Habits Revealed

Ian Crawford
Department of Economics, University of Oxford & IFS

March 2008

Abstract

Models which incorporate habits have been shown many times and in many contexts to be useful in both macroeconomics and microeconomics. This paper sets out necessary and sufficient empirical conditions for the habits model in the revealed preference/nonparametric tradition of Samuelson (1948), Houthakker (1950), Afriat (1967) and Browning (1989). This allows an assessment of habits models which is free from the confounding effects of a choice of functional form. The conditions in the paper are shown to be computationally straightforward and yield set identification results for certain features of the model. The ideas outlined are applied to a microeconomic panel dataset. The addition of habit formation to the discounted utility model is shown to improve the rationalisability of the microdata considerably. Even if habit formation is rejected by the data it is shown that modest and plausible allowance for heterogeneity in prices and interest rates is sufficient to bring consumption behaviour in line with the theory. Theory-consistent discount rates and welfare measures revealed by the data are presented. Overall, it appears that habits models are capable of providing an extremely powerful explanation of longitudinal household behaviour.

Acknowledgements I am grateful to Richard Blundell, Martin Browning, Mette Christensen, Richard Mash, Stephen Nickell, Frans Spinnewyn and seminar participants at Cambridge, Leuven, Oxford and York for helpful comments and to Neil Rickman who suggested looking at this topic in the first place. The usual disclaimer applies.
Email: ian.crawford@economics.ox.ac.uk

1 Introduction

Models which allow for habit formation have been used profitably to analyse a wide variety of micro and macroeconomic phenomena. Micro applications have, for example, included Becker and Murphy's (1988) classic study of the price-responsiveness of addictive activities, Meghir and Weber's (1996) work on intertemporal nonseparabilities and liquidity constraints and the explanation of asset-pricing anomalies such as the equity premium puzzle (Abel (1990), Campbell and Cochrane (1999), Constantinides (1990)). Macro-orientated studies have used habit-formation models to improve the ability of business cycle models to explain movements in asset prices (Jermann (1998), Boldrin *et al* (2001)), to investigate the idea that economic growth may cause savings rather than the other way around (Carroll *et al* (2000)) and to explain the finding that aggregate spending tends to have a gradual hump-shaped response to various shocks (Fuhrer (2000)).

Compared to the standard discounted utility model the principal feature of the habit-formation model is the relaxation of consumption independence. The implication of consumption independence in the standard discounted utility model is that tastes in one period are unaffected by consumption in another. Samuelson (1952) was evidently sceptical about this feature and noted that,

> "the amount of wine I drank yesterday and will drink tomorrow can be expected to have effects upon my today's indifference slope between wine and milk".

Similarly Koopmans (1960), who provided an axiomatic derivation of the discounted utility model, remarked that

> "One cannot claim a high degree of realism for [consumption independence], because there is no clear reason why complementarity of goods could not extend over more than one time period".

This, in effect, is an argument against the time-separability of preferences in the discounted utility framework. The leading example of the kind of behaviour which will give rise to nonseparabilities is, perhaps, habit formation (Duesenberry (1952), Pollak (1970), Ryder and Heal (1973), Spinnewyn (1981), and others). In habit formation models[1] the consumption vector is typically partitioned into a group of consumption goods and a group of addictive/habit-forming goods, and the period-t instantaneous utility function is allowed to depend on both current consumption and lagged consumption of the habit-forming goods. The effects of habit formation on preferences over consumption profiles and consequent behaviour can be fairly general: i.e. depending on how much one has already consumed and whether current consumption increases or decreases future utility, habit formation can lead to preferences for increasing, decreasing or even non-monotonic consumption profiles.

Thus far the empirical literature on habits models has been parametric. That is to say based on parametrisations of the Euler equation or consumption function (typically) and of the hypothesised underlying preference structure. The problem which an approach based on a statistical fit of a parametric model to the data is that any test of the theory must be a joint one conflating a test of the hypothesis of interest with a joint hypothesis regarding the functional form of the model plus a number of statistical/econometric auxiliary hypotheses. It therefore does not follow that a rejection of the econometric model necessarily implies a rejection of the hypothesis of interest. Similarly any model-based empirical identification of preference parameters equally rests on the choice of functional form.

This paper asks: *what are the nonparametric empirical implications of the habits model?* In particular; are there restrictions involving only data on observables which can allow us to test the model's empirical validity and (granted this) to recover its features? The path which is taken in this paper is based on the revealed preference approach developed in Samuelson (1948), Houthakker (1950), Afriat (1967) and Varian (1982) and the extension of these ideas to the perfect foresight/strong rational expectations life-cycle/permanent income version of the discounted utility model developed by Browning (1989) who showed how the constancy of the marginal utility of income across periods can be used to generate finite linear-programming type restrictions which only involve data on observables: discounted prices and quantities. These provide a simple yes/no test of exact, error free, consistency between the data and the theory. Despite the strength of the assumptions underlying the life cycle-permanent income model, Browning (1989) found that there were very strong theory-coherent regularities in the post war aggregate data sets for Canada, the US and the UK.

The benefits of this style of approach are well known[2]: it is designed to work using finite (even small) datasets, it requires only data on observables and it avoids the need to fit parametric (or indeed nonparametric) statistical models to the data. The price is that empirical identification is necessarily weakened; although to the extent that precise identification might flow from parametric/statistical assumptions this may be no bad thing.

No nonparametric test (in the sense of Afriat (1967), Varian (1982) and Browning (1989)) of the perfect foresight habits model has yet been proposed or implemented. Whilst Kubler (2004) shows

[1] It is worth noting that habits models bear a great many formal parallels with models of consumer durables (habit-forming goods being goods which are psychologically durable rather than - or as well as - physically durable), models of adaptive consumer learning, reference-point models, models incorporating rational anticipation and models of consumer behaviour under rationing.

[2] See for example the motivation given in Varian (1982).

that nonparametric testing of general nonseparable intertemporal choice models is not possible, the canonical habits model is rather special: it is additive and breaks intertemporal separability in a fairly specific manner. This paper asks whether the habits model is nonparametrically testable on the basis of observables. It is shown, using ideas akin to those from the rationing literature (Neary and Robert (1980) and Spinnewyn (1981)) that habits models are testable, and also that the proposed test is a rather straightforward one.

The plan of this paper is as follows. Section 2 presents necessary and sufficient empirical conditions for the habits model, describes the implementation of these conditions and sets out the way in which measurement errors might be accommodated. It also discusses the identification of preference features and the relationship between the test described here and other nonparametric tests in the literature (e.g. GARP and Browning's (1989) test of the life-cycle/permanent income model). Section 3 described the results of the application of these ideas to a microeconomic panel dataset. Section 4 concludes.

2 Characterising the habits model

2.1 Necessary and Sufficient Conditions

Suppose that there are T observations indexed[3] $t = 1, ..., T$ on a consumer's demands over time $\{\mathbf{q}_t\}$ and the corresponding prices $\{\mathbf{p}_t\}$ and interest rate $\{i_t\}$ which they faced. Let the commodity vector be partitioned into a group of consumption goods $\mathbf{q}_t^c$ and a vector of habit-forming goods $\mathbf{q}_t^a$ such that $\mathbf{q}_t = [\mathbf{q}_t^{c\prime}, \mathbf{q}_t^{a\prime}]'$. To develop the main ideas without the loss of a great deal of generality, the discussion will focus on the simplest case in which the effects of lagged consumption of the addictive goods only persist for one period. This is precisely the type of model considered in, for example, Becker, Grossman and Murphy (1994) *inter alia*, and it is used here to introduce notation and to fix ideas before considering the extension to a general lag structure. The discussion of this extension (which is straightforward) is postponed until the end of this section.

The first question is whether it is possible to find necessary and sufficient empirical conditions on the observable discounted price and quantity data under which these data are consistent with the short-memory habits model. To this end, consistency between the habits model and the data is defined as follows.

Definition 1. The time series of the interest rate, prices and quantities $\{i_t, \mathbf{p}_t^c, \mathbf{p}_t^a; \mathbf{q}_t^c, \mathbf{q}_t^a\}_{t\in\tau}$ satisfies the one-lag habits model if there exists a concave, strictly increasing (utility) function $u(.)$ and positive constants λ and β such that for all $t \in \tau$

$$\beta^{t-1}\mathbf{D}_{\mathbf{q}_t^c} u\left(\mathbf{q}_t^c, \mathbf{q}_t^a, \mathbf{q}_{t-1}^a\right) = \lambda \boldsymbol{\rho}_t^c$$

$$\beta^{t-1}\mathbf{D}_{\mathbf{q}_t^a} u\left(\mathbf{q}_t^c, \mathbf{q}_t^a, \mathbf{q}_{t-1}^a\right) + \beta^t \mathbf{D}_{\mathbf{q}_t^a} u\left(\mathbf{q}_{t+1}^c, \mathbf{q}_{t+1}^a, \mathbf{q}_t^a\right) = \lambda \boldsymbol{\rho}_t^a$$

where $\rho_t^i = p_t^i / \prod_{s=2}^{s=t}(1 + i_s)$ denotes discounted prices.

This says that the data are consistent with the theory if there exists a well-behaved instantaneous utility function (defined over the consumption goods and the habit-forming goods plus the one-period lag of the habit-forming goods), the derivatives of which satisfy the first order conditions of optimising behaviour. If such a utility function exists, and we know what it is, then it means that we can simply plug it into the habits model, solve the model and precisely replicate the observed demand choices of the consumer. To put it another way, the theory and the data are consistent if there exists a well-behaved and suitably-conditioned utility function which can provide perfect within-sample fit of the consumption/demand data.

[3] Denote the index set by $\tau = \{1, ..., T\}$.

From Definition 1 is it clear that the first order conditions for the consumption goods are identical to those of the standard life cycle model. Those for the habit-forming goods are a little more complex because the current consumption of the habit forming goods affects future utility as well as current utility. Nevertheless, as first pointed out by Spinnewyn (1981), these condition can be transformed into a form which is analogous to a no-habits model by defining suitable shadow discounted prices which summarise these welfare effects:

$$\boldsymbol{\rho}_t^{a,0} = \frac{\beta^{t-1}\mathbf{D}_{\mathbf{q}_t^a} u\left(\mathbf{q}_t^c, \mathbf{q}_t^a, \mathbf{q}_{t-1}^a\right)}{\lambda} \tag{1}$$

$$\boldsymbol{\rho}_t^{a,1} = \frac{\beta^{t-1}\mathbf{D}_{\mathbf{q}_{t-1}^a} u\left(\mathbf{q}_t^c, \mathbf{q}_t^a, \mathbf{q}_{t-1}^a\right)}{\lambda} \tag{2}$$

Expression (1) is the shadow discounted price of current consumption and measures the discounted willingness-to-pay for current consumption of the habit-forming goods. Expression (2) is the shadow discounted price of past consumption and measures the discounted willingness-to-pay for past consumption of the habit-forming goods. It is worth noting that the shadow discounted price of current consumption can be interpreted as the (observed) discounted price adjusted to account for the future welfare effects of current decisions. That is

$$\boldsymbol{\rho}_t^{a,0} = \boldsymbol{\rho}_t^a - \frac{\beta^t \mathbf{D}_{\mathbf{q}_t^a} u\left(\mathbf{q}_{t+1}^c, \mathbf{q}_{t+1}^a, \mathbf{q}_t^a\right)}{\lambda} \tag{3}$$

Given (1) and (2), the habits model entails an intertemporal dependence between the shadow discounted prices:

$$\boldsymbol{\rho}_t^a = \boldsymbol{\rho}_t^{a,0} + \boldsymbol{\rho}_{t+1}^{a,1} \tag{4}$$

The empirical/behavioural implications of the short memory habits model are therefore driven by: *(i)* links between the derivatives of discounted utility with respect to future and past consumption of the habit-forming goods and the (unobservable) shadow discounted prices, and *(ii)* intertemporal links between the (unobservable) shadow discounted prices and the (observable) discounted prices. The aim then, is to turn these insights into testable empirical conditions involving only observables. The following result can now be given:

Theorem 1. The following statements are equivalent:
(T) The time series of the interest rate, prices and quantities $\{i_t, \mathbf{p}_t^c, \mathbf{p}_t^a; \mathbf{q}_t^c, \mathbf{q}_t^a\}_{t\in\tau}$ satisfies the one-lag habits model.
(R) There exist shadow discounted prices $\{\boldsymbol{\rho}_t^{a,r}\}_{t\in\tau}^{r=0,1}$ and a positive constant β such that

$$0 \leq \sum_{\forall s,t\in\sigma} \boldsymbol{\pi}_s' \left(\mathbf{x}_t - \mathbf{x}_s\right) \quad \forall \sigma \subseteq \tau \tag{R1}$$

$$0 = \boldsymbol{\rho}_t^a - \boldsymbol{\rho}_t^{a,0} - \boldsymbol{\rho}_{t+1}^{a,1} \quad \forall \quad t, t+1 \in \tau \tag{R2}$$

where $\mathbf{x}_t = \left[\mathbf{q}_t^{c\prime}, \mathbf{q}_t^{a\prime}, \mathbf{q}_{t-1}^{a\prime}\right]'$ and $\boldsymbol{\pi}_t = \frac{1}{\beta^{t-1}}\left[\boldsymbol{\rho}_t^{c\prime}, \boldsymbol{\rho}_t^{a,0\prime}, \boldsymbol{\rho}_t^{a,1\prime}\right]'$ and $t \in \tau$, $\tau = \{2, ..., T\}$.

Proof. See the Appendix.■

Theorem 1 is an equivalence result. It says that if one can find suitable shadow prices and a discount rate such that restrictions (R1) and (R2) hold, then the data are consistent with the theory and there does indeed exist a well-behaved utility function which gives perfect within-sample rationalisation of the data. Conversely if such shadow discounted prices and a discount rate cannot be found then there does not exist any theory-consistent utility representation. Restriction (R1) is a cyclical monotonicity condition[4] which is an implication of the concavity of the instantaneous utility function and the constant marginal utility of lifetime wealth. This condition involves the shadow discounted prices discussed above. Restriction (R2) is the intertemporal link between the shadow prices.

The empirical test is thus a question of searching for shadow price vectors and a discount rate which satisfies the restriction in (R). These restrictions are non-linear in unknowns and look forbidding but are, in fact, computationally quite straightforward. The important feature to note is that, conditional on the discount rate, the restrictions are linear. This means that, for any choice of discount rate, the existence or non-existence of feasible shadow prices can be readily checked in a finite number of steps using phase one of a linear programme. The issue is then simply one of conducting an arbitrarily fine one-dimensional grid search over a sensible range[5] for the discount rate and running a linear programming problem at each node.

To end this section consider a more general model in which consumption of the habit-forming goods persists for R periods the instantaneous utility function is given by

$$u\left(\mathbf{q}_t^c, \mathbf{q}_t^a, \mathbf{q}_{t-1}^a, \mathbf{q}_{t-2}^a, ..., \mathbf{q}_{t-R}^a\right) \tag{5}$$

The definition of what it means for data to be consistent with the R-lag model and the corresponding necessary and sufficient conditions for theoretical consistency are given in the appendix (Definition R and Theorem R). Both are natural extensions of Definition 1 and Theorem 1. Once more the restrictions come in the form of a cyclical monotonicity condition and an intertemporal condition linking the shadow and spot prices of the habit-forming goods. However in this more general model the lag lengths involved in the consumption vectors are longer and the intertemporal links between shadow prices extend further. In other respects the restrictions are multi-period analogues of those in Theorem 1. Once more the conditions are linear given a choice of discount rate and so can be checked by grid search on the discount rate with a linear programming step at each node.

Note that whilst one can test data against the habits model with an arbitrary number of lags, there is an obvious empirical limit if the number of lags equals the number of observations. Indeed if this happens then the habits model is untestable/unrejectable because, in essence, one only has a single complete observation on the consumer - too few to check the dynamic consistency of a consumer's behaviour. Of course, when the lag length extends beyond the data period there are no complete observations at all.

2.2 Allowing for errors

The conditions in Theorems 1 and R, like all non-parametric/revealed preference type tests, are rather exacting in the sense that if either the consumer's or the data collector's "hand trembles" then the data may be inconsistent with the model even if the deviations induced are very small. One might be particularly concerned that measurement error could induce violations of the conditions even though the underlying true data are theory-consistent. A useful framework within which one can address the effects of measurement errors on these kinds of tests has been suggested by Varian (1990) and this section briefly discusses how the habits model fits into this approach.

Let D^0 denote the observed dataset $\{i_t, \mathbf{p}_t^c, \mathbf{p}_t^a; \mathbf{q}_t^c, \mathbf{q}_t^a\}_{t\in\tau}$ and let $\Delta(R)$ denote the set of all such datasets which are consistent with the R-lag model

$$\Delta(R) = \{D : D \text{ is consistent with the R-lag model}\} \tag{6}$$

Then a violation of the empirical conditions for the observed data simply means that the observed data lie outside the theoretically consistent range

$$D^0 \notin \Delta(R) \tag{7}$$

[4] Rockafellar, (1970, Theorem 24.8)

[5] Since $\beta = 1/(1+\delta)$, where δ is the consumer's rate of time preference $\delta \in [0,\infty] \Rightarrow \beta \in [0,1]$.

However, suppose that the data are contaminated by measurement error. Specifically suppose that the relationship between the true data D^* and the observed data is

$$D^* = D^0 + E \tag{8}$$

where $E = \{v_t; \mathbf{e}_t^c, \mathbf{e}_t^a; \mathbf{u}_t^c, \mathbf{u}_t^a\}_{t\in\tau}$ represents measurement error which is classical by assumption[6]. Thus $D^* = \{i_t + v_t; \mathbf{p}_t^c + \mathbf{e}_t^c, \mathbf{p}_t^a + \mathbf{e}_t^a; \mathbf{q}_t^c + \mathbf{u}_t^c, \mathbf{q}_t^a + \mathbf{u}_t^a\}_{t\in\tau}$. In this case a test statistic for the null hypothesis that the true data satisfy the model can be based on the loss function

$$L(E) = \frac{vec(E)' \, vec(E)}{\sigma^2} \tag{9}$$

where σ^2 is the variance of the measurement error. This is distributed as a $\chi^2_{2K(T-1)+T}$ and the null hypothesis that the true data satisfy the model would be rejected if the test statistic exceeded C_α, the critical value at the α significance level of the chi-squared distribution. Since the true data are unobserved one can instead compute the minimum perturbation to the data such that the perturbed data satisfy the model, and use the calculated errors as the basis for making conservative inferences. Of course the variance of the measurement errors is typically unknown but Varian (1990) suggests calculating how big it would need to be in order to reject the null and then comparing this to one's prior beliefs on the likely size of these errors. Alternatively one may be able to estimate it from a parametric or nonparametric fit of the data, or from other data sources. This provides a basis for analysing the model in the presence of measurement errors.

2.3 The relationship with other nonparametric tests

A natural question concerns how the test proposed in the previous section relate to other nonparametric integrability tests? Specifically, how does it relate to Browning's (1989) test of the life-cycle model/strong rational expectations hypothesis and the Afriat (1967), Varian (1982) Generalised Axiom of Revealed Preference (GARP) test. The first result to note is that whilst the test of the habits model does not imply the life-cycle model and neither is it implied by the Browning (1989) conditions, nevertheless the habits model nests the life cycle model in the following sense.

Theorem 2. *If the data $\{i_t, \mathbf{p}_t^c, \mathbf{p}_t^a; \mathbf{q}_t^c, \mathbf{q}_t^a\}_{t=1,\ldots,T}$ satisfies the R-lag model with $\boldsymbol{\rho}_t^{a,r} = \mathbf{0}$ for all $t \in \tau$ and $r \geq 1$ then the data also satisfies the conditions for the life-cycle model/strong rational expectations hypothesis.*

The life cycle model/strong rational expectations hypothesis can therefore be regarded as a special case of the habits model in which discounted willingness to pay for past consumption is always zero. The test proposed here can, therefore, be easily adapted to provide a test of the life cycle model by adding the constraints that $\boldsymbol{\rho}_t^{a,r} = \mathbf{0}$ for $r \geq 1$ to those in Theorems 1 and R, in which case the test becomes identical to that proposed in Browning (1989) (augmented to allow for time discounting which Browning does not explicitly consider). As a corollary note that this further restriction also provides the link between the integrability condition for the habits model and GARP.

Corollary 1. *If the data $\{i_t, \mathbf{p}_t^c, \mathbf{p}_t^a; \mathbf{q}_t^c, \mathbf{q}_t^a\}_{t\in\tau}$ satisfies the R-lag model with $\boldsymbol{\rho}_t^{a,r} = \mathbf{0}$ for all $t \in \tau$ and $r \geq 1$ then the data also satisfies GARP.*

[6] See for example, Varian (1990).

The intuition is straightforward: if the data satisfy the conditions for the habits model with this added zero-restriction on the shadow prices then habit formation is effectively ruled out and they then satisfy the conditions for the life-cycle model. GARP only requires within-period efficiency in expenditure, the string rational expectations life-cycle model however requires more; it requires the efficient within-period *and* between-period allocation of expenditure. The condition for the life-cycle model are is therefore over sufficient for GARP.

2.4 Identification

Given a dataset which is consistent with the habits model, the question then arises as to whether it might be possible to identify parts of the model. In general the restrictions in Theorems 1 and R will only provide set identification in the sense that, if there exist shadow prices and discount rates which are consistent with the habits model at all, then the constraints define a set of admissible values. Consider the discount factor; its identification set is given by

$$B(R) = \left\{\beta : \{i_t, \mathbf{p}_t^c, \mathbf{p}_t^a; \mathbf{q}_t^c, \mathbf{q}_t^a\}_{t\in\tau} \text{ satisfies the R-lag model}\right\} \tag{10}$$

The set of theory and data-consistent discount factors is not convex, a fact which stems from the non-linear nature of the restrictions implied by the model. Since the empirical test proceeds by means of a grid search on β this means that the empirical identification interval for β has "gaps" in it both at nodes where the conditions may be rejected and also between nodes at untested values of β. These second class of gaps can be made arbitrarily small by choosing a finer grid.

The other elements of principal interest in the habits model are the willingness-to-pay measures which capture the welfare effects of habit formation:

$$\frac{\mathbf{D}_{\mathbf{q}_{t-r}^a} u\left(\mathbf{q}_t^c, \mathbf{q}_t^a, \mathbf{q}_{t-1}^a, ..., \mathbf{q}_{t-R}^a\right)}{\lambda} = \left\{\frac{\boldsymbol{\rho}_t^{a,r}}{\beta^{t-1}}\right\}^{r=1,...,R} \tag{11}$$

Again, given that the data are theory-consistent there will be a set of combinations of shadow prices and discount factors which will be admissible under the restrictions. The empirical procedure will return theory-consistent combinations of these parameters and the identification set for the willingness-to-pay measures will be given by

$$P(R) = \left\{\left\{\frac{\boldsymbol{\rho}_t^{a,r}}{\beta^{t-1}}\right\}^{r=1,...,R} : \{i_t, \mathbf{p}_t^c, \mathbf{p}_t^a; \mathbf{q}_t^c, \mathbf{q}_t^a\}_{t\in\tau} \text{ satisfies the R-lag model; } \beta \in B(R)\right\} \tag{12}$$

Once more this identification set will be non-convex. The non-convexity of $P(R)$ stems from the non-convexity of $B(R)$. However, once again conditional on β the set of willingness-to-pay parameters is convex.

3 Testing habits in microeconomic panel data

This section investigates the ideas discussed above using a household level panel dataset. The empirical results are organised as follows. They begin with an investigation of the consumption of tobacco - one of the most studied habit-forming goods (see for example Chaloupka (1991), Becker, Grossman and Murphy (1994), Labeaga (1999), *inter alia*). The performance of the one-lag short memory habits model is looked at in comparison to the standard static utility maximisation model and the life-cycle model. The theory consistent set of discount rates is described for those households whose behaviour is rationalisable. For households which cannot be reconciled with the short memory habits model the effects of (i) allowing for measurement errors (ii) extending the lag length and (iii) allowing for habit formation in other goods is considered in turn. The impact on the rationalisability of data by the theory is shown in each case.

3.1 Data

The data used here to investigate the empirical implementation of the ideas outlined above is the Spanish Continuous Family Expenditure Survey (the *Encuesta Continua de Presupuestos Familiares* - ECPF). The ECPF is a quarterly budget survey of Spanish households which interviews about 3,200 households every quarter. These households are randomly rotated at a rate of 12.5% each quarter. Thus it is possible to follow a participating household for up to eight consecutive quarters. This dataset is a much studied survey which has often been used for the analysis of intertemporal models and particularly, latterly, the analysis of habits models (for example, Carrasco, Labeaga and López-Salido, (2005), Browning and Collado (2001, 2004)). The data used here are drawn from the years 1985 to 1997 and are the selected sub-sample of couples with and without children, in which the husband is in full-time employment in a non-agricultural activity and the wife is out of the labour force (this is to minimised the effects of nonseparabilities between consumption demands and leisure which the empirical application does not otherwise allow for). The dataset consists of 21866 observations on 3134 households. The data record household non-durable expenditures and these are disaggregated into 14 commodity groups (details are in the Appendix). The discounted price data are calculated from published prices aggregated to correspond to the expenditure categories and the average interest rate on consumer loans (these data and the issues they raise are further discussed below).

3.2 Results

3.2.1 Habits in Tobacco Consumption

The ECPF indicates that 76% of the sample have positive expenditures on tobacco products. Taking positive expenditures to be the indicator of smoking (since the data are quarterly it is assumed that infrequency of purchase is not a significant problem) what follows concentrates on this subsample of 2388 households.

The empirical results begin with the analysis of the comparative performance of the Varian (1982) test of GARP, the Browning (1989) test of the life-cycle/strong rational expectations hypothesis and the habits model with one lag on tobacco consumption[7]. It is important to note that each test is run *independently* using the data for each household in the sample, one at a time. The data across households are not pooled at any point. This therefore allows for complete heterogeneity, of unrestricted form across households with respect to (i) whether or not their behaviour is theory-consistent and (ii) the form of their preferences (provided that their behaviour is rationalisable at all). The results are reported in Table 1.

TABLE 1: Rationalisability results

Test:	Static u-max	Life-cycle	Habits (1 Lag)
Pass Rates:	97.24%	4.61%	24.41%

The first column in shows the pass rate for the GARP test. Recall that this tests for consistency between the data and the canonical static consumer choice model in which each period's budget is parametric. The results indicate a high level of agreement between the theory and model with about 97% of the sample satisfying GARP. The static model out-performs both the life-cycle model

[7] Following the literature it is sensible to look at the special version of the habits model in which the habit-forming good is bad for the consumer. That is, the version of the model in which past consumption reduces current utility. This boils down to adding the restriction that $\rho_t^{a,1} \leq 0$ to the conditions described in Theroem 1.

and the habits model by a significant degree. However, this is not surprising in because, as discussed above, the empirical requirements of the static demand model are much less stringent than those of the intertemporal model. Note that only observations $\{3, .., T\}$ are used in the calculations. Obviously with one lag one can only use $T-1$ observations in the test of the habits model so it is important for comparability to truncate the data used for the life-cycle model and GARP tests to cover the same data points. The extra truncation (by two periods) is to make the results in this table comparable with those in Table 2 (below) which in due course considers the extension to 2 lags. The next column reports the results of Browning's (1989) test of the life cycle model. It is found, in contrast to Browning's study of aggregate data series, that the life-cycle model is heavily rejected in these microdata. Less than 5 percent of the sample satisfy the conditions required. It would appear that the data are generally inconsistent with the strong rational expectations version of the life-cycle model.

The last columns show the pass rate for the one lag habits model. Recall that the life-cycle model can be regarded as a special case of the habits model in which the welfare effects of past consumption are restricted to be zero. Habits models are therefore less restrictive than the life-cycle model and the more lags which are allowed, the less restrictive they progressively become (until the number of lags equals the number of observations at which point they provide no testable restrictions). The pass rates for the habits models should therefore be no worse than those for the life-cycle model. The results in the table show that this is indeed the case and that the performance of the habits model is substantially better than that of the simple life-cycle model with about a quarter of smokers' behaviour rationalisable by the one-lag version of the model. Whilst the empirical results show a far better degree of agreement between the habits model and the data that between the life-cycle model and the data, the pass rates are far below those of the GARP test.

To investigate whether or not a household's consistency with one of these models is correlated with observables, pass/fail indicators for each household for each model (static, life-cycle and both habits model) were regressed on a number of standard observable household characteristics[8]. The pseudo R^2 of the probits were all around the 1% to 2% level and almost none of the coefficients were individually significant. It appears that whether or not a household's behaviour is likely to be rationalisable with theory is not predictable on the basis of standard observables.

3.2.2 Preferences

In the tests conducted above the grid search with respect to the discount rate was carried out, for every individual household, over the range $[0.95, 1]$ using grid points spaced at a quarter of one percentage point. As noted in section 2.4 the identification region for the discount rate is non-convex and may contain gaps at values which were inconsistent with observed behaviour and the model. For each household which satisfied the restrictions implied by the one-lag model a set of admissible discount rates was recorded.

Figure 1 illustrates the probability that each discount rate in the range examined is rationalisable conditional on *some* discount rate being appropriate. To put it another way the height of the line records the proportion of times each value of the discount rate was rationalisable over the sample of rationalisable household. If the line had reached 1 at any point that would mean that that value of β was acceptable for all of the rationalisable households, a value of 0.5 would have meant that that value of β was rationalisable with the data for only half of these households. The line slopes marginally upwards and is not smooth (due to the nonconvex nature of the identification set). The lowest success rate was for $\beta = 0.95$ and the highest was for $\beta = 0.98$. Given these are quarterly data it is reasonably pleasing that higher values of β are somewhat more easily rationalised than lower ones. Nevertheless it is important to bear the vertical scale in mind when interpreting this figure. The range of variation is narrow (around 4 percentage points) so that the line is, in fact,

[8] These were {age of the head of household, the number of children in the household and dummy variables for highest educational qualification=university degree, highest educational qualification=high school, head's occupation = professional/managerial, head's occupation = skilled, homeowner, renter, drinker}.

rather flat. One way of interpreting this is that, if a household's behaviour is theory consistent at all, then there is little to choose between different discount rates (at least over the range studied).

Figure 1: Theory-consistent consumer discount rates

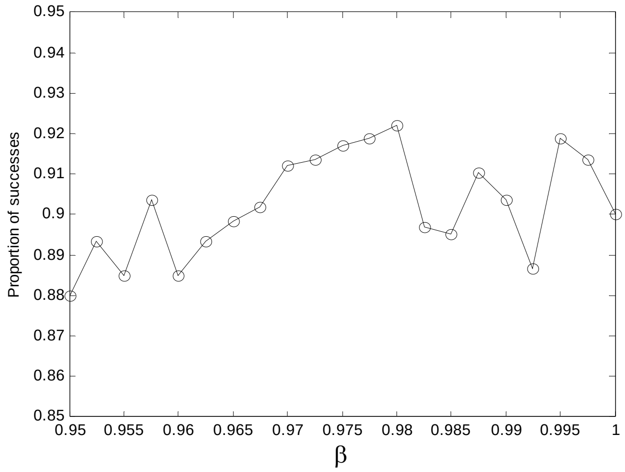
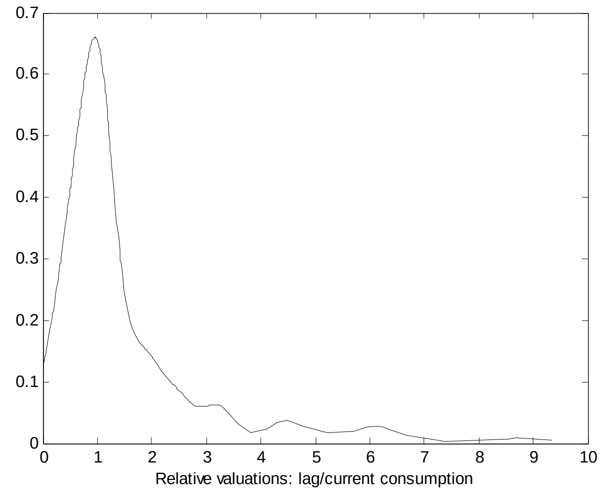


Figure 2 shows the distribution of absolute rates of substitution between current and lagged consumption of the habit-forming good amongst households whose behaviour is consistent with the short memory model. That is, it shows the distribution of ratios[9] of the shadowprice (1) and (2):

$$\frac{\rho_t^{a,1}}{\rho_t^{a,0}} = \frac{\mathbf{D}_{q_t^a} u\left(\mathbf{q}_t^c, q_t^a, q_{t-1}^a\right)}{\mathbf{D}_{q_{t-1}^a} u\left(\mathbf{q}_t^c, q_t^a, q_{t-1}^a\right)}$$

Figure 2: Theory-consistent rates of substitution



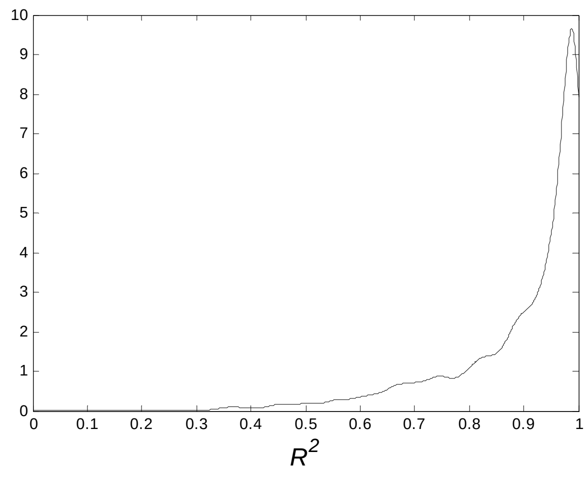
[9]Note that whilst the testing procedure only requires that feasible values are found for the shadow prices, the calculations here involve maximising and minimising $\rho_t^{a,1}/\rho_t^{a,0}$ at each observation to find bounds on the range of rates of substitution. The procedure `fmincon` in MatLab 7.3.0 was used to implement this taking the feasible values from the LP as starting values. The figure reports the Gaussian kernel density of the mid points of the bounds. An alternative would be to report the results of a kernel density estimate which placed a uniform distribution over the interval described by the bounds.

This measures how much the consumer is willing to pay for current relative to lagged consumption and measures the relative importance of the habit-formation component. A ratio which is less than one indicates that the lagged effect outweights the current effect and that the habitual element is rather strong. Rates of substitution greater than one would indicate relatively weak effects from habits. In the limit, of course as the habit effect drops to zero this measure would tend to infinity. It appears that for tobacco habits are important; the median value is -1.03 indicating that the habit is about as important as current consumption on average, and in fact 13% of the sample have relative valuations which are less than 0.5 indicating that, for them, the habitual element is twice as important as current consumption. Neverthess, as is seen from the figure there is a long right hand tail (which is actually truncated) and for half of the sample current consumption outweights lagged consumption whilst for about one quarter of household the effect of current consumption are twice as big as the lagged effect.

3.2.3 Allowing for Measurement Errors

For households whose behaviour violates the habits model it is possible, using the ideas outlined in section 2.2, to perturb the data so that they satisfy the model. As discussed above, the data are composed of expenditures on commodity groups which are collected in the ECPF, and corresponding price indices and a consumer interest rate series published by the *Instituto Nacional de Estadística*. Given that individual expenditures are recorded in the survey but the prices and the interest rate are not, but rather are national time series data, is seems most likely that if there is any measurement error most of it is in the discounted prices. I am not aware of any specific studies about price dispersion (or variation in the interest rates at which different households may borrow) in Spain but there is plenty of evidence for it in the UK[10] and there is no obvious reason to expect that Spain is much different. In view of this the discounted price data for each violating households has been perturbed by the minimum distance necessary such that they then satisfy the model.

FIGURE 3: The density of the distribution of $R^2 : \rho_t^i = \rho_t^{i*} + e_t^i$



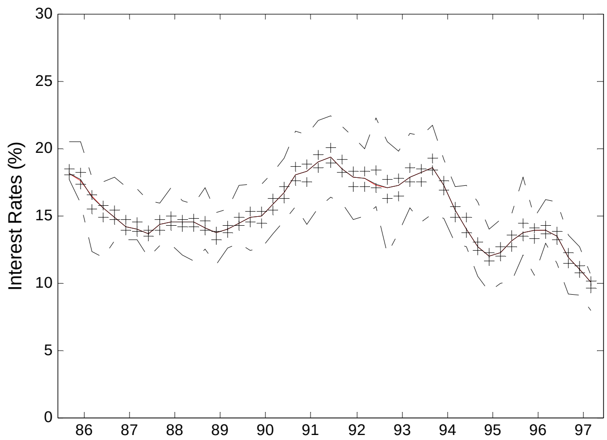
The results are hard to interpret directly since distance metrics like this depend on the units involved: in the absence of an estimate of the variance of the measurement error it is hard to tell whether the necessary perturbation is big. To help with interpretation the distances have been translated into R^2-type values based on how much the perturbations contribute to the fitting of the nearest theory-consistent values compared to the observed discounted price. If the observed discounted prices did satisfy the model the minimum perturbation required would be zero and the

[10]See for example Griffith and Leicester (2006).

R^2 would be 1. To the extent that the data violates the model and larger perturbations are required then $R^2 \to 0$. The interpretation of an R^2 around 1 is that the price data are "close" to passing. The calculation is carried out independently for each household which violates the model and for each value of the discount rate in the grid search. Figure 3 illustrates the density of the distribution of R^2 values. It shows a right-skewed distribution with 90% of the R^2 values greater than 0.7. The behaviour of many households appears to be reasonably close (on this measure) to rationalisable by the model.

Even if the observed and perturbed discounted prices are close by an R^2 measure it is still not completely clear whether the difference is economically significant. One interesting exercise is to take the perturbed (and now theoretically-consistent) discounted prices and to recover from them the implied interest rate which would rationalise the data. This allows for the fact that the aggregate discounted price data uses the published aggregate average rate of interest on consumer loans whilst in reality different households might vary widely in the cost of borrowing which they face. Figure 4 shows the time series of certain quantiles of the interest rate distribution which emerges.

FIGURE 4: Rationalisable interest rates and the observed interest rate



What appears to be a single solid line in the middle of the figure is, in fact two lines: they are the published consumer interest rate along with the median of the rationalisable (perturbed) interest rate distribution. However, it is impossible to tell them apart because they are virtually identical. The crosses indicate the quartiles of the rationalisable interest rate distribution. These are on average less than ± 0.5 percentage points of the observed interest rate over the period. In other words, for half of those households whose behaviour cannot be reconciled with the observed data an adjustment of only 0.5 percentage points in the interest rate they face is sufficient to be able to rationalise them. The outer dashed lines are the 90th and 10th percentiles of the rationalisable interest rate distribution. These lie, one average ± 2.5 percentage points from the observed interest rate over the period. Eighty percent of the distribution of theory-consistent rates are within these bounds which. Together these results seem to indicate that the distribution of theory-consistent interest rates is quite "peaky". The implication one might draw from Figures 3 and 4 is that it appears that only reasonably modest adjustments to the prices and interest rates faced by households are required to rationalise the data.

3.2.4 Adding Lags

The results in Table 1 showed that a habits model with one lag in tobacco consumption did something to improve the rationalisability of the data with theory compared to the unadorned life-cycle model. However, the proportion of the data which satisfied the habits model was still far lower than that for the static utility maximisation model. Possible explanations were discussed above and it was shown that fairly small household-specific adjustments to prices could reconcile the data with the model. This approach essentially imposes the model by altering the data. An alternative is to increase the number of lags. To explore this the number of lags in tobacco consumption was increase to two. Table 2 shows the results.

Table 2: Rationalisability results, adding lags

Test:	Static u-max	Life-cycle	Habits (1 Lag)	**Habits (2 Lags)**
Pass Rates:	97.24%	4.61%	24.41%	**91.33%**

The results in the first three columns recap those shown in Table 1 and are there for comparison. The final column shows the level of agreement between the data and the theory when the lag length is increased to two periods for those households whose behaviour was not previously rationalisable by the one-period habits model[11]. Increasing the lag length in tobacco consumption increases the pass rate substantially. This may plausibly be due to the length of time required for the addictive effects associated with tobacco consumption to dissipate. Note that as with Table 1 all of these results are based on the same observations ($t = 3$ to T) for each household in order for the results to be comparable. The increase in the ability of the habits model to rationalise the data is not, therefore, to do with the 2-lag model simply being tested against fewer observations than the short memory or the no-lags (life cycle) models. It appears to be due entirely to added flexibility of the longer lag structure. The implications appear to be significant: allowing for just two lags in the consumption of a single, plausibly habit forming, good can improve the agreement between the theory and the data from a situation in which almost none of observed behaviour is rationalisable (as with the strong rational expectations, life-cycle model) to a point at which the vast majority of the data are rationalisable.

3.2.5 Adding Goods

So far the empirical work has concentrated on tobacco; that is, the consumption vector has 14 disaggregated commodity groups in it, but amongst them only tobacco is allowed to have a lagged effect. Whilst tobacco is the classic habit-forming good in the literature, there is no reason to suppose that complementarities between consumption in different periods do not exist for other goods as well. Leaving aside alcohol and gambling expenditures which are almost as frequently investigated as tobacco, a far from exhaustive list of other commodities which have been looked at in the literature on habit-formation is heterogeneous enough to include milk[12], coffee[13], cinema[14] and religious practice[15]. With this in mind the next set of results looks at the effects of allowing for habits in all spending categories on the rationalisability of the data. As was the case with adding lags, one can think of this as a relaxation of zero-constraints on shadow prices.

Table 3: Rationalisability results, adding goods

Test:	Static u-max	Life-cycle	Habits (Tobacco)	**Habits (All goods)**
Pass Rates:	97.24%	4.61%	24.41%	**98.45%**

[11] Note that habits models with a one period lag are equivalent to habits models with a two period lag with an additional parameter restriction on the shadow prices of past consumption i.e. that they are equal to zero (see Theorem 2 in Section 4). Hence if a household's behaviour can be explained by a short memory habits model then it has to be explainable by a longer memory model too since the longer model involves the relaxation of an already-satisfied constraint.

[12] Auld and Grootendorst (2004).

[13] Olekalns and Bardsley (1996).

[14] Cameron (1999).

[15] Iannaccone (1990).

The results in the first three columns in Table 3 again recap those shown in Table 1. The final column shows the degree of rationalisability between the data and a short memory habits model in which all goods are allowed to be habit forming (note too that intertemporal complementarities can exits between different commodity goods). Once again, the number of observations involved in the test of each model is the same. Allowing for one-period habits in goods other than tobacco increases the rationalisability of behaviour as expected but now over 98% of the data are theory consistent. Finally, if one allows for two period lags in tobacco consumption (which Table 2 seemed to indicate is a good idea) and single period lags in all other goods one finds 99.87% agreement between the data and theory. That is to say all of the data except for those relating to three households are perfectly rationalisable with the habits model.

4 Conclusions

Gorman (1967) claimed that "It is commonplace that choices depend on tastes and tastes on past choices" and since then habits model have been shown, many times and in many contexts, to be useful in both macroeconomics and microeconomics. The literature suggests that habits models often fit the data well and provide insights into various economic issues which might otherwise prove resistant to straightforward explanation.

This paper has derived general empirical conditions for the habits model in the revealed preference tradition of Samuelson (1948), Houthakker (1950), Afriat (1967) and Browning (1989). This allows, for the first time, an assessment of habits models which is nonparametric and therefore free from the confounding effects of a choice of functional form. The conditions in the paper are shown to be computationally straightforward and to yield set identification results for certain features of the model.

The ideas outlined have been applied to a microeconomic panel dataset. It appears that, in contrast to the results for aggregate data found by Browning (1989), the strong rational expectations version of the life-cycle model is heavily rejected. However, the addition of habit formation to the discounted utility model was shown to improve the rationalisability of the microdata considerably - virtually to the point where one hundred percent of the data are perfectly rationalisable if one allows intertemporal complementarities for many goods. Even when habit-formation is rejected it was shown that rather modest and plausible allowance for heterogeneity in prices and interest rates was sufficient to bring consumption behaviour in line with the theory. Theory-consistent discount rates and welfare measures revealed by the data were presented. Overall, it appears that habits models are capable of providing an extremely powerful explanation of longitudinal household behaviour.

Appendix

A. Proofs

Proof of Theorem 1.

$(T) \Rightarrow (R)$: Definition 1 and the definitions of the shadow discounted prices in (1) and (2) imply (4) which is restriction (R2). Together they imply

$$\mathbf{D}u(\mathbf{x}_t)' = \lambda \boldsymbol{\pi}_t' \tag{P1}$$

where $\boldsymbol{\pi}_t = 1/\left(\beta^{t-1}\right)\left[\boldsymbol{\rho}_t^{c\prime}, \boldsymbol{\rho}_t^{a,0\prime}, \boldsymbol{\rho}_t^{a,1\prime}\right]$ and $\mathbf{x}_t = \left[\mathbf{q}_t^{c\prime}, \mathbf{q}_t^{a\prime}, \mathbf{q}_{t-1}^{a\prime}\right]'$. The concavity of the instantaneous utility function $u(\mathbf{x}_t)$ means

$$u(\mathbf{x}_s) - u(\mathbf{x}_t) \leq +\mathbf{D}u(\mathbf{x}_t)'(\mathbf{x}_s - \mathbf{x}_t) \qquad \forall\ t, s \in \tau \tag{P2}$$

Therefore concavity (P2) and optimising behaviour (P1) together imply that

$$u(\mathbf{x}_s) \leq u(\mathbf{x}_t) + \lambda \boldsymbol{\pi}_t'(\mathbf{x}_s - \mathbf{x}_t) \qquad \forall\ t, s \in \tau \tag{P3}$$

Now consider *any* subset of observations from τ and denote this subset by σ. Then summing across all observations within the subset gives

$$0 \leq \sum_{\forall s,t\ \in \sigma} \boldsymbol{\pi}_s'(\mathbf{x}_t - \mathbf{x}_s) \qquad \forall \sigma \subseteq \tau \tag{P4}$$

which is restriction (R1).

$(R) \Rightarrow (T)$: Restriction (R1) is a cyclical monotonicity condition (Rockafellar, 1970, Theorem 24.8). Cyclical monotonicity for the data $\{\boldsymbol{\pi}_t, \mathbf{x}_t\}_{t\in\tau}$ and the definition of $\boldsymbol{\pi}_t$ implies that there exists a concave, strictly increasing (utility) function $u(.)$ and positive constant λ such that

$$\mathbf{D}_{\mathbf{q}_t^c} u\left(\mathbf{q}_t^c, \mathbf{q}_t^a, \mathbf{q}_{t-1}^a\right) = \lambda \frac{1}{\beta^{t-1}} \boldsymbol{\rho}_t^c \tag{P5}$$

$$\mathbf{D}_{\mathbf{q}_t^a} u\left(\mathbf{q}_t^c, \mathbf{q}_t^a, \mathbf{q}_{t-1}^a\right) = \lambda \frac{1}{\beta^{t-1}} \boldsymbol{\rho}_t^{a,0} \tag{P6}$$

$$\mathbf{D}_{\mathbf{q}_{t-1}^a} u\left(\mathbf{q}_t^c, \mathbf{q}_t^a, \mathbf{q}_{t-1}^a\right) = \lambda \frac{1}{\beta^{t-1}} \boldsymbol{\rho}_t^{a,1} \tag{P7}$$

for all $t \in \tau$. Combining (P7) and restriction (R2) gives

$$\frac{1}{\lambda}\beta^{t-1}\mathbf{D}_{\mathbf{q}_{t-1}^a} u\left(\mathbf{q}_t^c, \mathbf{q}_t^a, \mathbf{q}_{t-1}^a\right) = \boldsymbol{\rho}_{t-1}^a - \boldsymbol{\rho}_{t-1}^{a,0} \tag{P8}$$

Backdating (P6) (which must hold for all t) substitute for $\boldsymbol{\rho}_{t-1}^{a,0}$ to rewrite (P8) as

$$\beta^{t-2}\mathbf{D}_{\mathbf{q}_{t-1}^a} u\left(\mathbf{q}_{t-1}^c, \mathbf{q}_{t-1}^a, \mathbf{q}_{t-2}^a\right) + \beta^{t-1}\mathbf{D}_{\mathbf{q}_{t-1}^a} u\left(\mathbf{q}_t^c, \mathbf{q}_t^a, \mathbf{q}_{t-1}^a\right) = \lambda \boldsymbol{\rho}_{t-1}^a \tag{P9}$$

which can then be updated to show

$$\beta^{t-1}\mathbf{D}_{\mathbf{q}_t^a} u\left(\mathbf{q}_t^c, \mathbf{q}_t^a, \mathbf{q}_{t-1}^a\right) + \beta^{t}\mathbf{D}_{\mathbf{q}_t^a} u\left(\mathbf{q}_{t+1}^c, \mathbf{q}_{t+1}^a, \mathbf{q}_t^a\right) = \lambda \boldsymbol{\rho}_{t-1}^a \tag{P10}$$

■

Proof of Theorem 2. Consider, without loss of generality the test for the one-lag habits model. If $\boldsymbol{\rho}_t^{a,1} = 0$ for all $t \in \tau$ then, from (R2) in Proposition 1 $\boldsymbol{\rho}_t^{a} = \boldsymbol{\rho}_t^{a,0}$ for all $t \in \tau$. Therefore $\boldsymbol{\pi}_t = \frac{1}{\beta^{t-1}} \left[\boldsymbol{\rho}_t^{c\prime}, \boldsymbol{\rho}_t^{a\prime}, \mathbf{0}^{\prime}\right]^{\prime}$, where $\mathbf{0}$ is a vector of zeros of appropriate length, and $\mathbf{x}_t = \left[\mathbf{q}_t^{c\prime}, \mathbf{q}_t^{a\prime}, \mathbf{q}_{t-1}^{a\prime}\right]^{\prime}$ .Substituting into R(1) in Proposition 1 we have

$$0 \leq \sum_{\forall s,t\ \in \sigma} \frac{1}{\beta^{s-1}} \left[\boldsymbol{\rho}_s^{c\prime}, \boldsymbol{\rho}_s^{a\prime}, \mathbf{0}^{\prime}\right]^{\prime} \left(\left[\mathbf{q}_t^{c\prime}, \mathbf{q}_t^{a\prime}, \mathbf{q}_{t-1}^{a\prime}\right]_t^{\prime} - \left[\mathbf{q}_s^{c\prime}, \mathbf{q}_s^{a\prime}, \mathbf{q}_{s-1}^{a\prime}\right]^{\prime}\right) \qquad \forall \sigma \subseteq \tau$$

or equivalently

$$0 \leq \sum_{\forall s,t\ \in \sigma} \frac{1}{\beta^{s-1}} \boldsymbol{\rho}_s^{\prime} \left(\mathbf{q}_t - \mathbf{q}_s\right) \qquad \forall \sigma \subseteq \tau$$

which is condition for the life-cycle model in Browning (Definition 1 and Proposition 1, (1989)) extended to allow for $\beta \neq 1$.■

Proof of Corollary 1. This follows immediately from Theorem 2 and Browning ((1989), Proposition 2). This is because GARP is a condition under which the data are consistent with a model of stable preferences and weak intertemporal separability. The conditions for SREH are stronger: additively time-separable and stable preferences.■

The R-lag habits model

Definition R. The time series of the interest rate, prices and quantities $\{i_t, \boldsymbol{\rho}_t^c, \boldsymbol{\rho}_t^a; \mathbf{q}_t^c, \mathbf{q}_t^a\}_{t=1,\dots,T}$ satisfies the R-lag habits model if there exists a concave, strictly increasing (utility) function $u\left(.\right)$ and positive constants λ and β such that

$$\beta^{t-1} \mathbf{D}_{\mathbf{q}_t^c} u\left(\mathbf{q}_t^c, \mathbf{q}_t^a, \mathbf{q}_{t-1}^a, \dots, \mathbf{q}_{t-R}^a\right) = \lambda \boldsymbol{\rho}_t^c$$

$$\beta^{t-1} \mathbf{D}_{\mathbf{q}_t^a} u\left(\mathbf{q}_t^c, \mathbf{q}_t^a, \mathbf{q}_{t-1}^a, \dots, \mathbf{q}_{t-R}^a\right) + \sum_{r=1}^{R} \beta^{k-1} \mathbf{D}_{\mathbf{q}_t^a} u\left(\mathbf{q}_k^c, \mathbf{q}_k^a, \mathbf{q}_{k-1}^a, \dots, \mathbf{q}_{k-R}^a\right) = \lambda \boldsymbol{\rho}_t^a$$

where $k \equiv t + r$ for all $t \in \{R+1, \dots., T\}$

Theorem R. The following statements are equivalent:
(T) The time series of the interest rate, prices and quantities $\{i_t, \boldsymbol{\rho}_t^c, \boldsymbol{\rho}_t^a; \mathbf{q}_t^c, \mathbf{q}_t^a\}_{t=\tau}$ satisfies the R-lag model.
(R) There exist shadow prices $\{\boldsymbol{\rho}_t^{a,r}\}_{t\in\tau}^{r=0,\dots,R}$ and a positive constant β such that

$$0 \quad \leq \quad \sum_{\forall s,t\ \in \sigma} \boldsymbol{\pi}_s^{\prime} \left(\mathbf{x}_t - \mathbf{x}_s\right) \qquad \forall \sigma \subseteq \tau \tag{R1}$$

$$0 \quad = \quad \boldsymbol{\rho}_{t-R}^a - \sum_{i=0}^{R} \boldsymbol{\rho}_{t-i}^{a,R-i} \quad \forall \quad t \in \tau \tag{R2}$$

where $\mathbf{x}_t = \left[\mathbf{q}_t^{c\prime}, \mathbf{q}_t^{a\prime}, \mathbf{q}_{t-1}^{a\prime}, \dots, , \mathbf{q}_{t-R}^{a\prime}\right]^{\prime}$ and $\boldsymbol{\pi}_t = \frac{1}{\beta^{t-1}} \left[\boldsymbol{\rho}_t^{c\prime}, \boldsymbol{\rho}_t^{a,0\prime}, \boldsymbol{\rho}_t^{a,1\prime}, \dots, \boldsymbol{\rho}_t^{a,R\prime}\right]^{\prime}$ and $t \in \{R+1, \dots., T\}$.

Proof of Theorem R. The proof is analogous toTheorem 1 by induction on R.■

B. Variable definitions

The commoditiy groups are as follows: Food and non-alcoholic drinks at home; Alcohol; Tobacco; Energy at home (heating by electricity); Services at home (heating not electricity, water, furniture repair); Non-durables at home (cleaning products); Nondurable medicines; Medical services; Transportation; Petrol; Leisure (cinema, theatre, clubs for sports); Personal services; Personal non-durables (toothpaste, soap); Restaurants and bars.

References

[1] Abel, A. (1990), "Asset prices under habit formation and catching up with the Jones." *American Economic Review*, 80, 38-42.

[2] Auld, M. C. and P. Grootendorst, (2004) "An empirical analysis of milk addiction" *Journal of Health Economics* 23(6), 1117-1133

[3] Afriat, S.N. (1967),"The construction of a utility function from expenditure data", *International Economic Review,* 8, 76-77.

[4] Baltagi, B. H. and J. M. Griffin (2002) "Rational addiction to alcohol: panel data analysis of liquor consumption" *Health Economics,* 11(6), 485-491

[5] YR: 2002

[6] Becker, G. and K. M. Murphy. (1988), "A theory of rational addiction." *Journal of Political Economy*, 96:4, 675-701.

[7] Becker, G. M. Grossman and K. Murphy, (1994), "An empirical analysis of cigarette addiction" American Economic Review, 84(3) 396-418.

[8] Bewley, S. (1977), "The permanent income hypothesis: A theoretical formulation", *Journal of Economic Theory*, 16, 252-292

[9] Böhm-Bawerk, E. von. (1889), *Capital and interest.* South Holland: Libertarian Press.

[10] Boldrin, M., L. Christiano, and J. Fisher. (2001), "Habit persistence, asset returns, and the business cycle." *American Economic Review*, 91, pp. 149-66.

[11] Browning, M. (1989), "A nonparametric test of the life-cycle rational expections hypothesis" *International Economic Review*, 30(4), 979-992

[12] Browning M. and M. D. Collado, (2001) "The response of expenditures to anticipated income changes: panel data estimates," *American Economic Review*, 91(3), 681-692.

[13] Browning M. and M. D. Collado, (2004). "Habits and heterogeneity in demands: a panel data analysis," CAM Working Papers 2004-18, University of Copenhagen.

[14] Cameron S.(1999), "Rational addiction and the demand for cinema" *Applied Economics Letters*, 6(9), 617-620

[15] Campbell, J. and J. Cochrane. (1999), "By force of habit: A consumption-based explanation of aggregate stock market behavior" *Journal of Political Economy*, 107, 205-51.

[16] Carrasco R., J-M. Labeaga and J. López-Salido, (2005), "Consumption and habits: Evidence from panel data," *Economic Journal*, 115(500), 144-165.

[17] Carroll, C, J. Overland, and D. Weil (2000), "Saving and growth with habit formation." *American Economic Review*, 90, 341-55.

[18] Chaloupka, F., (1991). "Rational addictive behavior and cigarette smoking". *Journal of Political Economy* 99, 722-742.

[19] Constantinides, G. (1990), "Habit formation: A resolution of the equity premium puzzle." *Journal of Political Economy*, 98:3, 519-43.

[20] Duesenberry, J. (1952), *Income, saving, and the theory of consumer behavior*. Cambridge, MA: Harvard University Press.

[21] Diewert, W.E. (1973), “Afriat and revealed preference theory”, *Review of Economic Studies*, 40, 419-426.

[22] Fisher, I. (1930). *The Theory of Interest.* New York: MacMillan.

[23] Fuhrer, J. (2000), “Habit formation in consumption and its implications for monetray-policy models.” *American Economic Review*, 90, 367-90.

[24] Gorman, W.M. (1967) “Tastes, Habits and Choices", *International Economic Review*, 8(2), 218-222

[25] Griffith, R. and A. Leicester (2006), “Do the poor pay more: evidence from the UK”, *Institute for Fiscal Studies*, mimeo.

[26] Hall, R. (1978), Stochastic Implications of the Life Cycle - Permanent Income Hypothesis: Theory and Evidence”, *Journal of Political Economy*, 86, 971-987.

[27] Houthakker, H. S. (1950), “Revealed preference and the utility function”, *Economica*, May, 159-174.

[28] Iannaccone , L. R. (1990), “Religious Practice: A Human Capital Approach” *Journal for the Scientific Study of Religion*, 29(3), 297-314.

[29] Jermann, U. (1998), “Asset pricing in production economies.” *Journal of Monetary Economics*, 41, 257-75.

[30] Koopmans, T. C. (1960), “Stationary ordinal utility and impatience”. *Econometrica*, 28, 287-309.

[31] Kubler, F, (2004), “Is intertemporal choice theory testable?” *Journal of Mathematical Economics* 40, 177-189

[32] Labeaga, J-M, (1999), “A double-hurdle rational addiction model with heterogeneity: Estimating the demand for tobacco” *Journal of Econometrics* 93 49-72

[33] Meghir, C. and G. Weber, (1996), “Intertemporal Nonseparability or Borrowing Restrictions? A Disaggregate Analysis Using a U.S. Consumption Panel,” *Econometrica,* 64(5), 1151-1181.

[34] Neary, J. P. and K. Roberts (1980), “The theory of household behaviour under rationing” *European Economic Review*, 13, 25-42.

[35] Olekalns, N and P. Bardsley (1996), “Rational Addiction to Caffeine: An Analysis of Coffee Consumption” *Journal of Political Economy*, 104(5),1100-1104.

[36] Pollak, R. (1970), “Habit formation and dynamic demand functions.” *Journal of Political Economy*, 78:4, 745-63.

[37] Rae, J. (1834), *The Sociological Theory of Capital* (reprint of original 1834 edition). London:Macmillan.

[38] Ryder, H. and G. Heal. (1973), “Optimal growth with intertemporally dependent preferences.” *Review of Economic Studies*, 40, 1-33.

[39] Samuelson, P. (1937), “A note on measurement of utility”, *Review of Economic Studies*, 4, pp.155-61.

[40] Samuelson, P. (1952), “Probability, utility, and the independence axiom”. *Econometrica*, 20:4, 670-78.

[41] Samuelson, P. (1948), "Consumption theory in terms of revealed preference", *Economica*, November, 243-253.

[42] Spinnewyn, Frans (1981), "Rational habit formation", *European Economic Review*, 15, 91-109.

[43] Varian, H. (1982), "The nonparametric approach to demand analysis", *Econometrica*, 50, 945-973.

[44] Varian, H. (1990), "Goodness-of-fit in optimizing models," *Journal of Econometrics*, 46(1-2), 125-140