AKF Memo

Household Energy and the Life-Cycle Model of Consumption

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AKF FORLAGET
February 2004

Preface

This study examines intertemporal consumption of energy by households. This is the first time consumption of energy is incorporated into the framework of the life-cycle model of consumption. Until now, empirical micro studies of the life-cycle model have mainly been based on data with information about food consumption. This is because one of the only existing panel data sets with information about consumption, The Panel Study of Income Dynamics, provides panel data only on food consumption. Food, however, differs in its characteristics from many other goods, for example energy. These differences are important to recognise in order to understand consumer behaviour. The results are of interest to researchers studying energy, but also generally for researchers studying intertemporal consumption allocation because the study highlights the need to incorporate commodity-specific characteristics into the life-cycle model of consumption. The study is also of general interest to non-researchers dealing with consumption issues in the energy field because it develops the understanding of consumer behaviour, e.g. how consumers respond to shocks to income, prices and variations in outdoor temperature.

I would like to thank Martin Browning, Guglielmo Weber, Eskil Heinesen, Mette Ejernæs and Anne Møller Danø for comments on earlier drafts of the paper. The results presented in this paper are based on research sponsored by the Nordic Energy Research Programme, Energy and Society, and by the Danish Energy Agency.

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February 2004

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Summary

Intertemporal consumption of household energy is examined. Energy has properties that are distinct from food often used in micro econometric analysis of intertemporal consumption. These properties relate to the fact that services derived from energy are the actual object of consumption rather than energy per se. For example, it is usually thought that households smooth consumption of food in order to smooth marginal utility. In contrast, smoothing marginal utility of an energy-derived service such as indoor temperature may require quite volatile consumption of energy due to variations in outdoor temperature. Energy is an example stressing the importance of recognising individual characteristics of commodities when modelling intertemporal consumption. This is done by introducing a household technology into the life-cycle framework. A register-based panel dataset with high quality information about consumption of natural gas and electricity for a sample of Danish households is used in the empirical analysis. In the empirical model preferences are allowed to be intertemporally non-separable. Models with rational and myopic habit formation are estimated.

1 Introduction

When the life-cycle model of consumption is confronted with micro data it is often done using data on food consumption because of the availability of relatively long time series of food consumption for individual households in the Panel Study of Income Dynamics. Well-known studies are Hall and Mishkin (1982), Runkle (1991) and Dynan (2000), but there are many others, see Browning and Lusardi (1996) for survey. It is usually thought that households smooth consumption in order to smooth marginal utility. This is what Hall (1978) postulated in his original model, and it appears plausible in the case of food consumption. In contrast, smoothing marginal utility of indoor temperature may require quite volatile consumption of energy due to variations in outdoor temperature. This difference has behavioural implications, for example that households need to keep a small buffer of liquid assets to insure themselves against weather shocks. Energy provides an example highlighting the importance of recognising the individual characteristics of commodities when modelling intertemporal consumption. Besides, energy is of interest in its own right because it constitutes one of the major categories among household nondurable expenditures, and because understanding household behaviour in this area has gained renewed importance in connection with market liberalisations.

This paper is the first to examine intertemporal consumption of household energy. Consumption of electricity and gas is modelled by introducing a household technology into the life-cycle framework. This technology translates the quantity of the market good, say natural gas, into services, degrees of indoor temperature, that are the actual object of consumption. This complicates the consumers' decision problem considerably. Again, it is useful to compare with consumption of a food item, say milk. When the household makes decisions about consuming milk information about quantity and price is displayed in the supermarket and is readily available. When buying electricity or gas the household pays on account, i.e. pays a priori for the expected level of consumption (based on the level of consumption in the previous period) and the bill is settled (once a year) after consumption has been realised. Establishing the exact link between the energy-derived service and the consumption of energy at some point requires the household to read the meter, obtain information about the current price, and evaluating the function mapping energy consumption into the energy-related service. Obtaining this information and evaluating the technology function can be a considerable task. The household may therefore use alternative information that is readily available and provide as a close proxy for the exact information. Such information is provided by the account level of consumption.

In the empirical analysis we estimate Euler equations from two models of intertemporal consumption allocation on household level panel data. The base model is the life-cycle model with rational expectations, where preferences are allowed to be intertemporally non-separable in the way of rational habit formation. At the outset the most attractive way to introduce habit formation appears to be in the form of rational habits (also called internal or forward-looking habits) because such preferences are consistent with rationally optimising consumers. Rational habit formation assumes that the household is aware of the habit. Consumers evaluate utility of consumption in period *t* relative to consumption in period *t-1*, and because they are rational about it they know that this affects future utility. In the second model preferences are myopically habit forming, see for example Muellbauer (1988). In the myopic model consumers put consumption in period *t* and all future periods relative to their own consumption in period *t-1*. As opposed to consumers in the rational model, they do not take into account the effect of the habit on future utility. This model can be considered an alternative to the rational model that yields almost the same utility flow as the rational model, but requires much less calculation in terms of calculating the expected future path for consumption[1].

The estimation is based on a unique Danish household level panel with annual information on consumption of natural gas and electricity covering the period 1990-1997. The energy consumption data are obtained from the billing registers of an electricity company and a natural gas company, covering an area surrounding the northern part of Copenhagen. Information is provided on annual consumption in physical units of electricity and natural gas. Moreover, we have information about the account level of consumption from the gas company. Register information of this type is generally thought to be of high quality compared to information about energy consumption obtained from surveys.

The contribution of this study relative to the previous studies on micro data of intertemporal consumption is to bring evidence on intertemporal consumption allocation of household energy. This is a commodity group that has never previously been modelled in any study of intertemporal consumption allocation, and it stresses the importance of addressing commodity-specific characteristics in the life-cycle model of consumption. A household technology is introduced into the Euler equation framework. This approach is novel to the literature on intertemporal consumption allocation, and it has implications for understanding the nature of consumer responses to shocks, for example shocks to prices or variations in outdoor temperature. The paper also provides further evidence on habit formation. Only four previous papers have studied habit formation on micro data, Hayashi (1985), Meghir and Weber (1996), Dynan (2000), and Carrasco et al. (2002), and they have all estimated models of rational habit formation[2]. The present study adds on to these studies by estimating a model of myopic habit formation and by taking a commodity group that none of these studies have modelled.

The plan of the paper is as follows. In the next section the theoretical framework of consumption over the life cycle will be presented. In section 3 the data are presented, and in section 4 issues relating to estimation of the habit models are dealt with. The results are presented in section 5, and section 6 concludes the paper.

2 The Life-Cycle Model

This section presents the life-cycle model with habit formation. Two versions are presented, one where habits are rational and another where habits are myopic. Consider a household (household indices are left out for convenience) maximising expected utility over the life cycle.

$$u_t = E_t\left[\sum_{s=0}^{T}\beta^s v\left(s^*_{j,t+s}, \eta_{j,t+s}\right)\right] \tag{1}$$

$s^*_{j,t+s}$ is the services from good *j* at time *t+s*. In this case *j = electricity* or *j = natural gas*. It is assumed that that utility from gas and electricity derived services is separable from all other goods, for example food. This is a necessary condition given the data, since information is held only about consumption of natural gas and electricity. Preferences are also assumed contemporaneously separable in gas and electricity. This would not be reasonable if for example electricity acts as a substitute for gas. In general, the case is that gas is used for heating in all the households, and that electricity is used for domestic appliances and possibly for supplementary heating. However, electricity is very expensive compared to natural gas due to taxes, and several other institutional initiatives have been implemented making it unlikely that electricity is used as a substitute for gas. For more on this issue, see Leth-Petersen (2002).

$s^*_{j,t+s} = \zeta(s_{j,t+s}, s_{j,t+s-1}, s_{j,t+s-2}, \ldots)$ is a function of a vector of quantities consumed of the *j*'th good or service in the current and previous periods. I shall refer to s^* as effective consumption and s as (actual) consumption. $\eta_{j,t+s}$ is a random independent preference shock to the demand for good *j* at time $t+s$ shifting the instantaneous utility. Since electricity and gas may have at least one common purpose, namely space heating, it is allowed that $\eta_{j,t+s}$ could be correlated with $\eta_{k,t+s}$, $j \neq k$. $E_t[\ ]$ is an expectation operator as of period *t*. β^s is a time discount factor that equals $\left(\frac{1}{1+\delta}\right)^s$ where δ is a discount rate subjective to the household. The subjective discount rate can vary with household characteristics, for example the age of the household. Taking i_t to be the nominal rate of interest, $p_{j,t}$ to be period *t* prices of s_j, the real rate of interest for good *j* is given by $r_{j,t} = \frac{(1+i_t)p_{j,t-1}}{p_{j,t}} - 1$.

If preferences are additively separable effective consumption equals actual consumption, $s^*_{j,t+s} = s_{j,t+s}$ and the first order condition for the problem becomes[3]

$$E_t\left[(1+r_{jt+1})\beta \frac{v'(s_{j,t+1},\eta_{j,t+1})}{v'(s_{j,t},\eta_{j,t})}\right] = 1 \tag{2}$$

If $(1+r_{j,t+1})\beta = 1$ marginal utility is planned to be constant throughout life and so is consumption if marginal utility is linear, i.e. if preferences are quadratic. This is the foundation of the life cycle permanent income hypothesis as presented by Hall (1978).

Preferences that exhibit habit formation relax the assumption of intertemporal separability. If habits are specified as subtractive then in the most general case effective consumption is $s^*_{j,t+s} = s_{j,t+s} - \alpha_1 s_{j,t+s-1} - \alpha_2 s_{j,t+s-2} - .....$ so that consumption in period $t+s$ is relative to consumption in all previous periods. This becomes analytically intractable because of the big number of state variables. The usual assumption invoked to make the habits model tractable is to set consumption in period $t+s$ relative to consumption only in period $t+s-1$, so that $s^*_{j,t+s} = s_{j,t+s} - \alpha_1 s_{j,t+s-1}$. This is the so-called short memory form. In this case (1) becomes

$$v_t = E_t\left[v(s_{j,t} - \alpha_j s_{j,t-1}, \eta_{j,t}) + \beta v(s_{j,t+1} - \alpha_j s_{j,t}, \eta_{j,t+1}) + \beta^2 v(s_{j,t+2} - \alpha_j s_{j,t+1}, \eta_{j,t+2}) + ...\right] \tag{3}$$

If $\alpha_j > 0$ preferences are rationally habit forming. Habits are rational because the agent takes into account the effect of current consumption on future marginal rates of substitution. Habit formation reflects that the agent gets used to a consumption level, and implies that there is persistence in the response to income of price shocks. If $\alpha_j < 0$ consumption exhibits durability. Durability means that the household buys a quantity of the commodity in mind and adds it to a stock. In this way, buying in one period will lower the expenditure in the following period, hence the negative autocorrelation in changes of expenditures. Note, however, that durability relates specifically to expenditures as opposed to consumption. In the present case we consider actual consumption, and durability should be a virtual impossibility. The first order condition is

$$v_t = E_t\left[v'\left(s_{j,t} - \alpha_j s_{j,t-1}, \eta_{j,t}\right) - \beta\alpha_j v'\left(s_{j,t+1} - \alpha_j s_{j,t}, \eta_{j,t+1}\right)\right] = \\ E_t\left[\left(1 + r_{j,t+1}\right)\beta\left(v'\left(s_{j,t+1} - \alpha_j s_{j,t}, \eta_{j,t+1}\right) - \beta\alpha_j v'\left(s_{j,t+2} - \alpha_j s_{j,t+1}, \eta_{j,t+2}\right)\right)\right] \quad (4)$$

The left-hand side of (4) yields the cost in terms of marginal utility of foregoing one unit of consumption in period *t*. The right-hand side gives the benefit in marginal utility of increasing consumption by $\left(1 + r_{j,t+1}\right)$ units in period *t+1*. The Euler equation simply gives the trade-off between consumption in two periods. The difference between the additive case $\left(\alpha_j = 0\right)$ and the case with rational habit formation is that an increase in consumption in the previous period lowers utility in the present period. In the presence of habits, i.e. $\alpha_j > 0$, consumption is planned to increase throughout the life if $\left(1 + r_{j,t+1}\right)\beta \geq 1$. This does not necessarily mean that realised consumption will be observed to increase monotonically throughout life. Negative shocks or negative taste shifts can cause consumption to decrease in any particular period. The process is expected to be stationary, i.e. $0 \leq \alpha_j < 1$. This is because if $\alpha_j > 1$ then an increase in consumption would lower lifetime utility. Moreover, if $\alpha_j = 1$ lifetime utility is not increased by an increase in consumption. Both cases clearly do not make much sense. Thus, it is expected that $0 \leq \alpha_j < 1$.

Assuming that *T* is large and $r_{j,t} = r_j$, (4) can be simplified to the familiar and more convenient form[4].

$$E_t\left[(1+r_j)\beta\frac{v'(s_{j,t+1}-\alpha_j s_{j,t},\eta_{j,t+1})}{v'(s_{j,t}-\alpha_j s_{j,t-1},\eta_{j,t})}\right]=1 \quad (5)$$

Setting $r_{j,t}=r_j$ amounts to assuming static and point expectations about future real rates of interest. It does not mean that actual real rates of interest do not change over time only that identification is not obtained through real interest rate variation. Invoking this assumption follows Hayashi (1985) and Dynan (2000)[5].

When habits are rational the agent is rational about the effect of habits on future utility and he makes a life-cycle plan that takes the effect of current consumption on future marginal rates of substitution into account. Such preferences are forward looking. Muellbauer (1988) suggests an alternative formulation where habits are backward looking or myopic. In this case preferences can be described by

$$v_t = E_t\left[v(s_{j,t}-\alpha_j s_{j,t-1},\eta_t)+\beta v(s_{j,t+1}-\alpha_j s_{j,t-1},\eta_{t+1})+\beta^2 v(s_{j,t+2}-\alpha_j s_{j,t-1},\eta_{t+2})+....\right] \quad (6)$$

Myopic habits imply that the consumer makes a mistake every period. The expectation at period *t* to the marginal utility in period *t+1* is $v'(s_{j,t+1}-\alpha_j s_{j,t-1})$, but when he reaches period *t+1* the actual marginal utility is $v'(s_{j,t+1}-\alpha_j s_{j,t})$.

At first sight, myopia appears to be very disturbing since the agent appears not to maximise utility. The myopic model can be considered an alternative to the rational model that requires less effort to evaluate in terms of expected future marginal utility, since consumption in period *t* and all future periods is relative to the consumption level in period *t-1*. In the results section we will present evidence that the myopic model yields a utility stream that is close to the utility stream derived from the rational habits model. The loss in utility from not following the optimal consumption stream may in fact be so small as to outweigh the calculation costs associated with following the optimal path. In this sense the myopic model may not be that disturbing.

The first order condition[6]

$$E_t\left[\left(1+r_j\right)\beta\frac{v'\left(s_{j,t+1}-\alpha_j s_{j,t-1},\eta_{j,t+1}\right)}{v'\left(s_{j,t}-\alpha_j s_{j,t-1},\eta_{j,t}\right)}\right]=1 \tag{7}$$

The difference between the myopic and the rational case is found in the nominator in (7) $s_{j,t+1}$ is relative to $s_{j,t-1}$ rather than $s_{j,t}$.

Thus far we have presented models of consumption of energy-derived services, for example living room temperature, as derived from the use of natural gas, or lighting as derived from the use of electricity. The consumption of energy-derived services is, however, unobserved and to make (5) and (7) operational for estimation assumptions, about how energy-derived services, $s_{j,t+1}$, are related to quantities of energy, $q_{j,t+1}$, are needed. It is assumed that each household is endowed with an unobserved household specific technology τ_j that transforms energy $q_{j,t+1}$ into energy-derived services[7]. Recalling that electricity is used for domestic appliances, and that natural gas is used for space heating and hot water, different household technologies are required for electricity and natural gas. Considering electricity the household technology is assumed to take the form

$$s_{el,t+1}=\tau_{el}\, q_{el,t+1} \tag{8}$$

(8) assumes that the technology is constant throughout the observation period. τ_{el} may be thought of as a vector of technologies associated with different appliances, so that $q_{el,t+1}$ is total consumption of electricity. This assumption of fixed technology is not a particularly plausible one, since electricity consumption relates to the use of all sorts of domestic appliances, and the stock of these is hardly constant over the eight years covered by the data. Assuming fixed technology is necessary because we do not observe the household stock of electric appliances. However, (8) does point to the fact that dynamics observed from $q_{el,t+1}$ can stem from changes in the technology stock, i.e. from accumulation of new appliances, as well as from changes in the use of the existing technology. This is a necessary assumption for identification, but one that should be born in mind when interpreting the results.

For consumption of natural gas the function mapping consumption of natural gas into room temperature is assumed to be given by

$$\begin{aligned} s_{gas,t+1} &= \tau_{gas}\, d_{t+1}^{-1}\tilde{q}_{gas,t+1} \\ &= \tau_{gas}\, q_{gas,t+1} \end{aligned} \qquad (9)$$

(9) indicates that room temperature, $s_{gas,t+1}$, is derived by the use of natural gas, $\tilde{q}_{gas,t+1}$, through the (unobserved) technology τ_{gas}, assumed to be constant across time. The technology parameter comprises the joint influence of the building shell and the boiler. Assuming this to be fixed is likely not to be critical for gas, since each household is equipped with only one boiler and the building shell is more or less fixed. Finally, a factor d_{t+1}^{-1} indicating the number of degree days, i.e. outdoor temperature, in period *t+1* relative to a normal year enters (9). In a cold year d_{t+1} is bigger than one and in a warm year d_{t+1} is smaller than one, so that more gas is needed to obtain a given service level, i.e. indoor temperature, in a cold year and less is needed in a warm year. Thus, $q_{gas,t+1} = d_{t+1}^{-1}\tilde{q}_{gas,t+1}$ is the degree day corrected level of consumption. (9) tells that if d_{t+1} is fluctuating a lot then market consumption of natural gas, $\tilde{q}_{gas,t+1}$ may in fact also be quite volatile in order to smooth utility[8]. Households respond immediately to a shock to outdoor temperature[9]. Moreover, for households to form expectations about future consumption they need to make assumptions about the process that d_{t+1} follows. The gas company that has provided the data for this study assumes that annual temperature realisations follow a white noise process with a fixed mean of 2906 degree days. We will return to this issue in section 5.

The final step in making the model operational for estimation is to assume a functional form for the preferences. Preferences of the isoelastic form are assumed. Using $s_{j,t+1} = \tau_j\, q_{j,t+1}$ we get

$$v(\tau_j q_{j,t} - \alpha_j \tau_j q_{j,t-1}) = \exp(\phi_j a_t + \eta_{j,t})\frac{(\tau_j q_{j,t} - \alpha_j \tau_j q_{j,t-1})^{1-\rho}}{1-\rho}.$$

a_t is a vector of observed demographic characteristics and $\exp(\phi_j a_t)$ is a taste-shift function associated with a_t. This, for example, addresses that a given household may want to increase the room temperature when a new-born child enters the household. $\eta_{j,t}$ is an unobserved preference shock. ρ is the coefficient of relative risk aversion, and concavity of the utility function requires that ρ is positive. Inserting in (5) yields

$$E_t\left[(1+r_j)\beta(\exp(\phi_j \Delta a_{t+1} + \Delta\eta_{j,t+1}))\left(\frac{q_{j,t+1}-\alpha_j q_{j,t}}{q_{j,t}-\alpha_j q_{j,t-1}}\right)^{-\rho}\right]=1 \tag{10}$$

Where, crucially, the technology, τ_j, cancels out because it is assumed fixed. Moreover, rational expectations are assumed, so that (10) can be rewritten as

$$(1+r_j)\beta(\exp(\phi_j \Delta a_{t+1} + \Delta\eta_{j,t+1}))\left(\frac{q_{j,t+1}-\alpha_j q_{j,t}}{q_{j,t}-\alpha_j q_{j,t-1}}\right)^{-\rho} = 1+\varepsilon_{j,t+1} \tag{11}$$

where $\varepsilon_{j,t+1}$ is the expectation error that is mean-zero and serially un-correlated since consumers are not allowed making systematic mistakes when planning consumption for their remaining life. The rational expectations assumption implies that any information in the information set, i.e. any information dated *t* or earlier, is orthogonal to the expectation error. Note also the unobserved preference shocks $\eta_{j,t+1}$ and $\eta_{j,t}$. These imply that only information dated *t-1* or earlier is orthogonal to the unobserved parts of (11). This is used for identification.[10] Note that any presence of fixed heterogeneity, for example entering through *a*, is differenced away in the Euler equation. Taking natural logarithms yields

$$\Delta \ln(q_{j,t+1}-\alpha_j q_{j,t}) = \frac{1}{\rho}\ln[(1+r_j)\beta] + \frac{1}{\rho}\phi_j \Delta a_{t+1} + \frac{1}{\rho}\Delta\eta_{j,t+1} - \frac{1}{\rho}\tilde{\varepsilon}_{j,t+1} \tag{12}$$

where the approximation $\tilde{\varepsilon}_{j,t+1} \approx \ln(1+\varepsilon_{j,t+1})$ is applied. This approximation is also applied by Hayashi (1985) and Dynan (2000). The log-approximation is chosen because there is not much hope to identify ρ from the very limited variation in the real interest rate that is present in the data. The log-approximation implies that the ρ parameter is absorbed into a constant term[11]. This seems to be the best strategy given that estimation of ρ is not the primary interest in the present study.

If there is no habit formation $\alpha_j = 0$, (12) collapses to the standard case where consumption changes are determined by the subjective discount rate, the real interest rate, taste shifts, and expectation errors. If habit formation is present $\alpha_j > 0$, on the other hand, *expected* consumption is ever increasing at a decreasing rate if $(1+r_j)\beta \geq 1$. As already mentioned this does not mean that *actual* consumption cannot decrease from one specific period to the next following a taste shift or a negative expectation error. Habit formation, however, has the effect to smooth out the adjustment to any shock or taste shift, so that the adjustment does not happen immediately.

When habit formation is myopic the first-order condition for maximisation becomes

$$E_t\left[(1+r_j)\beta\left(\exp\left(\phi_j \Delta a_{t+1} + \Delta\eta_{j,t+1}\right)\right)\left(\frac{q_{j,t+1} - \alpha_j q_{j,t-1}}{q_{j,t} - \alpha_j q_{j,t-1}}\right)^{-\rho}\right] = 1 \qquad (13)$$

(13) looks almost identical to (10), except for the last term in the numerator. It does not seem obvious that rational expectations are consistent with myopic preferences, since myopic households make systematic mistakes. Therefore, at this point, the expectation error of the myopic household is denoted, $\upsilon_{j,t+1}$, to indicate that it does not have the same characteristics as the expectation error in (12). This implies that not all information in the information set is necessarily orthogonal to the error. However, if $\upsilon_{j,t+1}$ is not autocorrelated then at least information dated *t-2* or earlier must be orthogonal since nothing dated *t-2* enters (13). This is used for identification. Moreover taking natural logs (12) becomes.

$$\Delta \ln\left(q_{j,t+1} - \alpha_j q_{j,t-1}\right) = \frac{1}{\rho}\ln\left[(1+r_j)\beta\right] + \frac{1}{\rho}\phi\Delta a_{t+1} + \frac{1}{\rho}\Delta\eta_{j,t+1} - \frac{1}{\rho}\tilde{\upsilon}_{j,t+1} \qquad (14)$$

Again, the approximation $\tilde{\upsilon}_{j,t+1} \approx \ln(1+\upsilon_{j,t+1})$ is applied. Equations (12) and (14) will be estimated, and results from here will be presented in section 5.

3 Data

The empirical analysis is based on household level panel data with annual observations covering the period 1990-1997. The consumption data are obtained from the electricity company NESA A/S and the gas company HNG I/S, and the sample covers the distribution systems of these companies, i.e. an area surrounding Copenhagen. The companies supply energy to their customers through a service line from the distribution system. In this way gas and electricity are completely perishable goods since it is not possible to store any of them. The energy consumption data are obtained from the billing registers of two energy companies. The billing registers contain information about the exact meter readings and the dates of the reading. Consumption data for gas and electricity thus have the important quality that they are well measured compared to expenditure survey data.

The billing procedure for the two companies is of particular interest here. For the gas company the billing cycle is annual running from June to May in the following year. All customers prepay on account for an expected level of consumption. At the end of the billing period the meter is read and the final bill is settled. The account payment is split into portions that are due four times during the billing period. For the gas company account payments are made in September, November, February, and March. On each of these bills the customer is informed about the account level of consumption on which the payment is based. A similar procedure with four annual account payments and a yearly settlement is also used by the electricity company.

The electricity company has provided the actual consumption data, i.e. the meter readings, and the gas company has provided the actual consumption data as well as the calculated measure of consumption that forms the basis for charging account payments from customers. The account level of consumption for natural gas is calculated by normalising the consumption of the previous year with respect to variations in the weather and the billing period. The underlying assumption invoked by the gas company is that annual realisations of outdoor temperature are generated by a white noise process with a fixed mean assumed by the gas company to be 2906 degree days per year. Degree days are plotted for the period 1980-2002 in figure A1 in the appendix. The graph shows considerable degree day variation over the observation period. It also shows that a white noise process may provide a reasonable, albeit crude, description. The account level of consumption for electricity is not made available here, but the company informs that it is given by the level of consumption in the previous year without any corrections.

The energy consumption data have been merged to public administrative register data giving information about the characteristics of the household. The administrative registers provide information about type, size, and vintage of the house, family composition, age of the family members, and information about household income.

The sample is limited to include couples with or without children living in a single-family house. Both adults are required to be full-time employed, and no old-age pensioners or students are included in the sample. This rather tight delimitation is taken in order to work with a homogenous sample that reduces the risk of creating erroneous dynamics because of incomplete modelling of labour supply and retirement decisions.[12] This should also minimise the chance that any temporal dependencies we might find should be due to liquidity constraints, cf. Meghir and Weber (1996). Browning and Crossley (2001) find that credit constrained households are mostly found among households with members out of work, and only among a fraction hereof. Movers are excluded because we do not have enough information to describe the changes in the technology implied by the move. Moreover, if a household is observed with $\Delta \ln q_t < -0.5$ or $\Delta \ln q_t > 0.5$ for either gas or electricity for some t all observations are deselected for this household. The dataset is constructed by considering the customers of one energy supplier for each energy type in the period considered. Therefore, only eight price points are present for each energy type. The prices are graphed in figure A2 in the appendix.

The sample analysed here contains observations of 2,308 households. Each household is observed between five and eight consecutive times in the period 1990-1997, and the panel is thus unbalanced. The unbalancedness appears from table 3.1.

Table 3.1 Number of Households by Number of Observations

Number of time periods	5	6	7	8	Σ
Number of households	5	5	6	6	2,308

The data include information about individual households' consumption of energy, i.e. natural gas and electricity. All the households use natural gas for space heating (central heating) and hot tap water. When connected to the natural gas distribution system, the practice is that no other primary heating system is present in the house. In some cases natural gas is also used for cooking instead of electricity, but this is not observed. Electricity is used for domestic appliances and may be used for supplementary heating. The stock of electric appliances is unobserved.

The age span of the sample, defined in terms of age of the oldest person, covers families with ages 26-67. The mean and median age is 45. Some of the households in the sample experience changes in the family sizes in the observation period because children enter and leave the family. In the sample 535 family increases and 704 decreases are observed.

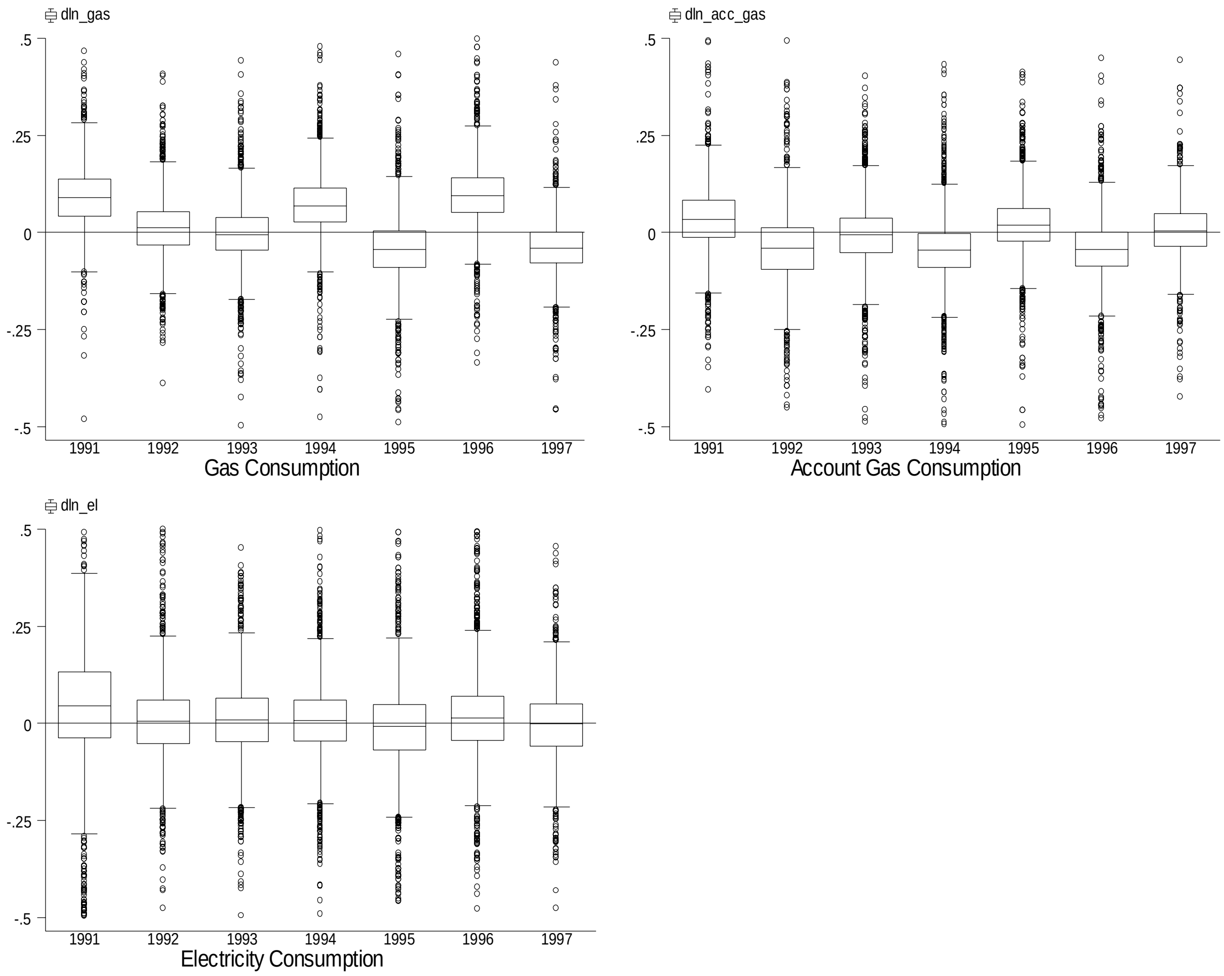
Means and standard deviations for the three consumption variables are given in table 3.2. From these initial descriptive statistics it is seen that much more energy is used in the form of gas than electricity. This reflects that electricity is used for domestic appliances rather than heating, whereas gas is used for space heating in a relatively cold country. It is also seen that gas consumption exhibits far more variability than electricity consumption. This reflects both cross-sectional variation in consumption of gas, but also variability across time due to changing weather conditions from year to year. The standard deviation of account level of consumption for gas is lower than for the actual consumption, because account consumption is adjusted for temperature variations.

Table 3.2 Means and Standard Deviations for Consumption Variables

kWh	Natural gas Consumption	Natural gas Account	Electricity Consumption
Mean	24,243	22,192	5,078
Standard deviation	8,061	7,337	2,256

The smoothness of electricity consumption and the variability of gas consumption are illustrated more clearly in figure 3.1. The top row gives changes in the natural logs of measured consumption of natural gas in kWh to the left and changes in natural logs of account consumption to the right. The bottom row gives the changes in logs of measured consumption of electricity in kWh.

Figure 3.1 Box Plots of Changes in log Consumption of Gas (top row, actual and account) and Electricity (bottom row, actual)



The figure clearly illustrates how the consumption of electricity develops smoothly whereas the development in the consumption of natural gas is volatile. The development in natural gas account consumption does some of the job in smoothing out the shocks to natural gas consumption, but does not do it perfectly.

One way to take a first look at the dynamic properties of the data is to fit a VAR with two equations, one for electricity and one for natural gas. In table 3.3 results from estimating a VAR with one lag are presented. Also a number of conditioning variables are included: two variables describing entry and exit of children from the household, age of the oldest person in the household, number of persons in the household in the first observation year, and a number of time dummies to pick up common shocks. Common shocks can be present due to changes in the prices of gas and electricity, variation in the weather conditions, and other aggregate influences that may affect the consumption. There is no cross-sectional variation in prices nor degree days, and we choose to address the joint influence of the common shocks by including a series of time dummies. Only estimates based on actual consumption are included, since estimates based on account consumption do not present any qualitative differences.

According to the strictest version of Permanent Income Hypothesis (cf. equation (2) with quadratic utility and no preference shocks) consumers rationally plan consumption to be constant across the life cycle, and consumption changes are thereby reduced to white noise reflecting expectation errors. Given that consumers take all available information into account when they plan for the remaining part of their life, all variables in the information set at time *t* should be orthogonal to the current change in consumption. This means that in the strictest version one should not observe any lagged changes of consumption being correlated with current changes. The results in table 3.3 clearly indicate that this is not the case here. In both the gas equation and the electricity equation the parameter of the first lag of the change in consumption is significant and negative. This is not inconsistent with the PIH if preference shocks are allowed for. If consumers face unobserved preference shocks that shift marginal utility, this will introduce a moving average term, and lagged consumption changes will be observed to be negatively correlated with current consumption changes. Negative autocorrelation is also generally attributed to durability of the commodity in mind. This can be ruled out though, since natural gas and electricity in the way they are distributed and consumed here are perfect perishables. However, time non-separable preferences cannot be ruled out based on this evidence, since a possible habit effect may be dominated by unobserved preference shocks. The estimates in table 3.3 do not give any indication of feedback effects from gas to electricity and vice versa. Estimating the VAR without the time dummies (not reported) leaves the feedback parameters significant. This is consistent with common shocks being present.

Table 3.3 VAR estimates

	Gas, $\Delta \ln q_t^{gas}$		Electricity, $\Delta \ln q_t^{el}$	
Variable	Parameter	St. Err.	Parameter	St. Err.
$\Delta \ln q_{t-1}^{gas}$	-0.2225**	0.0140	-0.0138	0.0116
$\Delta \ln q_{t-1}^{el}$	-0.0043	0.0075	-0.0673**	0.0132
Child enter	0.0261**	0.0046	0.0534**	0.0064
Child leave	-0.0154**	0.0035	-0.0580**	0.0046
Ln(age)	-0.0003	0.0047	-0.0956**	0.0060
# persons 1)	-0.0003	0.0009	-0.0040**	0.0011
D93	-0.0360**	0.0031	-0.0009	0.0039
D94	0.0369**	0.0031	-0.0009	0.0038
D95	-0.0582**	0.0028	-0.0149**	0.0037
D96	0.0541**	0.0034	0.0126**	0.0042
D97	-0.0504**	0.0030	-0.0025	0.0039
Constant	0.0341*	0.0190	0.3841**	0.0240

Note: ** indicates significance at 5% level. * indicates significance at 10% level. Robust standard errors.

1) Number of persons in the first observation year.

In the structural empirical model these features of the data are addressed by allowing for preferences to be time non-separable and by allowing for unobserved preference shocks. Moreover, we include a set of time dummies to pick up aggregate shocks, and we allow the preference shocks to be contemporaneously correlated across equations. This is explained in more detail in the next section.

4 Estimation

In this section issues relating to estimation will be described. Considering the model with rational habit formation, the equations to be estimated are given by (12). These can be written more compactly as

$$\Delta \ln\left(q_{j,i,t+1} - \gamma_{j,0} q_{j,i,t}\right) - \gamma_{j,1} - \gamma_{j,2} \Delta a_{j,i,t+1} = u_{j,i,t+1} = f_{j,i,t+1}\left(\gamma_j\right) \quad (15)$$

for $j = (el, gas),\ j \neq k,\ t = 1991,\ldots,1996$, $i = 1,\ldots,N$

where $\gamma_{j,0} = \alpha_j$, $\gamma_{j,1} = \frac{1}{\rho}\ln\left[\left(1 + r_j\right)\beta\right]$, $\gamma_{j,2} = \frac{1}{\rho}\phi_j$, $u_{j,i,t+1} = -\frac{1}{\rho}\tilde{\varepsilon}_{j,i,t+1} + \frac{1}{\rho}\Delta\eta_{j,i,t+1}$, $j = (el, gas)$. Note that i is introduced as an identifier for the individual household. (15) constitutes a system of two non-linear equations. The system can be summarised

$$f_i(\gamma) = \begin{bmatrix} f_{j,i}\left(\gamma_j\right) \\ f_{k,i}\left(\gamma_k\right) \end{bmatrix} \quad (16)$$

$f_{j,i} = \left(f_{j,i,1992},\ldots,f_{j,i,1997}\right)'$, $j = (el, gas),\ j \neq k$. The taste shifters are assumed to be exogenous, so that $\gamma_{j,2}$ is estimated without further complications, the parameter $\gamma_{j,0}$ is likely to be estimated inconsistently by non-linear least squares because $u_{j,i,t+1}$ carries an MA(1) term due to the presence of preference shocks. $u_{j,i,t+1}$ is orthogonal to any available information two periods or more behind. Leaving aside exogenous variables the orthogonality conditions for household i for each equation can be summarised as $E_t\left[q_{j,i,t+1-m}\ f_{j,i,t+1}\left(\gamma_j\right)\right] = 0$ for $t = 1991,\ldots,1996$, $m \geq 2$, thereby providing *l=(T-2)(T-1)/2=21* moment restrictions for each equation for households observed in all years. The moment restrictions for the whole system can be expressed compactly as $E_t[Z_i' f_{it+1}(\gamma)] = 0$. For households observed in all years 1990-1997 the Z_i-matrix takes the block diagonal form, cf. Arellano & Bond (1991).

$$Z_i = \begin{bmatrix} \begin{matrix} q_{j,i,90} & 0 & 0 & \dots & 0 & \dots & 0 \\ 0 & q_{j,i,90} & q_{j,i,91} & \dots & 0 & \dots & 0 \\ . & . & . & \dots & . & \dots & . \\ 0 & 0 & 0 & \dots & q_{j,i,90} & \dots & q_{j,i,95} \end{matrix} & 0 \\ 0 & \begin{matrix} q_{k,i,90} & 0 & 0 & \dots & 0 & \dots & 0 \\ 0 & q_{k,i,90} & q_{k,i,91} & \dots & 0 & \dots & 0 \\ . & . & . & \dots & . & \dots & . \\ 0 & 0 & 0 & \dots & q_{k,i,90} & \dots & q_{k,i,95} \end{matrix} \end{bmatrix} \qquad (17)$$

where all the exogenous variables are left out for convenience. In (17) the first row gives the instruments for equation j for 1992, the second row for equation j for 1993, and so on and so forth.

The parameters of (16) are estimated by non-linear GMM (NLGMM). Stacking the moment conditions over individuals, the NLGMM estimator picks the vector of parameters γ that minimises the criterion

$$J = f(\gamma)' Z W^{-1} Z' f(\gamma) \qquad (18)$$

Noting that the $i=1,\dots,n$ households are observed across T_i periods, and that there are two equations in the rational model, f is a $\sum_{i=1}^{n} 2(T_i - 2)\times 1$ vector, Z is a $\sum_{i=1}^{n} 2(T_i - 2)\times 2l$ matrix of instrumental variables, and W is some weighting matrix of dimension $2l \times 2l$. Denoting the number of parameters in each equation by m, then in the exactly identified case, i.e. $m=l$, J would be zero. In the case where the parameters are overidentified, i.e. $l>m$, the moment equations imply restrictions. If the model is incorrect some of these restrictions will be violated. Therefore, J can be evaluated as test statistic for overidentifying restrictions that is chi-square distributed with 2(*l-m)* degrees of freedom when the two equations are estimated jointly. If the orthogonality conditions implied by the model are satisfied, minimisation of *J* will provide consistent and efficient estimates of the parameters.

Assuming that the households in the sample make their decisions independently one choice of weighting matrix could be

$$W = n^{-1}\sum_{i=1}^{n} Z_i' f_i f_i' Z_i \tag{19}$$

For the rational model Z_i is the $2(T_i - 2)\times 2l$ matrix of instruments for individual *i*, and f_i is the $2(T_i - 2)\times 1$ vector of residuals. In the Euler equation the error term $u_{j,it+1}$ is MA(1). Therefore, the matrix $f_i f_i'$ is restricted to have nonzero elements only in the diagonal and the first subdiagonals within each equation. Moreover, contemporaneous correlation of error terms across equations, i.e. $E\lfloor f_{j,i,t+1} f_{k,i,t+1}\rfloor \neq 0$ for $j = (el, gas)$, $j \neq k$, is allowed for as well to accommodate possible contemporaneous correlation of preference shocks. The weighting matrix is itself a function of the parameters to be estimated. (18) is estimated using the continuous updating GMM estimator, where the weighting matrix is continuously altered as the parameter vector is changed in the minimisation. This procedure has been shown to have superior performance in finite samples compared to the usual two stage/iterative estimators, Hansen et al. (1996).

Asymptotic standard errors of the parameter estimates that are robust to heteroscedasticity of general forms are calculated after estimation according to (20).

$$Var(\hat{\gamma}) = \left(\left[\frac{\partial f(\hat{\gamma})}{\partial \gamma} \right]' Z \hat{W}^{-1} Z' \left[\frac{\partial f(\hat{\gamma})}{\partial \gamma} \right] \right)^{-1} \tag{20}$$

Estimation of the myopic model proceeds in the same fashion, except that (14) can only be estimated for the period 1993-1997, since the first valid instrument for $u_{j,i,t+1}$ is $q_{j,i,t-2}$. Consequently, for this model 15 moment restrictions are available for each equation for households observed in all years.

5 Results

The presentation of the results progresses in two steps. First, the results from estimating the rational (12) and myopic (14) habits models estimated on the actual consumption data are presented. There is indication that the Euler equation for gas, in particular, does not give a good description of the data, both for the rational and the myopic model. Second, the rational and the myopic model are re-estimated on the account consumption data for gas. It will be argued that behaviour based on account information provides a close approximation to behaviour based on actual consumption information, and that using the account consumption information saves the agent a good deal of calculation.

5.1 Estimates of Euler equations based on market consumption data

The model with rational habit formation (12) and the model with myopic habit formation (14) have been estimated on the actual consumption data. In each case Euler equations for electricity and natural gas are estimated jointly allowing for contemporaneous correlation of preference shocks, as explained in section 4. Estimates are presented in table 5.1. To obtain good starting values for the joint estimation, the Euler equations for gas and electricity are first estimated independently.

The size of the household in the first observation year and the natural logarithm of age of the oldest person in the household are included in all estimations and assumed exogenous. These variables are entered to allow for heterogeneous growth rates of consumption. In terms of the theoretical model this corresponds to allowing households to have heterogeneous discount factors. We also include dummy variables to indicate entry and exit of family members, i.e. children. This follows the utility function that was introduced in section 2 allowing for utility to change with demographic changes.

Time dummies are included to capture expectation errors that are common to the households in the sample in any particular year. Time dummies will pick up any common effect, i.e. effects arising from weather variation, changes in prices or any other aggregate influence. The rational expectation life-cycle model of section 2 implies that shocks are mean-zero across time, but not for one particular cross-section. It is perfectly consistent with the model that all households may be wrong in the same direction at one point in time. One example in the present context is due to weather variations, which are of central importance to the consumption of natural gas for heating. Assuming, for example, that people's expectations about weather variations are formed by a model saying that annual temperature follows a white noise process with a constant mean then any realisation of weather conditions that is different from the mean weather conditions will emerge as an expectation error. As all people in the sample face the same weather conditions they will all guess wrongly in the same direction about the weather conditions in the following year.

Estimation results for the model with rational habit formation are presented in the left part of table 5.1. Results from estimating the myopic model are presented in the right part of table 5.1.

Table 5.1 Estimates of Rational and Myopic Euler Equations for Natural Gas and Electricity

	Rational				Myopic			
	Electricity		Gas		Electricity		Gas	
	Param.	Std err.	Param.	Std err.	Param.	Std err.	Param.	Std err.
Constant	0.3440**	0.0243	-0.0184	0.0190	0.3749**	0.0608	-0.0358	0.0360
α	0.1618**	0.0396	0.1210**	0.0599	-0.0007	0.1528	0.3474**	0.0959
Child enter	0.0623**	0.0078	0.0303**	0.0078	0.0459**	0.0094	0.0390**	0.0099
Child leave	-0.0660**	0.0063	-0.0184**	0.0043	-0.0627**	0.0116	-0.0250**	0.0080
Ln(age)	-0.0879**	0.0060	0.0050	0.0056	-0.0937**	0.0152	0.0043	0.0084
# persons[1)]	-0.0035**	0.0011	-0.0002	0.0008	-0.0045**	0.0013	0.0013	0.0014
D93	0.0082	0.0052	0.0789**	0.0120	-	-	-	-
D94	0.0077*	0.0045	-0.0114**	0.0057	0.0035	0.0038	0.1184**	0.0175
D95	-0.0091**	0.0045	-0.0593**	0.0044	-0.0125**	0.0043	-0.0516**	0.0082
D96	0.0287**	0.0053	0.1117**	0.0165	0.0186**	0.0045	0.1569**	0.0240
D97	0.0022	0.0048	-0.0589**	0.0056	0.0001	0.0038	-0.0476**	0.0077
J (DF)	123.10 (40)				82.39 (28)			
J (DF) [2)]	36.65 (20)		86.96 (20)		34.65 (14)		49.43 (14)	

** indicates significance at 5% level. * indicates significance at 10% level.

1) Number of persons in the first observation year. 2) J statistic from single equation estimation.

Results from the rational model indicate that there is significant habit formation for both electricity and natural gas. Estimates of the variables for changes in the family size, assumed exogenous, are estimated significantly and they take the expected signs. Estimates of the parameters of the time dummies indicate that the consumption of gas is heavily influenced by aggregate shocks. For example 1996, which was a particularly cold year relative to the other years in the data period, a positive parameter is estimated. This is indication of a positive shock to consumption of gas in this year. In the electricity equation, on the other hand, there is less evidence that aggregate shocks are as important, except for a significantly negative parameter for 1995 and a positive parameter for 1996. In the electricity equation the subjective discount rate appears to be correlated with the age of the oldest person in the household and with the size of the family unit. There is no evidence of such correlation in the gas equation. Also a series of dummies with information about the level of education of the person in the household with the highest education, have been tried. These were not of any importance.

The J-statistic for the system indicates that the rational model is rejected.[13] J-statistics for each equation obtained from the initial estimation of the two equations are also reported and they reveal that problems are related primarily to the gas equation. The single equation J-statistic for the electricity equation is borderline rejected. The gas equation, on the other hand, is clearly rejected. Thus, rejection of the overall model appears to stem primarily from the gas equation.

Estimates of the myopic model suggest that there is no myopic habit formation in the consumption of electricity. Myopic habit formation is somewhat stronger for gas consumption. Again, the J-statistic for the joint model indicates rejection. J-statistics from independent estimation of the two equations are reported, and they show the same pattern as for the rational model. Rejection of the joint model appears to be driven primarily by rejection of the gas equation. Comparing the individual J-statistics of the myopic model with the corresponding statistics of the rational model does not give any clear indication as to which model do best. For electricity both models are borderline rejected whereas for gas both the rational and the myopic model are clearly rejected. We will come back to some of the behavioural implications of the myopic model relative to the rational model in the next section.

One reason for violating the orthogonality conditions so strongly in the gas equation could be that variations in outdoor temperature cause strong idiosyncratic shocks due to the household specific technology, cf. (9). Common shocks that impact differently on different households can imply violation of the orthogonality conditions. This is discussed by Chamberlain (1984), and Browning and Lusardi (1996). The orthogonality conditions rest upon the individual expectation errors averaging to zero across time. The problem arises because there is not enough data to calculate a good estimate of the average expectation error for each individual household. The suggestion by Chamberlain is to collect longer time series for each individual in order to obtain a better estimate of the average individual specific expectation error. It is difficult for the econometrician to obtain more data, since the length of the panel is given. For the household the problem is similar. The household technology function suggests that it is a considerable task to evaluate the link between consumption of energy and the energy-derived service in order to calculate the exact size of the shock. A solution for the individual as well could then be to collect a longer time series of consumption data. The time average of the forecast errors will then converge to zero if the weather process is in fact a white noise process. This is, however, also difficult for the individual household, since it may not have a long time series available if it has not been living in the same house (or had the same technology) for many years. A third solution is to use information already corrected for effects of these shocks. Such information is provided by the account consumption level. This is readily available and is purged at the individual level for variations in outdoor temperature. In the next section the Euler equations are re-estimated on the account consumption data.

5.2 Estimates of Euler equations based on account consumption for natural gas

The models based on actual consumption assume that the household has information about the marginal price of the energy-derived service under consideration. For this to hold it is required that the household currently collects price information and evaluates how much energy to use as input into the household technology to derive a given level of services, cf. (8) and (9). In the case of indoor temperature the household needs to establish the link between consumption of gas and indoor temperature for a particular realisation of the outdoor temperature, and this requires disentangling the effect of degree-day variation from the household-specific technology, cf. (9). This is the only way the household can obtain the exact information about the marginal price of indoor temperature at some given point in time. As pointed out before, this is a complex and costly calculation, and moreover quite different from buying and consuming food products, say milk. When a household buys milk it observes the marginal price readily in the supermarket before making the purchase. It is suggested here that the household may use the account consumption measure as an approximation to the actual consumption measure when deciding about future consumption of gas. This information is readily available and provides an estimate of what to consume at mean weather conditions. If the household perceives the annual realisation of outdoor temperature to be drawn from a white noise process with a fixed mean then using the account consumption measure saves the household a great deal of calculation, and information gathering, and it provides the household with an estimate that it can use in the planning of how to smooth future marginal utility without having to evaluate the technology function (9) explicitly.

In this section results from estimating the Euler equations from the rational and the myopic habits models on the account consumption data are presented. The account consumption versions of the rational and myopic Euler equations are only estimated for natural gas. The account measure for electricity is given by last year's consumption uncorrected. The Euler equations for electricity based on account consumption are hence not empirically distinguishable from the ones based on actual consumption data.

Results from estimating the gas Euler equations for the rational and the myopic model are reported in table 5.2. Generally, parameter estimates do not change much relative to the estimates presented in table 5.1. The habits parameter is significant and assumes roughly similar magnitudes for both the rational and the myopic models. The age parameter turns negative and becomes significant. In this way the pattern is more similar to what was found for the electricity equations, cf. table 5.1. Time dummies are still significant even though the account data are degree day corrected. This probably reflects that the degree day correction is not precise or that other aggregate influences are still in play. The most remarkable change, though, is that the J-statistic attains half the size of the corresponding models estimated on actual consumption data. This is consistent with individual specific shocks effects causing the violation of the moment conditions in the Euler equations based on actual consumption. The rational and the myopic models appear to give an equally good description of the account consumption data for natural gas.

Table 5.2 Estimates of Rational and Myopic Euler Equations for Natural Gas. Estimates are based on account consumption

	Rational		Myopic	
	Parameter	Std error.	Parameter	Std error.
Constant	-0.0125	0.0193	0.0010	0.0269
α	0.2181**	0.0421	0.3065**	0.0029
Child enter	0.0061	0.0067	0.0037	0.0074
Child leave	-0.0048**	0.0052	-0.0177**	0.0072
Ln(age)	-0.0127**	0.0047	-0.0148**	0.0066
# persons [1)]	-0.0007	0.0009	-0.0007	0.0012
D93	0.0369**	0.0069	-	-
D94	0.0481**	0.0059	0.0279**	0.0041
D95	0.1680**	0.0105	0.1686**	0.0035
D96	-0.0759**	0.0100	-0.0733**	0.0036
D97	0.0780**	0.0102	0.0415**	0.0039
J (df)	42 (20)		26 (14)	

** indicates significance at 5% level.

1) Number of persons in the first observation year.

Overall, the results tell that the empirical life-cycle models give better descriptions of the account data than of the actual consumption data. This may be because households are in fact using the account information rather than actual consumption information to plan future consumption.

In order to explore the plausibility of the suggestion that consumers use account consumption instead of actual consumption for planning how to smooth future marginal utility, the utility streams derived from actual consumption and account consumption over the observation period are calculated and compared for all households in the sample. This will indicate the welfare costs associated with using account consumption rather than actual consumption for planning future marginal utility.

To do this we perform an experiment where households are assumed to have weak rationally habit forming preferences, with a habit parameter of 0.2. The discount factor and the interest factor are both set to one, and all households are given a coefficient of relative risk aversion of 2. Based on these parameters the utility streams associated with actual consumption and account consumption are calculated for all the households in the sample. In any particular year account consumption will deviate from actual consumption due to the white noise component in the temperature realisation. Therefore, account consumption will provide a better estimate when the number of periods is big. Correcting the calculated deviation in utility streams for the number of times the household is observed in the sample the (median) deviation is 2.5%. This corresponds to 9 days of consumption relative to the annual total consumption. If the household perceives these welfare costs to be small compared to the costs associated with evaluating actual consumption in terms of the household technology and the realisation of the weather process, cf. (9), in order to attain the optimal path then it may be entirely rational to act according to account consumption rather than actual consumption.

A similar experiment can be employed to compare the welfare costs associated with deviating from the optimal path by acting according to the myopic model rather than the rational model. In the myopic model, at time t the household sets current and all future consumption relative to the consumption level in $t-1$. This greatly simplifies the calculation of the future path relative to the rational habits model where consumption in any period is set relative to consumption in the previous period. Comparing the utility streams derived from the myopic model and from the rational model yields a (median) 1% deviation when the calculation is based on account consumption. This corresponds to 3.5 days of consumption relative to the yearly consumption level. If the household perceives these costs as small compared to the additional costs associated with calculating the expected future consumption path from the rational model then it may be entirely rational to act according to the myopic model.

6 Conclusion

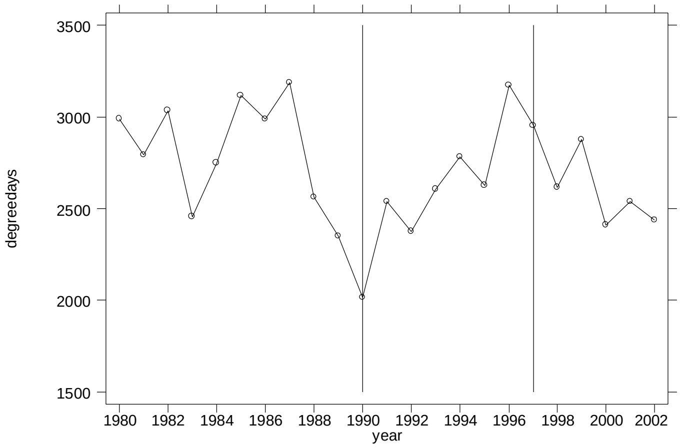
The paper presents an empirical analysis of intertemporal allocation of consumption of energy by households. Energy is an input to a household technology and the joint use of energy and the household technology provide the energy-derived service that is the actual object of consumption. We introduce a household technology into the life-cycle model. The household technology explicitly recognises the indirect nature of energy. This has important implications for the way consumers smooth marginal utility over the life cycle. This study, for example, points to that consumption of energy may be very volatile in order to smooth utility from the energy-derived service.

Euler equations are estimated for consumption of natural gas and electricity for a sample of Danish households. Household-specific technologies are introduced, and preferences are allowed to be habit forming. Models with rational and myopic habit formation are estimated. There is indication of weak habit formation, and the myopic model appears in some cases to do at least as well as the rational model. It is suggested that consumers may use the myopic model as an approximation to the rational model, because the deviation from the optimal path implied by the myopic model may be so small so as to outweigh the additional costs associated with calculating the optimal path. The household technology implies that it can be costly for households to acquire exact information about the link between quantities of energy and quantities of the energy-derived service. It is suggested that households may decide on their purchase strategies based on approximate information that is readily available and provides as a close proxy to the true consumption information. Such approximate information is provided by the account level of consumption.

The analysis calls attention to the importance of recognising individual goods characteristics when modelling intertemporal consumption allocation. This is one of the first studies to do so. Energy is a particular case, but other goods have other characteristics that are important to recognise in future work in order to gain a broader understanding of how consumers plan consumption over the life cycle, and respond to different kinds of shocks. Car transport, water, communication, insurance, medicine, durables, leisure, tobacco, and alcohol are other examples of commodities with distinct characteristics that need to be recognised in an empirical analysis of intertemporal consumption allocation.

Appendix

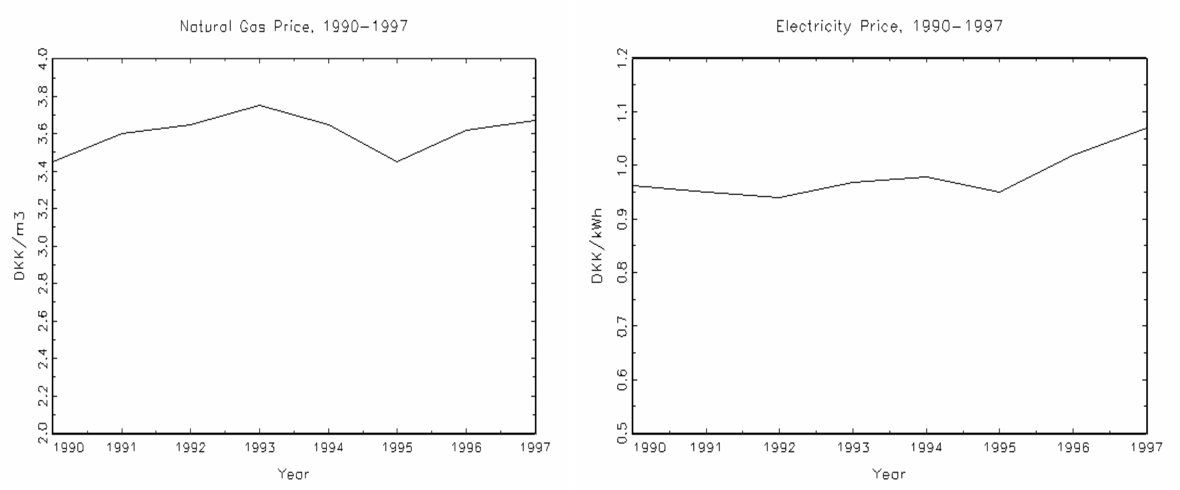
Figure A1 Degree Days, 1980-2002



Source: HNG I/S.

Note: The two vertical lines indicate the observation period of the consumption data. Number of degree days per year is given by $Degree\ days = \sum_{t=1}^{365}(17^\circ C - \tau_t)$ if $\tau_t \leq 17^\circ C$ where τ_t is the average temperature of day t.

Figure A2 Marginal Prices of Natural Gas and Electricity, 1990-1997



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Sammenfatning

Husholdningernes energiforbrug og livscyklusmodellen

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Februar 2004

Undersøgelsen handler om husholdningers allokering af forbrug af energi over tid. Energi har egenskaber, som er forskellige fra fødevarer, som ofte analyseres i mikroøkonometriske studier af intertemporal allokering af forbrug. Disse egenskaber relaterer sig til, at husholdningerne ikke efterspørger energi i sig selv, men derimod efterspørger serviceydelser produceret med energi som input. For eksempel antages det generelt, at husholdninger holder deres forbrug af fødevarer nogenlunde konstant for at udglatte den marginale nytte over tid. I modsætning hertil kan konstant indendørstemperatur kræve et meget omskifteligt forbrug af energi, hvis udendørstemperaturen varierer meget. Energi er et eksempel på, at det er vigtigt at tage højde for varespecifikke karakteristika, når man modellerer intertemporal forbrugsallokering. Det gøres ved at introducere en husholdningsteknologi i livscyklusmodellen for forbrug. Den empiriske analyse foretages på et registerbaseret paneldatasæt med information om et stort antal husholdningers forbrug af naturgas og elektricitet. Der estimeres modeller, hvor der gives mulighed for vanedannelse i husholdningernes præferencer.

Notes

1. In the macro literature external habits have been suggested, for example Abel (1990) and Cochrane and Cambell (1999). Consumers with external habits evaluate utility of consumption relative to the consumption history of some reference group. This Catching-up-with-the-Joneses formulation has the convenient modelling feature that increasing consumption today does not increase the habit tomorrow. We choose to focus on the myopic model as an alternative to the rational model. The myopic model appears more attractive than the Catching-up-with-the-Joneses model, because there is nothing to suggest how the econometrician should pick the reference group.

2. Hayashi (1985) and Dynan (2000) estimate Euler equations from life-cycle models with habit formation. Habit formation is a phenomenon that relates strictly to preferences. Liquidity constraints also create dependence on variables in the information set, i.e. time dependence. This is explicitly recognised by Meghir and Weber (1996). They use the relative price variation between goods to derive within period MRS between goods, and use this as a check of the Euler equation estimates. The presence of dynamic effects in the Euler equation can only be interpreted as intertemporal non-separability (or habits) if the same dynamic effect is found in the MRS between goods. Persistence in the raw consumption series can be due not only to habits, but also to fixed heterogeneity. Fixed heterogeneity in the levels of the consumption series is differenced out in the standard approach to estimating Euler equations on panel data. Carrasco et al. (2002) re-estimate the model of Meghir and Weber on Spanish data, but allow for fixed heterogeneity in the growth rates of consumption. Identification essentially requires additional differencing of the Euler equation. The present paper follows the approach of Hayashi (1985) and Dynan (2000) by only estimating Euler equations. The strategy of Meghir and Weber requires ample variation in the relative prices between goods. The data at hand contain only eight points of observation for prices, and it does not make much sense to try to identify the MRS between goods hereof. We try to safeguard from the presence of liquidity constraints by choosing the sample carefully. This issue is discussed in more detail in the data section.

3. To see this we use a variational argument. In this case the household chooses the optimal consumption programme $\left(\hat{s}_{j,t}, \hat{s}_{j,t+1}, \hat{s}_{j,t+2}, .., \hat{s}_{j,T}\right)$. Since this is optimal we must have, for some small ε,
$$E_t\left[v\left(\hat{s}_{j,t}, \eta_{j,t}\right) + \beta v\left(\hat{s}_{j,t+1}, \eta_{j,t+1}\right) + ...\right] \geq E_t\left[v\left(\hat{s}_{j,t} + \varepsilon, \eta_{j,t}\right) + \beta v\left(\hat{s}_{j,t+1} - \left(1 + r_{j,t+1}\right)\varepsilon, \eta_{j,t+1}\right) + ...\right]$$
The right-hand side is maximised by setting $\varepsilon = 0$. Find the first order condition w.r.t ε of the right hand side, $E_t\left[v'\left(\hat{s}_{j,t} + \varepsilon, \eta_{j,t}\right) = \beta v'\left(\hat{s}_{j,t+1} - \left(1 + r_{j,t+1}\right)\varepsilon, \eta_{j,t+1}\right)\left(1 + r_{j,t+1}\right)\right]$. Evaluate this at $\varepsilon = 0$ to get $E_t\left[v'\left(\hat{s}_{j,t}, \eta_{j,t}\right) = \beta\left(1 + r_{j,t+1}\right)v'\left(\hat{s}_{j,t+1}, \eta_{j,t+1}\right)\right]$.

4. For details of the proof we refer to Hayashi (1985).

5. Meghir and Weber (1996) and Carrasco et al. (2002) base their estimations on (4). The strategy of Meghir and Weber requires ample price variation. In the present case we do not seek to identify habit formation from the price variation. This is seen as the only possible identification strategy given the data at hand. All the households in the sample are customers at the same company. Therefore, no cross-sectional price variation is

present implying that only eight price points are available. Moreover, prices do not vary much over the data period, cf. figure A2 in the appendix. There is thus not much hope to identify from variation in the real interest rate, and identification from this information is even more difficult when strong common effects are present, due to for example a cold winter. There is, in fact, considerable degree-day variation in the sample period, and in the empirical model we take common shocks into account by including time dummies.

6. In this model static expectations about the interest rate are not strictly needed. The assumption will be maintained, though, because it makes comparison of the two models simpler.

7. This implies that the real rate of interest is a function not only of the nominal interest rate, and energy prices, but also of the efficiency of the technology, so that households with more efficient technologies respond less to changes in the energy price.

8. If outside temperature is volatile households need to hold liquid assets to accommodate the variability in expenditures required to smooth marginal utility. This suggests that for households with very low level of liquid assets and no access to credit, variability in outside temperature can have significant welfare effects.

9. This is automated if the households have thermostats installed.

10. The model also applies to the instantaneous flow of consumption measured at some given points in time, where time is measured continuously. If this is the true scenario and the applied consumption measure is a time aggregate then expectation error will follow an MA(1) process with serial correlation 0.25, cf. Hall (1988) and Working (1960). For all practical purposes this means that if the actual decision interval is shorter than the observation period, which is annual, then $\varepsilon_{j,t+1}$ will follow an MA(1) process with positive serial correlation. This would also imply that only information lagged two periods or more, i.e. information dated *t-1* or earlier, will be orthogonal to $\varepsilon_{j,t+1}$.

11. The log-approximation has been criticised by Caroll (2001) because unobserved higher order terms that are functions of the first order terms are introduced into the error term implying that the information set is no longer orthogonal to the error term causing problems to identify parameters like the elasticity of intertemporal substitution. Pozzi (2003) shows in a Monte Carlo study of the standard model without habits that it is only the estimate of the elasticity of intertemporal substitution that is affected by the log-approximation. It is unresolved if the log-approximation affects estimation of α_j in the habits model.

12. Consumption may be traded off with leisure, e.g. because one does not heat the house or does not use electric appliances when on the job.

13. One frequently suggested reason for rejecting the model is that households are credit constrained. Constraints of this type imply that not all variables in the information set are orthogonal to the error. As mentioned in section 3 the sample has been selected so as to minimise the chance that the households in the sample are liquidity constrained. To safeguard, credit constraints have been tested for following Hayashi (1985) by including changes in income and instrumenting appropriately with lagged values of income. If some households were credit constrained the parameter on income changes would be significant. This was not the case.