lighting, communication, transport, etc.). These services are demanded by households and require inputs of energy flows, *E*, and a certain stock of durables, *K*. The main characteristic of the durable stock for energy demand of households is the efficiency of converting an energy flow into a service level $S = \eta_{ES} E$, where *E* is the energy demand for a certain fuel and *S* is the demand for a service inversely linked by the efficiency parameter (η_{ES}) of converting the corresponding fuel into a certain service. For a given conversion efficiency, a service price, p_S, (marginal cost of service) can be derived, which is a function of the energy price and the efficiency parameter:

$$p_S = \frac{p_E}{\eta_{ES}} \tag{16}$$

These prices of services (p_S) become arguments of the vector of commodity prices in the overall consumption model (p_i). This is similar to Khazzoom's (1980, 1989) approach of dealing with services and reveals the property that the service price decreases with an increase in efficiency. Differentiating the quantity of energy demanded E (S, η_{ES}) with respect to η_{ES} gives:

$$\frac{d \log E}{d \log \eta_{ES}} = -(1 + \varepsilon_{ii}) \tag{17}$$

In (17) the total change in E brought about by an efficiency change incorporates the direct (engineering) effect that equals -1 and the indirect effect via service demand. As an increase in efficiency also leads to a decrease in the service price and thereby to an increase in service demand, we get the reaction of service demand measured by the service price elasticity, ε_{ii}. Equation (17) is identical with formulas of the total effect of efficiency on energy demand including the rebound effect, as derived by Brännlund, et al. (2007), Berkhout, et al. (2000), and Khazzoom (1980). In opposition to most studies which use a (estimated) *energy* price elasticity as a measure of the direct rebound effect, we use a (estimated) *service* price elasticity. From a theoretical and behavioural point of view, it might be reasonable to assume that consumers react to lower energy costs in the same fashion as they react to lower costs of services. In an econometric perspective, the parameter value based on the energy price is a biased estimate of the true service price elasticity, because the long-term time series of service prices differs considerably from the long-term time series of energy prices.

Henly, et al. (1988) have critizised this simple rebound formula, as it neglects the fact that energy efficiency is embodied in the stock of households' capital goods and therefore a technical energy efficiency improvement has as a prerequisite an investment in new and more efficient appliances. In their formulation, they take into account the necessary investment in order to increase efficiency by $\frac{\partial \log K}{\partial \log \eta_{ES}}$ and the impact this additional investment expenditure has on service demand $\frac{\partial \log S}{\partial \log K}$, via income effects and expenditure elasticities within a given budget constraint. That yields the following expression for the rebound effect:

$$\frac{d \log E}{d \log \eta_{ES}} = -\left(1 + \varepsilon_{ii} + \frac{\partial \log K}{\partial \log \eta_{ES}} \frac{\partial \log S}{\partial \log K}\right) \qquad (18)$$

The idea behind this extended formulation of the rebound effect is that – as capital costs increase due to investment in appliances with higher energy efficiency – less will be spent on satisfying 'service' demand.

In our model the reaction of current service demand to the capital stock ($\frac{\partial \log S}{\partial \log K}$) is determined by the dynamic equation for nondurables (equation (12)) and the AIDS model. For simulation exercises we take into account technical information about the relationship between additional capital cost and the introduction of more energy efficient capital stocks for households ($\frac{\partial \log K}{\partial \log \eta_{ES}}$) in the categories vehicles, energy-using appliances, and video, audio, computer goods. This is equivalent to recent work presented by Mizobuchi (2008), where this capital cost term ($\frac{\partial \log K}{\partial \log \eta_{ES}}$) is derived from technological data sets about capital costs and efficiency of appliances. Therefore, our model enables us to calculate the full rebound effect as defined by Henly, et al. (1988).

The following expressions for expenditure (ε_i) and uncompensated price elasticities (ε_{ij}^U) within the AIDS model can be derived (Green, and Alston, 1990):

$$\varepsilon_i = \frac{\beta_i}{w_i} + 1 \tag{19}$$

$$\varepsilon_{ij}^U = \frac{\gamma_{ij} - \beta_i w_j}{w_i} - \delta_{ij} \tag{20}$$

Via the Slutsky equation the following general relationship holds between the compensated (ε_{ij}^C) and the uncompensated elasticity (ε_{ij}^U): $\varepsilon_{ij}^C = \varepsilon_{ij}^U + \varepsilon_i w_j$. The compensated elasticity measures the pure price effect and assumes that the household is compensated for the income effect of a price change. Applying the Slutsky equation in the case of the AIDS model yields for the compensated elasticity:

$$\varepsilon_{ij}^C = \frac{\gamma_{ij} - \beta_i w_j}{w_i} - \delta_{ij} + \varepsilon_i w_j \tag{21}$$

In (20) and (21) δ_{ij} is the Kronecker delta with $\delta_{ij} = 0$ for $i \neq j$ and $\delta_{ij} = 1$ for $i = j$.

The demand for energy-commodity, E_i, is determined by the level of service demand, S_i, and energy efficiency for the appliance using the relevant energy carrier ($\eta_{E(i)S(i)}$) as well as energy efficiency for the other appliances ($\eta_{E(j)S(j)}$). Energy efficiency for a different appliance ($\eta_{E(j)S(j)}$) has an impact on energy demand for good *i* due to cross price effects, which is a special feature of our model of total household consumption.

The commodity classification *i* in this model includes:

(i) food, and beverages, tobacco, (ii) clothing, and footwear, (iii) services for private transport (via input of gasoline/diesel), (iv) services for heating (via input of solid fuels, oil, gas, district heating), (v) services for electricity using appliances (via input of electricity), (vi) public transport services, (vii) operation of vehicles (other than fuel), and (viii) other (non-energy) commodities and services.

Data on private consumption (1990 to 2008) in current prices and the corresponding price indices are directly taken from private household sector data in National Accounts of Austria (in COICOP classification). These data are related to data on conversion efficiency of household appliances to derive the service price (marginal cost of service) as defined by equation (16). The data on conversion efficiency comprise indices of efficiency of capital stocks for major energy-using appliances, in the sector of heating, electricity, and passenger car transport. The main data source for efficiency is the ODYSSEE database (http://www.odyssee-indicators.org), data on efficiency of the passenger vehicle fleet have been originally generated through a compilation of technological characteristics of the registered car fleet in Austria from 1990 to 2007. A detailed description of the efficiency data set for heating, electricity, and passenger cars can be found in Meyer, and Wessely (2009), as well as in Kratena, et al. (2009).

The impact of effiency improvements can be seen in *Table 1* in terms of the different path of energy and 'service' prices between 1990 and 2008. Especially in the period from 1990 to 2000, efficiency increases have dampened energy price increase considerably, so that 'service' prices of heating and electricity have been almost constant. These stylized facts underline the importance of an unbiased estimate of the rebound effect by using 'service' prices and estimating the 'service' price elasticity.

Table 1: Energy and service prices for fuels for private transport, heating, and electricity, 1990 – 2008

2.2 Demand for durables

In the overall model of intertemporal optimisation, both the level of nondurables, C, and the stock of durables, K, are chosen to maximize the expected value of utility. The solution to this optimization problem in the presence of liquidity constraints has been used to determine nondurable expenditure, once K is given. The existence of liquidity constraints has been tested through significance tests on the error correction parameter of θ_{2t+1} in the dynamic specification of the model (equation (10)). It has also been analysed, how this parameter in turn depends on the parameter φ (a measure for the part of durables that can be financed).

What is required to close the model for the durable stock, therefore, is a demand function for durables which is consistent with the intertemporal optimization model in the presence of liquidity constraints.

The literature on the demand for durables following the permanent income hypothesis (among others: Bernanke, 1984; Caballero, 1993; Carroll, 1997; and Eberly, 1994) mainly has used panel data at the household level to explain the aggregate behaviour in durable expenditure. The individual household behaviour is characterized by lumpy expenditure for durables, because durables can only be purchased in large units and therefore cannot be adjusted smoothly. In addition, the purchase of durables and adjustment in the stock of durables incurs significant transaction costs for households. It has been shown that an individual household model of durables adjustment within a lower (s) and an upper (S) bound for the target stock is well suited for explaining the smooth behaviour of aggregate expenditure for durables. These

(s, S) models of adjustment for durables use household survey data and analyse the density distribution of stock adjustment across households and thereby bridge the gap to aggregate data of durable expenditure.

In the model presented here, aggregate data from National Accounts for different types of durables (vehicles; video, audio, computer goods; energy-using appliances, and other durables (furniture, etc.)) will be used. Starting point is the observation that in the permanent income hypothesis a target stock, K_t*, for each durable exists, that is driven by wealth (measured by financial assets, A_t), the relative price of durables to nondurables, p_D, and user costs, $p_I(r + \delta)$, as in Caballero (1993):

$$\log (K_t*) = \beta_0 + \beta_1 \log (A_t) + \beta_2 \log (p_{Dt}) + \beta_3 \log (p_{It}(r_t + \delta)) \qquad (22)$$

In (22) p_I is the price of the durable (investment) goods, the interest rate, r_t, changes over time, and the depreciation rate, δ, is assumed to be constant. Introducing liquidity constraints into this framework as in Eberly (1994) would result in taking into account variables measuring liquidity in (22) in addition to or instead of financial wealth, A_t.

The other conclusion from the permanent income hypothesis is that the actual stock of durables, K_t, equals the target stock, K_t*, plus a 'departure' variable, D_t :

$$\log (K_t) = \log (K_t*) + \log (D_t) \qquad (23)$$

Under the permanent income hypothesis, a positive wealth shock would immediately increase the target stock, K_t*, so that the variable D_t and the target stock, K_t*, are contemporaneously negatively correlated. Caballero (1993) shows that equation (23) can therefore be seen as a cointegrating relationship. That means that lagged error terms $\log(D_{t-1})$ in (23) which are equal to $(\log(K_{t-1}) - \log(K_{t-1}*))$ could be used in a dynamic specification of the change in the durable stock or of durable expenditure. Instead of using this error correction model type, we apply a more general functional form of a stock adjustment model, as proposed by Egebo, et al. (1990), allowing for a more flexible type of adjustment towards the 'target' stock:

$$\log(K_t) - \log(K_{t\text{-}1}) = t_1 \, [\log(K_t{}^*) - \log(K_{t\text{-}1})] + t_2 \, [\log(K_{t\text{-}1}) - \log(K_{t\text{-}2}) \,] \qquad (24)$$

In equation (24) we include adjustment terms of first and second order, where the equilibrium condition is given by $t_1 > 0$. The sign of the adjustment term of second order, t_2, is ambiguous and decides about the path of the adjustment process. Inserting the equation for the path of the target stock (22) into (24) yields the final specification of the stock adjustment model:

$$\begin{aligned}\log(K_t) - \log(K_{t\text{-}1}) = \alpha_K + \beta_K \log(A_t) + \gamma_K \log(p_{Dt}) + \rho_K \log(p_{It}(r_t + \delta)) - \\ - t_1 \log(K_{t\text{-}1}) + t_2 \, [\log(K_{t\text{-}1}) - \log(K_{t\text{-}2})] \qquad (25)\end{aligned}$$

Note that the parameters β_K, γ_K, and ρ_K in (25) are products of the original parameters in (22) and the adjustment parameter t_1 in (24).

The commodity classification for durables in this model includes:

(i) purchase of vehicles, (ii) energy-using appliances, (iii) video, audio, computer goods, (iv) other durables. The consumption for housing from National Accounts comprises rents and imputations and is in our model directly linked to the stock of dwellings, which are not part of the consumption data. The data source for durable expenditure (1990 to 2008) in current prices and the corresponding price indices is National Accounts of Austria (in COICOP classification). Expenditure data have been converted into stock data (K) by applying the perpetual inventory method and using the following average lifetimes for the different stocks of durables: 14 years for vehicles, 12 years for appliances, 5 years for video, audio, computer goods, and 10 years for other appliances. For calculating the starting values of the stocks in 1990, the full time series of expenditure from 1976 on has been used. Therefore the starting value of the stocks can be directly generated from the observed expenditure data and no assumptions have to be made. The different lifetimes imply a depreciation rate for each type of stock, which together with prices for the durable consumption categories and the 3 month (EURIBOR) interest rate determine the user costs of each type of stock.

2.3 Energy and direct emissions of households

The consumption model yields results for a vector of expenditure in current prices as well as constant prices, comprising the vector of non-energy nondurables, c_{NE}, of energy nondurables, c_E, and of durable expenditure, k. The energy nondurables consist of fuel for private transport, heating, and electricity. At this aggregate level of energy demand, a fully consistent link between expenditure data and (physical) energy NAMEA data, both from National Accounts, is achieved. The core variables of this link are prices of these energy demand categories, which partly come as deflators from the COICOP National Accounts data and partly have been derived by combining expenditure data and physical data. Additionally, the price information from OECD (Energy Prices and Taxes) and other national sources have been taken into account. The combination of expenditure and physical data yields prices per unit of energy content (million €/TJ). The final link between the two data sets is achieved by equations relating the deflators from the COICOP National Accounts data to the prices per unit of energy content.

The NAMEA energy data set differentiates between 19 inputs of energy and contains physical energy input (in TJ) for each of the 19 energy sources in the household sector, including private transport. The aggregates of the energy demand categories 'fuel for private transport', 'heating', and 'electricity' in energy units are further split up into the 19 energy inputs by applying fixed subshares. These subshares can be extrapolated into the future for reference scenarios or changed for the purpose of simulations. CO_2 emissions are directly linked to the

19 energy inputs by fixed CO_2 emission coefficients for each energy source. The resulting data for CO_2 emissions only show very small deviations from the official NAMEA air emission data.

3. An input-output model with energy and emissions

The consumption model block is linked to an input-output framework as in Mongelli, et al. (2010) by using a bridge matrix. The total vector of private consumption in COICOP classification, $\mathbf{c}_C$, consists of non-energy nondurables, $\mathbf{c}_{NE}$, energy nondurables, $\mathbf{c}_E$, and durable expenditure, $\mathbf{k}$: $\mathbf{c}_C = \begin{pmatrix} c_{NE} \\ c_E \\ k \end{pmatrix}$. Direct emissions of households are directly linked to energy consumption of households in energy units, which in turn is linked to $\mathbf{c}_E$, as described above.

The consumption vector in COICOP classification, $\mathbf{c}_C$, is transformed into a consumption vector by commodities of an input-output model, $\mathbf{c}$, by applying the bridge matrix, $\mathbf{B}_c$, between the categories of consumption in national accounts (COICOP) and the final demand vector, $\mathbf{c}$, i.e. $\mathbf{c} = \mathbf{B}_C \, \mathbf{c}_C$.

The input-output model is based on the symmetric input-output tables (2000 and 2005) of Austria in the classification of NACE-2 digit (60) homogenous branches. Statistics Austria has applied commodity technology to derive these symmetric IO tables from a make-use system and the problem of negative technical coefficients has been overcome by manual adjustment. The bridge matrix links the COICOP vector (in purchaser prices) to the NACE-2 digit vector (in purchaser prices). For this purpose trade and transport margins in private consumption have been taken from the make-use tables and added to the consumption vector of the symmetric IO table. Additionally we use the information of domestic and imported symmetric IO tables for 2000 and 2005 to calculate import shares c^m of private consumption. Multiplying the COICOP vector **c** by a diagonal matrix of import shares $\hat{C}^m$ or by $\left(I-\hat{C}^m\right)$ yields the vector of imported consumption goods and of consumption goods from domestic production, $\mathbf{c^m}$, and $\mathbf{c^d}$:

$$c^m = \hat{C}^m B_C \begin{pmatrix} c_{NE} \\ c_E \\ k \end{pmatrix} \; ; \; c^d = \left(I-\hat{C}^m\right) B_C \begin{pmatrix} c_{NE} \\ c_E \\ k \end{pmatrix} \tag{26}$$

After this multiplication, trade and transport margins have to be subtracted again, in order to arrive at consumption vectors in basic prices.

The input-output quantity model

In the input-output quantity model domestic output is given by the product of the sum of endogenous consumption demand in basic prices ($\mathbf{c^d}$) and exogenous final demand ($\mathbf{f^{d*}}$), and the Leontief inverse of domestic production (with the matrix of domestic technical coefficients, $\mathbf{A^d}$):

$$x = \left(I - A^d\right)^{-1}\left(c^d + f^{d*}\right) \tag{27}$$

Similar to the approach chosen in the household sector, the NAMEA energy accounts for all industries in the detail of 19 energy carriers are directly linked to the output level in each industry, x_i. This is carried out in a nested structure, first linking total energy input to the output level and then splitting up this total energy input with the use of subshares.

Though all these direct energy input coefficients and all subshares for detailed energy types are constant for the moment, the framework would in principle enable us to modify them for simulations or to extrapolate them for certain scenarios.

The (column) vector of indirect household emissions is given as the product of the transposed energy input matrix and the (column) vector of fixed CO_2 emission factors per unit of energy input, $\mathbf{v_{EM}}$. The energy input matrix has the dimension energy types * industries, and is directly linked to the gross output in terms of energy input coefficients, in the matrix $\mathbf{A^e}$. The (column) vector of total emissions by industries and the indirect household emissions are therefore given with:

$$em = \left(A^e \hat{x}\right)' v_{EM} \qquad ; \qquad em_{CI} = \left(A^e \left(I - A^d\right)^{-1} \hat{c}^d\right)' v_{EM} \tag{28}$$

In (28) $\hat{x}$, and $\hat{c}^d$ are diagonalised matrices of the vectors of output and domestic consumption, respectively. Total emissions attributable to households are made up of direct emissions caused by energy use in households, $\mathbf{em_{CD}}$, and indirect household emissions, $\mathbf{em_{CI}}$.

The input-output price model

As in Mongelli, et al. (2010), the consumption model is linked to the input-output model in quantity terms as well as in price terms. The input-output price model determines output prices for given matrices of domestic technical coefficients ($\mathbf{A^d}$) and technical coefficients of imports ($\mathbf{A^m}$), as well as 'value added coefficients'. In our case we differentiate between energy (*e*) and non-energy (*ne*) commodities, as in the case of a partitioned model (see: Miller, and Blair, 2009; or Kratena, and Schleicher, 1999). In the quantity model this differentiation has only been introduced in the consumption block. In the price model, energy commodities are treated as separated from non-energy commodities in order to simulate the impact of energy price shocks. The vector of energy prices, $\mathbf{p^e}$, is directly linked to the international prices of crude oil (Brent), gas, and coal. These output prices are therefore treated as exogenous in the input-output price model and enter the cost push-equation (29) together with the above mentioned matrix of energy inputs per unit of output, $\mathbf{A}^{\mathbf{e}}$. The (row) vector of domestic output prices of non-energy commodities is then given by energy costs, costs of imported non-energy inputs (with import prices, $\mathbf{p}^{\mathbf{m,ne}}$), the product of value added coefficients, $\mathbf{v}^{\mathbf{d,ne}}$, and the Leontief inverse of domestic output (both for non-energy), as well as the vector of net taxes per unit of output, $\mathbf{t}_{\mathbf{n}}$:

$$p^{d,ne} = v^{d,ne}\left(I - A^{d,ne}\right)^{-1} + p^{e} A^{e,ne} + p^{m,ne} A^{m,ne} + t_{n} \qquad (29)$$

The input-output model is set up in basic prices, so that equation (29) determines output prices in basic prices. In order to link the consumer prices for the COICOP vector $\mathbf{c}_{\mathrm{C}} = \begin{pmatrix} c_{NE} \\ c_{E} \\ k \end{pmatrix}$ to the input-output price model, the conversion between basic prices and purchaser prices has to be implemented. We deal with this problem by introducing a vector of statistical differences, u_C, which additionally captures the difference between the 'hypothetical' price of consumption goods from input-output balances (import shares and bridge matrix) and the actual price information in COICOP from National Accounts. In equation (30) the left hand side represents this information from National Accounts. The right hand side shows the products of domestic output prices and import prices with the import and domestic share-weighted bridge matrix, respectively. As National Accounts calculate the COICOP deflators via using the input-output information, the vector of statistical differences is almost zero (differences mainly arise from using different base years for import and bridge matrices in official statistics and in our model).

$$\begin{pmatrix} p^{C,NE} & p^{C,E} & p^{k} \end{pmatrix} = p^{d}\left(I - \hat{C}^{m}\right)B_{C} + p^{m}\hat{C}^{m}B_{C} + u_{C} \qquad (30)$$

Shocks in the price model can then be introduced by changing net taxes, $\mathbf{t_n}$, value added coefficients, $\mathbf{v}^{\mathbf{d,ne}}$, or the international prices of crude oil (Brent), gas, and coal.

5. Econometric estimation results

In the following, econometric estimation results for the different parts of the consumption model are presented. Starting point of the econometric analysis is the equation for nondurable expenditure, C_t, which has been derived from the dynamic optimisation model (equation (11) and (12)). As we treat the expenditure for housing and for vehicle operation via a direct link to the stock of the corresponding durables, expenditure C_t is total nondurable expenditure minus these two categories. In the next step, this demand for nondurables is split up into 7 consumption categories (food, beverages, and tobacco; clothing, and footwear; fuels for private transport; public transport services; electricity; heating; other nondurables) applying an AIDS demand system. The last part of the model describes the capital stocks of total durables as well as of different durable types (purchase of vehicles; energy-using appliances; video, audio, computer goods) with stock adjustment equations which are consistent with the (S, s) adjustment model for durables.

Estimation results for nondurable expenditure

Equation (11) defines the long-run equilibrium between nondurable expenditure and the stock of durables derived from dynamic optimization under liquidity constraints. Before setting up this cointegrating equation, we tested the variables for non-stationarity, applying ADF tests. The results showed that both the total durable stock as well as total non-durable expenditure follow a unit root process and are difference stationary. The cointegrating relationship between nondurable consumption and the durable stock shows the theoretically expected signs for the parameter values and the low Durbin-Watson test results. The influence of the durable stocks on nondurable expenditure is positive, while the relative price of durables exerts a negative influence and the sign is larger than –1, as required for a negative price elasticity. The estimation results of equation (11) determine the long run relationship and the parameter of the error correction term (Z_{t-1}) in equation (12) is negative. Short-run deviations from the equilibrium relationship therefore induce adjustments towards equilibrium according to this parameter. Equation (12) has in a first step been specified including dynamic lags of C_t as well as the interest rate. Including dynamic lags could account for additional dynamics resulting from adjustment lags, as Chah, et al. (1995) have pointed out. According to specification tests (information criteria), the final version of equation (12) only includes the growth rate of the durables stock, the error correction term and dummy variables for policy shocks which are not shown in *Table 2*.

Table 2: Parameter estimation results for nondurable expenditure, 1990 – 2008

The AIDS model of budget shares is described in equation (15). The budget share equations have been estimated with the SUR (Seemingly Unrelated Regression) system estimator accounting for contemporaneous correlation which is a specific property of any additive demand system. 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:

$$\sum_{i=1}^{n}\alpha_i = 1;\ \sum_{i=1}^{n}\gamma_{ij} = 0;\ \sum_{i=1}^{n}\beta_i = 0;\ \sum_{j=1}^{n}\gamma_{ij} = 0;\ \gamma_{\mathrm{ij}} = \gamma_{ji}$$

Homogeneity and symmetry have been already implied by inserting parameters. Another general restriction in demand systems is that the underlying expenditure (cost function) must be concave and that own price elasticities must be negative for all values of budget shares in the sample. This turned out to be fulfilled for all parameter estimates except the one for electricity. We added a manual adjustment in the form of an additional restriction for this parameter to fulfil concavity even at extreme values of the electricity budget share in the sample.

The estimation results in *Table 3* reveal that out of six estimated own price parameters (γ_{ii}) four turn out to be significant at the 1% level. Five out of six income parameters (β_i) also yield significant estimation results at the 1% level. For the cross price parameters (γ_{ij}) the estimation results are less satisfying. In total, six out of fifteen cross price parameters (γ_{ij}) turn out to be significant, some of them at less than 1% significance level.

Table 3: Parameter estimation results for AIDS model of nondurable expenditure, 1990 – 2008

The estimated parameter values together with the data for the budget shares are, in a next step, used to calculate expenditure elasticities and compensated price elasticities according to expression (19) and (21). *Table 4* shows the values for the calculated elasticities applying the sample mean of the budget shares. All own price elasticities show the expected negative sign and are below unity except for clothing and footwear and for public transport services. For the energy commodities the estimated service price elasticities lie within the bounds in the literature, except for fuels for private transport, which show a relatively high own price elasticity (–0.45). The direct rebound effects which can be expected from our model, therefore also lie within the bounds in the literature (Greening, and Greene, 1997; and Greening, et al., 2000). It must be noted anyway that these direct price induced rebound effects are only one aspect of the overall model impacts and are based on *ceteris paribus* assumptions. If all commodity prices and total nondurable expenditure changes, the overall feedback effect on energy consumption will be significantly different from the direct rebound effect.

Table 4: Compensated price and expenditure elasticities

The cross price elasticities between the energy commodities partly have positive signs (fuels for transport vs. electricity and vs. heating), indicating a substitutive relationship, and partly negative signs (electricity vs. heating), indicating a complementary relationship. The substitutive relationship between fuels for transport and heating as well as electricity means that higher expenditure for private transport *ceteris paribus* leads to lower expenditures for the other energy commodities. This is the 'normal' case within any pair of goods in household theory. The complementary relationship between heating and electricity can be explained by a technological relationship in the development of heating appliances leading to increasing amounts of electricity for system regulation. The cross price elasticity between fuels for private transport and public transport services is positive, indicating a substitutive relationship, as expected. Note that due to the formula (21) the cross price elasticities are not symmetric, as they are linear combinations of symmetric cross price parameters with different budget shares.

The expenditure elasticities shown in *Table 4* are positive for all commodities, except for clothing and footwear. This is due to a very pronounced decrease of the budget share in the observation period. For energy commodities all expenditure elasticities are above unity indicating that energy reacts above average to overall nondurable expenditure in the observation period in Austria. The expenditure elasticity for public transport services is 2.45, which is the highest value of all commodities.

Estimation results for durable expenditure

Equation (25) describes the general form of the stock adjustment model used for the stock of durables in this model. The main variable is financial wealth, A_t, which has to be complemented or replaced by other variables in the presence of liquidity constraints. As the most recent income accounts of the Austrian National Accounts include some changes in net wealth of households and liquidity constraints have been identified in the case of nondurables, we use disposable income of households as the explanatory variable instead of A_t. The relative price of durables is the same as in the model of nondurables. User costs for different types of durables have been calculated applying the price index of expenditure, the depreciation rate, and the EURIBOR interest rate. We tested for the existence of adjustment terms of first and second order and after specification tests only included the first order term of stock adjustment.

Disposable income of households turns out to be significant for all types of durables, for total durables and purchase of vehicles this variable enters with a one period lag. As the unit price of vehicles and of total durables is relatively high compared to the unit price of energy-using appliances and of video, audio, computer goods, lagged income is the relevant variable for these stocks. For vehicles and appliances, user costs of capital turn out to be significant at the

10% level. For total durables only the relative price of durables can be used as an explanatory variable and user costs did not lead to significant estimates. Video, audio, computer goods have a significantly lower unit price and lifetime and the demand for these durables therefore is mainly determined by the current income of households.

The stock adjustment terms of first order are all significant at the 1% level and show similar values in a bound between –0.11 and –0.19. In general, we conclude that the stock adjustment model chosen here corroborates the theory of demand for durables in an intertemporal setting.

Table 5: Parameter estimation results for durable stocks, 1990 – 2008

6. Simulation results: A scrappage policy scheme for private cars

We tested the full model consisting of the dynamic consumers' model, the input-output quantity model, and the input-output price model in an exemplary simulation exercise describing a scrappage policy for private cars. In 2009 different EU countries (for example Germany, France, Spain, and Austria) introduced a specific scrappage policy scheme for private cars as a supporting measure against the financial and economic crisis.

The basic assumption in our simulation exercise was that the scrappage policy scheme leads to additional public expenditure which is not compensated by other measures. We motivate this assumption by an underlying fiscal policy rule like in DSGE models (Ratto, et al., 2009), where fiscal policy reacts to an output gap. We further assume that the scrappage policy leads to a permanent 20% decrease in vehicle prices and to a 20% increase in the average fuel efficiency of the car fleet. The assumption on efficiency improvement is based on the historical data of fuel efficiency improvement between 1990 and 2008 and the assumption that the scrappage policy leads to a structural shift in the car fleet. In most countries one main condition of the scrappage policy is that only at least 10 years old cars enter the policy scheme. This automatically leads to an increase in average fuel efficiency, without any change in the structure of newly registered cars. Recent data after the introduction of scrappage policy measures in different EU countries show that, in addition to that, the new cars substituting the scrapped cars were much more fuel efficient than what would be expected from the observed trend in fleet efficiency. Both effects together contribute to the increase in average fuel efficiency. The assumptions underlying this simulation exercise are arbitrary and are certainly no base for a full economic evaluation of European scrappage policy schemes. Such an evaluation is beyond the limits of this paper and is left to future research.

The scrappage policy scheme is introduced in an *ex post* simulation exercise for the period 2002 to 2007 and represents a sustained price shock of 20% for private cars, financed by a scrappage premia that fully increases the public deficit. The price decrease in vehicles is implemented by changing the corresponding net tax vector in equation (29) and the efficiency increase by directly changing the exogenous efficiency of private cars. The simulation results show that, in a first instance, the scrappage policy would have led to an increase of 26.5% in purchases of vehicles in the 5th year after the implementation of the policy, compared to the historical data. Total durable consumption in current prices is unchanged in the simulation exercise due to the above mentioned substitution mechanism between different categories of durables. Due to the price decrease in purchase of vehicles an 'income effect' exerts a considerable positive demand shock for durables in constant prices in the magnitude of 9.5%. The substitution effect within durable consumption is compensated by the income effect for energy-using appliances, and for video, audio, computer goods, as both categories are slightly higher than in the historical data. This is not the case for the category of other durables, which decreases by 2.2% compared to the historical data.

The increase in the stock of durables also leads to higher nondurable expenditure of 5.8%, according to equation (12) and due to the increase in the net asset position of households. For the different categories within nondurable expenditure, we observe considerable differences in the results. Whereas food, beverages and tobacco, public transport services, electricity, and other nondurables show increases in demand, clothing and footwear as well as fuels for private transport decrease, compared to the historical data. These differences in results mainly mirror the different expenditure elasticities. The decrease in fuel for private transport demand is due to the increased fuel efficiency induced by the scrappage policy. The impact is the same for gasoline and diesel, as no specific measures affecting the structure of the car stock have been assumed for the scrappage policy scheme. Total consumer expenditure in constant prices is increased by 4.9%. We also tried to quantify the rebound effect of higher efficiency of private cars. For this purpose a scenario in which the scrappage policy is implemented, but where no efficiency increase occurs, is simulated. The difference in 'service' demand between this scenario and the full scrappage policy scenario gives us the information about the magnitude of the rebound effect. In *Figure 1* the three different paths for gasoline can be observed and in Figure 2 for diesel. The middle path describes the outcome of the scrappage policy simulation including the efficiency improvement. For a scrappage policy without efficiency improvement, gasoline and diesel demand would follow the highest trajectory. The lowest line shows the hypothetical development of gasoline and diesel demand in the case, where the scrappage policy is implemented and efficiency increases, but service demand is the same as in the scenario without efficiency. This path therefore represents a scenario without any rebound effect and can be used to quantify all different rebound effects on 'service' demand that are captured in our model. In addition to direct price induced rebound effects we also include capital costs and their feedback on service demand (equation (18)). In general the rebound effects compensate about half of the hypothetical engineering effect of efficiency on energy demand in both cases. This result is close to the direct price induced rebound effect which can be seen from the own (service) price elasticity and accounts to 45%. In the case of our simulation the capital cost terms of the enlarged rebound effect concept do not change the picture considerably, because for the households the additional investment is financed by the scrappage policy scheme and the budget constraint is not effective.

Table 6: Simulation results for a car scrappage policy: private consumption, energy demand, and direct CO2 emissions, 2002 – 2007

Figure 1: Simulation results for a car scrappage policy: private consumption, gasoline demand (in TJ) with and without rebound effect

Figure 2: Simulation results for a car scrappage policy: private consumption, diesel demand (in TJ) with and without rebound effect

Differences to the historical data can also be observed in the other energy consumption categories of households, not only in fuels for private transport. This might be seen as an additional feature of our model for evaluating the overall energy and emission impact of policy measures. Due to 'income' and cross price-effects, electricity demand increases considerably (by almost 7%), and heating demand also increases, though, to a smaller extent. In total, these changes in energy demand result in a decrease in direct households' CO_2 emissions of 135.000 tons (*Table 7*) or 0.8% (*Table 7*).

Table 7: Simulation results for a car scrappage policy: private consumption, energy demand (in TJ), and emissions

The increase in private consumption induces an overall increase in gross output of 1.7%. Large output increases can be observed in the following industries and service sectors: food products, and beverages; electrical energy, gas, and steam; trade, maintenance and repair; hotel and restaurant services; land transport and air transport, as well as in the other service sectors (except public services).

Table 8: Simulation results for a car scrappage policy: gross output at constant prices, 2002 – 2007

The output increase leads to higher indirect emissions of household demand, which are concentrated in the following industries and service sectors: food products, and beverages; other non-metallic mineral products; electrical energy, gas, and steam; land transport and air transport.

Although car fuel efficiency is considerably higher in our simulation exercise, the scrappage policy measure increases overall CO_2 emissions. Direct emissions of households are reduced due to lower car fuel demand, but this is more than compensated by the increase in indirect CO_2 emissions. The main driving forces for higher indirect CO_2 emissions are the increases in electricity demand and transport service demand of households. Besides that, higher consumers' demand also induces increases of output and emissions in other industries (for example food products, and beverages) in the linked consumption/IO model. We are fully aware that these results are biased by our assumption of a sustained scrappage policy scheme. Usually scrappge policies are limited to one year and therefore have no permanent impact on total consumption. On the other hand we also assumed a permanent and large (20%) impact on car fuel efficiency that biases the results for emissions in the other direction. Additionally, the results are biased compared to other studies about the emission effect of car fleet renewal like Kagawa, et al. (2008), as Austria has only a small car manufacturing sector and global indirect emissions linked to the production of new cars are underestimated.

Table 9: Simulation results for a car scrappage policy: CO2 emissions, 2002 – 2007

7. Conclusion

In this paper we present a dynamic consumer optimisation model integrated into an IO framework model. The dynamic optimization model of households with liquidity constraints uses data on the stock of durable goods and purchases of nondurables. Durable goods provide services which are relevant for utility and in some cases use energy input for the production of these services (energy-using appliances, purchase of vehicles). The average energy-efficiency of the durable stock is one important factor for energy demand in addition to income and prices. The feedback from energy-efficiency to service prices is responsible for the 'rebound effect' of energy-efficiency improvements.

In line with the philosophy in IGEM (Goettle, et al., 2007), the model is specified in a way to yield specifications of the demand for total nondurables that can be directly estimated econometrically. For splitting up the total demand of nondurables across seven different consumption categories, the Almost Ideal Demand System (AIDS) is used. In addition, we also take into account substitution between different categories of durables.

The model is linked to an input-output quantity and price model like in Mongelli, et al. (2010), so that it can be used for evaluating the environmental and economic impacts of different policy measures for energy efficiency in the household sector. In an exemplary simulation exercise for a scrappage policy scheme for private cars, we find that the additional indirect emissions from higher consumption induced by this policy more than compensate for the lower emissions even in the case of considerable improvements in car fuel efficiency. This is partly due to the rebound effect of higher efficiency that accounts to about half of the hypothetical engineering effect on fuel demand.

The model will be used in future research for the evaluation of different energy and environmental policy measures, especially the implementation of energy and climate policy measures in order to meet the EU 20/20 targets in the non 'Emission Trading Sector" (non-ETS). In this context, the calculation of overall (direct and indirect) emissions can be seen as an important feature to make interdependencies between the targets in ETS and non-ETS transparent.

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Table 1: Energy and service prices for fuels for private transport, heating, and electricity, 1990 – 2008

	Fuels for private transport		Heating		Electricity	
	Energy	Service	Energy	Service	Energy	Service
1990	70.9	86.0	81.8	99.9	84.6	94.5
1991	69.4	82.2	84.5	101.7	85.5	93.9
1992	74.0	85.7	84.6	100.4	87.1	93.7
1993	72.6	82.0	84.0	98.0	88.6	94.4
1994	74.9	83.0	83.4	95.0	89.6	94.5
1995	79.3	86.2	84.9	95.0	90.9	94.9
1996	86.3	92.0	89.0	97.8	95.9	99.3
1997	88.5	92.9	92.7	100.1	98.5	101.1
1998	83.8	86.7	88.8	93.9	98.5	100.2
1999	85.2	86.7	89.5	92.8	97.8	98.6
2000	100.0	100.0	100.0	100.0	100.0	100.0
2001	96.2	94.5	104.5	102.7	102.1	101.3
2002	93.6	89.8	102.8	99.7	99.0	97.4
2003	93.9	88.0	104.3	99.6	100.0	97.6
2004	102.0	94.8	111.1	105.3	102.7	99.5
2005	114.0	105.0	122.5	116.1	105.8	101.8
2006	122.4	111.9	130.4	122.7	109.5	104.6
2007	124.2	113.1	136.7	126.9	119.6	113.5
2008	146.2	131.9	145.8	132.8	121.7	114.7

Table 2: Parameter estimation results for nondurable expenditure, 1990 – 2008

	$\log C_t$	$\Delta\log C_t$
$\log K_t$	0.4842 (0.0432)***	
$\log p_{Dt}$	– 0.5645 (0.0674)***	
$\Delta\log K_t$		0.2149 (0.1381)*
$Z_{t\text{-}1}$		– 0.5075 (0.1355)**
Adjusted R^2	0.989	0.53
Durbin Watson	0.504	1.82

*, **, and *** indicate a significance level of 10%, 5%, and 1% respectively.

C_t = nondurable expenditure (without housing and vehicle operation), K_t = current cost stock of households' durables, p_{Dt} = price of durables/price of nondurables, $Z_{t\text{-}1}$ = error term of cointegrating relationship (left column in *Table 2*).

Table 3: Parameter estimation results for AIDS model of nondurable expenditure, 1990 – 2008

	Parameter estimates	Standard error
$\gamma_{FO,FO}$	0.1625	0.0152***
$\gamma_{CL,CL}$	– 0.0105	0.0156
$\gamma_{F,F}$	0.0226	0.0054***
$\gamma_{PT,PT}$	– 0.0031	0.0081
$\gamma_{EL,EL}$	0.0200	0.0200***
$\gamma_{HE,HE}$	0.0203	0.0067***
$\gamma_{FO,CL}$	– 0.0096	0.0111
$\gamma_{FO,F}$	– 0.0087	0.0057**
$\gamma_{FO,PT}$	0.0031	0.0079
$\gamma_{FO,EL}$	– 0.0064	0.0059
$\gamma_{FO,HE}$	0.0216	0.0076***
$\gamma_{CL,F}$	– 0.0124	0.0059*
$\gamma_{CL,PT}$	0.0169	0.0086*
$\gamma_{CL,EL}$	0.0063	0.0060
$\gamma_{CL,HE}$	0.0090	0.0083
$\gamma_{F,PT}$	0.0022	0.0037
$\gamma_{F,EL}$	0.0030	0.0028
$\gamma_{F,HE}$	0.0081	0.0047
$\gamma_{PT,EL}$	– 0.0061	0.0046*
$\gamma_{PT,HE}$	0.0094	0.0048**
$\gamma_{EL,HE}$	– 0.0015	0.0037
β_{FO}	– 0.0610	0.0084***
β_{CL}	– 0.1435	0.0107***
β_{F}	0.0145	0.0054***
β_{PT}	0.0272	0.0057***
β_{EL}	0.0167	0.0042***
β_{HE}	0.0068	0.0064

	Adjusted R^2	Durbin Watson
Food, beverages, tobacco	0.9729	2.44
Clothing, footwear	0.9824	1.88
Fuel for private transport	0.7118	1.25
Public transport services	0.7545	1.46
Electricity	0.4926	2.16
Heating	0.7478	2.09

*, **, and *** indicate a significance level of 10%, 5%, and 1% respectively. The COICOP categories are: FO = Food, beverages, tobacco, CL = Clothing, footwear, F = Fuel for private transport, PT = Public transport services, EL = Electricity, HE = Heating (solid fuels, oil, gas, district heating).

Table 4: Compensated price and expenditure elasticities

	Food, beverages, tobacco	Clothing, footwear	Fuel for private transport	Public transport services	Electricity	Heating
				Compensated price elasticities		
Food, beverages, tobacco	**– 0.0137**	0.0506	0.0020	0.0344	– 0.0070	0.1394
Clothing, footwear	0.1028	**– 1.0102**	– 0.0834	0.1938	0.0897	0.1259
Fuel for private transport	0.0087	– 0.1793	**– 0.4504**	0.0685	0.0929	0.2127
Public transport services	0.3688	0.9995	0.1631	**– 1.1479**	– 0.3014	0.5319
Electricity	– 0.0564	0.3499	0.1671	– 0.2272	**– 0.1725**	– 0.0274
Heating	0.8678	0.3774	0.2939	0.3086	– 0.0212	**– 0.3412**
				Expenditure elasticities		
	0.6979	– 0.4818	1.3239	2.4494	1.6710	1.2111

Table 5: Parameter estimation results for durable stocks, 1990 – 2008

	Total	Purchase of vehicles	Energy-using appliances	Video, audio, computer goods
		$\Delta\log K_t$		
$\log YD_t$			0.1618 (0.0492)***	0.0575 (0.050)*
$\log YD_{t-1}$	0.0401 (0.0137)**	0.0542 (0.0165)***		
User costs		– 0.0109 (0.0073)*	– 0.0035 (0.0226)*	
$\log p_{Dt}$	– 0.1640 (0.0554)**			
$\log K_{t-1}$	– 0.1870 (0.0311)***	– 0.1795 (0.0281)***	– 0.1445 (0.0345)***	– 0.1127 (0.0252)***
Adjusted R^2	0.976	0.93	0.777	0.907
Durbin Watson	2.03	2.03	1.39	1.15

*, **, and *** indicate a significance level of 10%, 5%, and 1% respectively.

K_t = current cost stock of households' durables, YD_t = disposable household income (including wealth effects), p_{Dt} = price of durables/price of nondurables.

Table 6: Simulation results for a car scrappage policy: private consumption, energy demand, and direct CO_2 emissions, 2002 – 2007

	2002	2003	2004	2005	2006	2007
			Difference in %			
Total Consumer Expenditure, current prices	1.8	2.6	3.0	3.2	3.2	3.2
Total Consumer Expenditure, constant prices	3.3	4.2	4.7	4.9	4.9	4.9
Durable goods, current prices	0.0	0.0	− 0.1	− 0.1	− 0.1	− 0.1
Durable goods, constant prices	9.7	9.7	9.7	9.6	9.5	9.5
Purchase of vehicles	27.8	27.8	27.5	27.2	26.7	26.5
Energy-using appliances	0.6	0.9	1.0	1.1	1.1	1.1
Video, audio, computer goods	0.2	0.3	0.3	0.4	0.5	0.5
Other durables	− 2.6	− 2.7	− 2.6	− 2.6	− 2.4	− 2.2
Rents, housing	0.0	0.0	0.0	0.0	− 0.1	− 0.1
Non-durable goods, current prices	2.5	3.7	4.3	4.5	4.6	4.6
Non-durable goods, constant prices	3.4	4.7	5.3	5.7	5.8	5.8
Food, beverages, tobacco	2.4	3.4	3.8	3.9	4.0	4.0
Clothing, footwear	− 0.4	− 1.4	− 2.2	− 2.8	− 3.1	− 3.2
Fuels for private transport (gasoline, diesel)	− 5.5	− 4.3	− 3.2	− 2.5	− 2.1	− 2.4
Public transport services	6.0	9.5	11.0	11.8	12.0	11.9
Electricity	2.8	5.1	6.2	6.6	6.8	6.8
Heating	− 1.7	0.2	0.7	1.5	1.7	1.2
Other goods and services	3.9	5.6	6.3	6.7	6.8	6.8

Table 7: Simulation results for a car scrappage policy: private consumption, energy demand (in TJ), and emissions

	2002	2003	2004	2005	2006	2007
			Difference in %			
Heating	− 1.7	0.2	0.7	1.5	1.7	1.2
Electricity	2.8	5.1	6.2	6.6	6.8	6.8
Gasoline	− 5.5	− 4.3	− 3.2	− 2.5	− 2.1	− 2.4
Diesel	− 5.5	− 4.3	− 3.2	− 2.5	− 2.1	− 2.4
CO_2 emissions, difference in 1,000 tons	− 672	− 391	− 241	− 94	− 55	− 135
CO_2 emissions, difference in %	− 3.5	− 1.9	− 1.2	− 0.5	− 0.3	− 0.8

Table 8: Simulation results for a car scrappage policy: gross output at constant prices, 2002 – 2007

	2002	2003	2004	2005	2006	2007
			Difference in %			
Total gross output	0.9	1.3	1.5	1.6	1.7	1.7
Food products and beverages	1.8	2.5	2.6	2.7	2.7	2.7
Electrical energy, gas, steam, hot water	0.6	1.5	1.9	2.1	2.2	2.2
Trade, maintenance and repair services of motor vehicles and motorcycles; retail sale of automotive fuel	0.7	1.2	1.5	1.8	1.9	2.1
Hotel and restaurant services	3.3	4.9	4.9	5.1	5.1	5.0
Land transport; transport via pipeline services	1.4	2.2	2.6	2.8	2.8	2.8
Air transport services	3.2	5.2	5.0	5.5	5.8	5.9
Health and social work services	2.1	3.3	3.6	4.0	4.3	4.6
Other services	2.8	4.0	4.4	4.6	4.7	4.7

Table 9: Simulation results for a car scrappage policy: CO_2 emissions, 2002 – 2007

	2002	2003	2004	2005	2006	2007
			Difference in 1,000 tons			
Households	− 672	− 391	− 241	− 94	− 55	− 135
Production	313	564	811	870	969	870
Food products and beverages	23	26	25	30	32	31
Other non-metallic mineral products	25	39	47	54	62	70
Electrical energy, gas, steam, and hot water	78	185	321	298	295	235
Land transport; transport via pipeline services	50	77	107	144	193	186
Air transport services	76	109	148	169	174	160
Total	− 359	173	570	776	914	735

Figure 1: Simulation results for a car scrappage policy: private consumption, gasoline demand (in TJ) with and without rebound effect

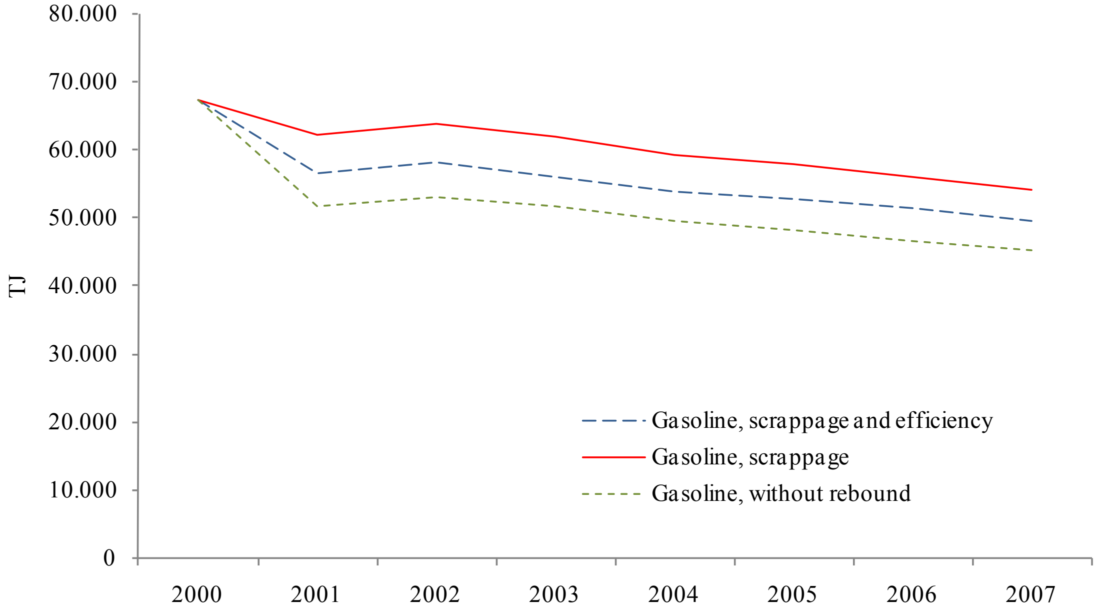

Figure 2: Simulation results for a car scrappage policy: private consumption, diesel demand (in TJ) with and without rebound effect