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AGE EFFECTS ON CONSUMER DEMAND: AN ADDITIVE PARTIALLY LINEAR REGRESSION MODEL

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Age effects on Consumer Demand: An Additive Partially Linear Regression Model

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Abstract

An additive partially linear regression model is used to estimate nonparametrically the effects of total expenditure and age in the context of Engel curves and investigate the specification and welfare interpretation of the age effects in parametric models of consumer behavior. Empirical analysis based on data drawn from the UK Family Expenditure Survey shows that modelling of the effects of age requires a more sophisticated approach than that generally adopted in parametric demand analysis. It also shows that failing to adequately capture these effects can have misleading welfare implications.

JEL Classification: C14, D12

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1 Introduction

The bene…ts of using nonparametric methods in empirical demand analysis have been recently highlighted by Blundell and Duncan (1997), Gozalo (1997), Donald (1997), Pendakur (1999) and Lyssiotou, Pashardes and Stengos (1999) among others. These studies are mostly concerned with …nding appropriate ways of modelling the e¤ect of expenditure on consumer demand. In this paper we concentrate mainly on the age e¤ects and our approach also di¤ers from previous empirical investigations insofar as we use an additive Partially Linear Regression model to do so.

The additive PLR model can be seen as a way of tackling the ‘curse of dimensionality’ problem, one of the most important weaknesses of nonparametric estimation methods. In recent papers Linton and Nielsen (1995), Fan, Härdle and Mammen (1996) and Fan and Li (1996) all employ marginal integration as a way of obtaining estimates of the components of the additive regression model. Linton and Nielsen’s (1995) paper deals with a simple additive model with two components, whereas Fan, Härdle and Mammen (1996) and Fan and Li (1996) extend the regression function to allow for a more general partially linear formulation. In this paper we follow the treatment of Fan and Li (1996) that results in estimates with better …nite sample properties.

The nonparametric investigation of how expenditure and age a¤ect consumer demands is important because these two variables are generally found to have pronounced e¤ects on consumer behavior (Blundell, Pashardes and Weber 1993 and Gozalo 1997). Furthermore, expenditure and age are continuous variables and their parameterization can be associated with a wider margin of misspeci…cation error than other variables entering demand systems as dummies. The importance of using an additive PLR model relates to the fact that in the context of this model the expenditure and age e¤ects on consumer can both be investigated nonparametrically at the same time. This can improve efficiency and reduce the risk of obtaining misleading conclusions about the effects of one of these variables because the effects of the other are misspecified.

We investigate empirically the points raised above using individual household data drawn from the UK Family Expenditure Survey and use the results obtained from nonparametric analysis to examine the modelling of age and expenditure effects in a parametric system of Engel curves. Furthermore, we examine the welfare implications of alternative parameterization of the age effects using the concept of the relative equivalence scale, defined as the ratio of the true cost of living indices of two households with different demographic characteristics (Blundell and Lewbel 1991). Generally this scale is used for calculating differences in the effects of inflation on the cost of living of households with and without children (e.g. Dickens, Fry and Pashardes 1993). In this paper we use the relative equivalence scale to compare the effects of inflation on the cost of living of households with differences in the age of head.

The structure of the paper is as follows. Section 2 describes the additive PLR model and reports empirical results obtained from its application to individual household to data. Section 3 investigates the implications of the nonparametric results for the parametric specification and welfare interpretation of age effects in a system of Engel curves. Section 4 concludes the paper.

2 An additive partially linear regression model

Consider the following additive PLR model with two regressors:

$$w_i = \alpha + g_1(X_{1i}) + g_2(X_{2i}) + u_i, \quad i = 1, \ldots, n; \tag{1}$$

where $\{w_i, X_{1i}, X_{2i}\}_{i=1}^{n}$ are independently and identically distributed (i.i.d.) random variables, $E(u_i | X_{1i}, X_{2i}) = 0$; α is an unknown parameter, $g_1(\cdot)$ and $g_2(\cdot)$ are unknown univariate functions that obey the identifiability condition that $E(g_1(X_1)) = 0$ and $E(g_2(X_2)) = 0.$

As shown by Stone (1985, 1986) the additive components $g_s(.)$ $(s = 1, 2)$ in (1) can be consistently estimated at the same rate as a fully nonparametric regression with only one regressor. This can be done by employing marginal integration as in Linton and Nielsen (1995), Fan, Härdle and Mammen (1996) and Fan and Li (1996). In this paper we follow the treatment of Fan and Li (1996) that results in estimates with better finite sample properties. The idea behind marginal integration in the context of equation (1) can be described as follows.

Let $E(w|X_1 = x_1, X_2 = x_2) = a(x_1, x_2).$ One can estimate $a(x_1, x_2)$ by a nonparametric local smoother, say $\hat{a}(x_1, x_2)$, and then obtain an estimator of $\{g_1(x_1) + \alpha\}$ by integrating $\hat{a}(x_1, x_2)$ over z_2, i.e., $\tilde{m}_1(x_1) = n^{-1}\sum_{j=1}^{n}\hat{a}(x_1, X_{2j}).$ Since $E(g_1(X_1)) = 0,$ we can obtain the estimator of $g_1(x_1)$ by subtracting the sample mean of $\tilde{m}_1(.)$ from $\tilde{m}_1(x_1)$, i.e. $\hat{g}_1(x_1) = \tilde{m}_1(x_1) - n^{-1}\sum_{i=1}^{n}\tilde{m}_1(X_{1i}).$ Similarly, we can obtain an estimator for $g_2(x_2).$

Equation (1) can be extended to allow for an additive linear component. In that case we have

$$w_i = \alpha + Z_i^T\beta + g_1(X_{1i}) + g_2(X_{2i}) + u_i, \quad i = 1, ..., n, \tag{2}$$

where Z_i is a variable (discrete or continuous) of dimension q, β is a $q \times 1$ vector of parameters and α is a scalar parameter as before. We can obtain a $\sqrt{n}-$consistent estimator of β using Robinson's (1988) approach. Let us denote such an estimator by $\hat{\beta}.$ Equation (2) can be then written as

$$w_i - Z_i^T\hat{\beta} = \alpha + g_1(X_{1i}) + g_2(X_{2i}) + u_i + Z_i^T(\beta - \hat{\beta}), \quad i = 1, ..., n, \tag{3}$$

where $u_i, + Z_i^T(\beta - \hat{\beta})$ is the new composite error term. In a similar fashion as with equation (1) we can apply marginal integration to equation (2) to obtain estimates of $g_1(x_1)$ and $g_2(x_2).$

We estimate the above model for a system of Engel curves consisting of six categories of non-durable commodities: food, alcohol, fuel, clothing, other goods and services.[1]. The data used are drawn from the 1980 UK Family Expenditure Survey (FES) and include two-adult households whose head is under retirement age and not self-employed. For the nonparametric analysis in this section a random sample consisting of 427 observations is selected from these data.

Introducing the subscript h to denote households, the dependant variable w_{ih} is de…ned as the share of the i^{th} good in the budget of the h^{th} household whereas, the regressors X_{1h} and X_{2h} are de…ned as the age of household head and the logarithm of the household budget, the two continuous variables normally included in demand systems estimated from individual household data. The vector Z_h is de…ned to include a large number of dummy variables re‡ecting family composition, sex, employment and economic position of members, housing tenure and other household characteristics found elsewhere to have a signi…cant e¤ect on consumer behavior by studies using UK FES data (Blundell et. al. 1993).[2]

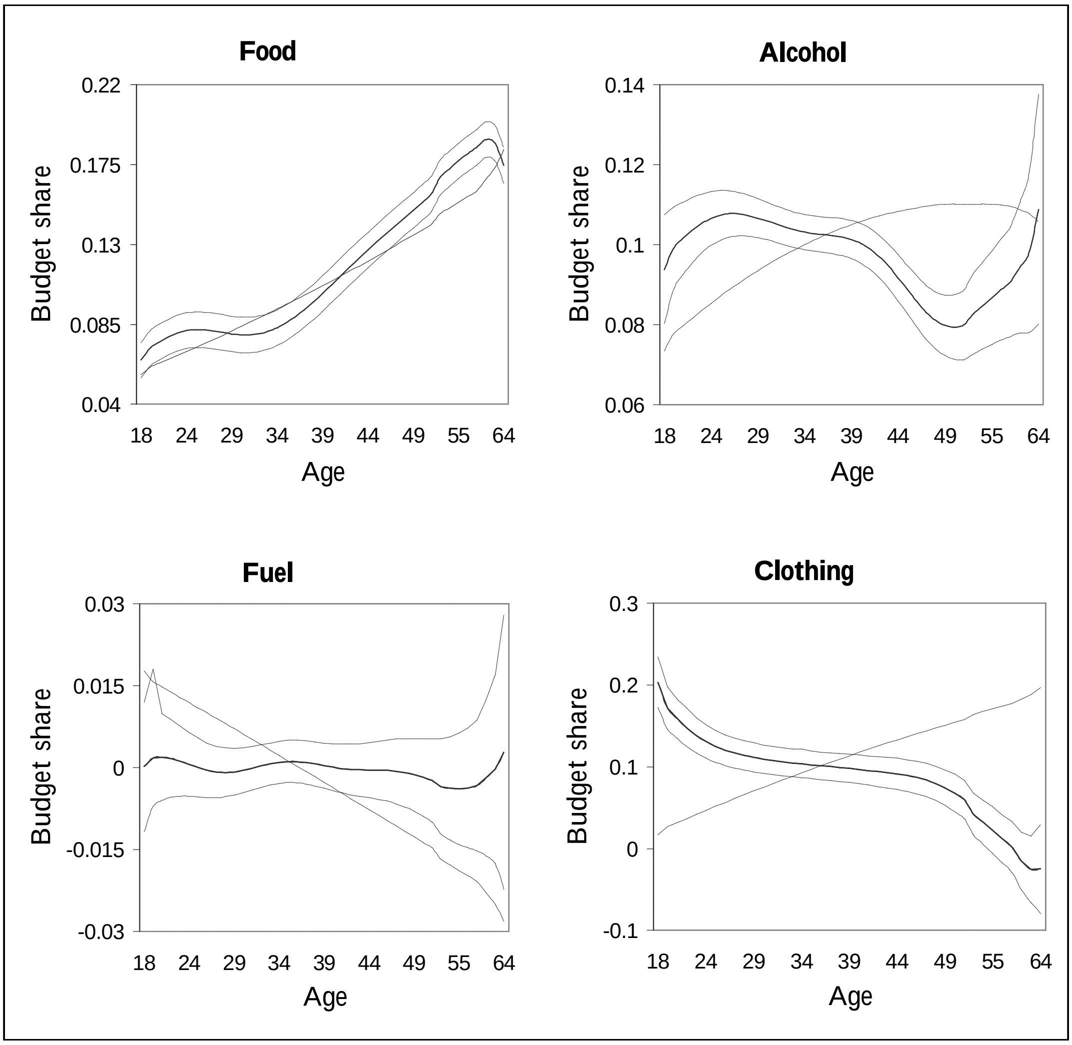
In the diagrams of Figure 1 the heavy continuous line shows the estimated age e¤ect on the budget shares of food, alcohol, fuel and clothing obtained from the additive PLR model (3). The light line shows the age e¤ect obtained from a semiparametric estimation where the logarithm of expenditure enters the budget shares nonparametrically, whereas age and other household characteristics enter parametrically. This semiparametric speci…cation includes age and age square as explanatory variables as in other empirical studies mentioned above. Also in the diagrams of Figure 1 we report the 95% con…dence band (light discontinuous lines) corresponding to the nonparametric

[1] The assumption concerning durable goods is that they act as conditioning variables and this is modelled by including dummies for housing tenure, the size and value of the house, car ownership, the presence of smokers in the household etc. in the vector of household characteristics.

[2] To capture possible interactions between the age of household head and the logarithm of household budget we have also included the product of these two variables among the Z vector. This product term was found to be signi…cant.

estimates obtained from the additive PLR model.[3]

Figure 1: Nonparametric age effects



The difference between the age effects estimated from the additive PLR model and those estimated from the semiparametric model is striking. In three out of four goods presented in Figure 1 (alcohol, fuel and clothing) the Engel curves obtained from the two models go mostly in different directions so that the parametric estimates are within the 95% confidence band of the nonparametric ones only where the lines estimated from

[3] The smoothing parameters in the graphs were chosen as $c s_{x_i} n^{-1/5}$, where s_{x_i} is the estimate of the standard deviation of X_i, $i = 1, 2$. The choice of c was done by cross-validation in a range between 0.5 and 2.

the two models intersect! The most pronounced difference occurs in the case of clothing where the nonparametric results suggest that age has a negative effect on the budget share globally, whereas the parametric results suggest exactly the opposite. Even in the case of food where the differences between the two models are not so pronounced, the parametric results are outside the 95% confidence band of the nonparametric estimates over a wide range of age variation (i.e. households with head between 20-25 and 45-60 years old).

3 Age effects in parametric demand analysis

In this section we investigate the modelling of age effects in a parametric system of Engel curves in the light of the nonparametric results of the previous section. More specifically, the same categories of non-durable goods estimated nonparametrically in the previous section are estimated parametrically using the system of Engel curves

$$w_{ih} = \alpha_i + \sum_k \beta_{ik} Z_{hk} + \sum_s \left(\theta_{is} + \sum_j \gamma_{ijs} D_{jh} \right) X_{1h}^s + \sum_r \lambda_{ir} X_{2h}^r \qquad (4)$$

where the variables Z_{hk}, X_{1h} and X_{2h} are as defined in the previous section.

The choice of (4) reflects the fact that it is sufficiently general to cover many of the popular Engel curves and demand systems estimated with individual household data, e.g. those of Working (1943), Deaton and Muellbauer (1980) and subsequent generalizations such as Blundell et. al. (1993) and Banks et al (1997). Moreover it can allow for the rather complex nonlinear age effects on the budget shares, suggested by the results obtained from the additive PLR model in the previous section. More specifically, (4) can accommodate (i) a polynomial form, $\Sigma_s \theta_{is} X_{1h}^s$; to capture higher order age effects and (ii) a dummy variable form, $\Sigma_s \Sigma_j \gamma_{ijs} D_{jh} X_{1h}^s$; to capture age effects peculiar to certain household groups.

Following initial investigation we found that the Quadratic Logarithmic version of

(4), i.e. $r = 2$; with up to cubic age effects, $s = 3$; and dummies to capture the behavior of households with heads under 30 was sufficiently general to explain the age and log expenditure effects on the budget shares in our sample.[4] In terms of the logarithmic expenditure effects, this result is in agreement with the findings of most previous empirical studies in the literature, Lewbel (1991), Blundell et al (1993), Pashardes (1995), Banks et al (1997) and Lyssiotou et al (1999) among others. This, however, is not true for the age effects in the sense that we find no empirical evidence in support of the hypothesis that these effects are linear and quadratic, as reported in the aforementioned studies.

This point is illustrated empirically by estimating the system of Engel curves

$$w_{ih} = \alpha_i + \sum_k \beta_{ik} z_{hk} + \sum_{s=1} \left(\theta_{is} + \mu_{is} D_{<30}\right) x_{1h}^s + \sum_{r=1} \lambda_{ir} x_{2h}^r; \qquad (5)$$

where $D_{<30} = 1$ for households with head under 30 and $D_{<30} = 0$ otherwise. As in the previous sections six categories of non-durable commodities are considered (food, alcohol, fuel, clothing, other goods and services) and the data are drawn from the 1980 UK FES.[5]

The first pair of columns in Table 1, under the heading 'full', shows parameter estimates and t-ratios obtained from the estimation of (5) without any restrictions on the age effects. The second pair of columns in Table 1, under the heading 'quadratic', shows parameter estimates and t-ratios obtained from (5) subject to the restrictions that there are no cubic age effects ($\theta_{i3} = 0$; all i) and no dummy effects for households with head under 30 ($\mu_{is} = 0$; all i and s). As shown by in the last line of the second pair of columns in Table 1 this hypothesis implies 15 parameter restrictions and reduces

[4] The Quadratic Logarithmic demand system (Lewbel 1991) itself comes from a general demand system of the form, $w_{ih} = \sum_{r=1}^{R} \lambda_{ri}(p; z_h) F_r[y_h - a(p; z_h)]$; the rank of which equals the rank of the n by R matrix of elements λ_{ri}. Lewbel (1989) proved that utility maximization requires that the rank of demand systems in this form must be less than or equal to four and Gorman (1981) proved that when $F_r(\cdot) = \cdot^{r-1}$, utility maximization requires that the rank of (4) must be less or equal to three, with $\lambda_{4i} = \kappa \lambda_{3i}$ for some scalar κ.

[5] The observations used for the estimation of (5) correspond to households with two-adults and a head under retirement age and not self-employed, a total of 2770 observations.

the 2 Log-Likelihood (2LL) statistic by 154. Therefore, it fails decisively the Â^2-test at the 5 signi…cance level.

Table 1: Parameter estimates for the age effects

Age effect		Empirical specification							
		Full		Quadratic		Cubic		Dummies	
		Param.	t-ratio	Param.	t-ratio	Param.	t-ratio	Param.	t- ratio
Linear	Food	-0.0771	-0.6	0.0406	2.7	-0.1495	-2.2	0.0902	4.2
	Alcohol	-0.0078	-0.1	-0.0224	-2.0	0.0220	0.4	-0.0293	-2.2
	Fuel	-0.0094	-0.1	0.0103	1.2	0.0216	0.6	0.0029	0.3
	Clothing	-0.0112	-0.1	-0.0454	-2.9	-0.1369	-1.9	-0.0280	-1.2
	Other	-0.2667	-2.3	0.0040	0.3	0.0643	1.1	-0.0365	-2.0
Quadratic	Food	0.0303	1.0	-0.0025	-1.4	0.0452	2.8	-0.0077	-3.2
	Alcohol	-0.0034	-0.2	0.0013	1.0	-0.0099	-0.8	0.0020	1.3
	Fuel	0.0033	0.2	-0.0006	-0.6	-0.0033	-0.4	0.0002	0.2
	Clothing	-0.0016	-0.1	0.0041	2.2	0.0268	1.5	0.0022	0.9
	Other	0.0552	2.1	-0.0012	-0.8	-0.0163	-1.2	0.0030	1.5
Cubic	Food	-0.0028	-1.2	-		-0.0038	-2.9	-	
	Alcohol	0.0004	0.3	-		0.0009	0.9	-	
	Fuel	-0.0002	-0.2	-		0.0002	0.3	-	
	Clothing	0.0003	0.1	-		-0.0018	-1.3	-	
	Other	-0.0038	-2.0	-		0.0012	1.1	-	
Linear dummies	Food	0.0085	0.2	-		-		0.0527	2.0
	Alcohol	-0.0100	-0.5	-		-		-0.0100	-0.9
	Fuel	-0.0100	-0.5	-		-		-0.0100	-0.9
	Clothing	0.0645	1.4	-		-		0.0587	2.1
	Other	-0.1086	-2.9	-		-		-0.0486	-2.2
Quadratic dummies	Food	-0.0010	-0.1	-		-		-0.0163	-1.7
	Alcohol	0.0034	0.5	-		-		0.0034	0.8
	Fuel	0.0034	0.5	-		-		0.0034	0.8
	Clothing	-0.0245	-1.5	-		-		-0.0225	-2.2
	Other	0.0365	2.7	-		-		0.0157	1.9
Test statistics:									
Root MSE	Food	0.09817		0.09834		0.09820		0.09819	
	Alcohol	0.07598		0.07597		0.07595		0.07598	
	Fuel	0.05665		0.05663		0.05663		0.05666	
	Clothing	0.10446		0.10454		0.10452		0.10445	
	Other	0.08386		0.08401		0.08399		0.08390	
	Services	0.10838		0.10843		0.10838		0.10844	
2LL drop (restrictions)		-		154 (15)		20 (10)		12 (5)	

Next we investigate the question whether one needs to augment the 'quadratic' model to include cubic age effects and effects for households with head under 30 or adding just one of these two types of effects is sufficient. To answer this question we impose on (4) the corresponding restrictions (i) $\theta_{i3} = 0$; all i; and (ii) $\mu_{is} = 0$; all i and s, separately. The parameter estimates and standard errors obtained from these restrictions are reported in the third and fourth pair of columns in Table 1 (under the heading 'cubic' and 'dummies', respectively) with the reduction in the 2LL statistic appearing in the last line. On the basis of the χ^2-test none of the two sets of restrictions can be rejected at the 5 significance level. Therefore, the data used in our empirical analysis suggest that either a model with up to cubic age effects or a model with up to quadratic age effects and dummies to capture the behavior of households with head under 30 is an adequate empirical specification of the age effects on consumer demands.

In the remainder of this section we illustrate how welfare measures derived from observed consumer behavior can be affected by the alternative parameterization of the age effects defined by the 'full', 'quadratic', 'cubic' and 'dummies' models defined above. The welfare measure chosen for this illustration is the relative equivalence scale comparing the effects of a price change on the cost of living of households. Here we define this scale for a price change from P_0 to P_t and the cost of living comparison is between households in different age groups. Using the subscript o to denote households in the reference age category, the relative equivalence scale is

$$R_{ho}(P_t; P_0) = \frac{C(P_t; Z_h; X_{1h}; U_h) / C(P_0; Z_h; X_{1h}; U_h)}{C(P_t; Z_h; X_{1o}; U_o) / C(P_0; Z_h; X_{1o}; U_o)}; \qquad (6)$$

where $C(P_\ell; Z_h; X_{1m}; U_m)$ represents the cost of reaching the utility level U_m at prices P_ℓ by a household with head aged X_{1m}; for $\ell = 1; 0$ and $m = h; o$:

Under the Quadratic Logarithmic model the cost function has the form

$$\ln C(P_\ell; Z_m; U_m) = \beta(P_\ell; Z_m; X_{1m}) + \frac{\lambda_1(P_\ell) U_h}{1 - \lambda_2(P_\ell) U_h}; \qquad (7)$$

where the $\beta(P_\ell; Z_m; X_{1m})$; $\lambda_1(P_\ell)$ and $\lambda_2(P_\ell)$ functions are homogeneous in prices. We assume that at base period prices there is a compensation for age differences between households types are such that $U_h = U_o$. The logarithm of the relative equivalence scale showing the compensation for inflation required so as to maintain this utility parity in the new price regime is

$$\ln R_{ho} = [\beta(P_t, Z_h, X_{1h}) - \beta(P_t, Z_o, X_{1o})] + [\beta(P_0, Z_o, X_{1o}) - \beta(P_0, Z_h, X_{1h})] \qquad (8)$$

Assuming that $\beta(P_\ell, Z_m, X_{1m})$ has the usual translog form

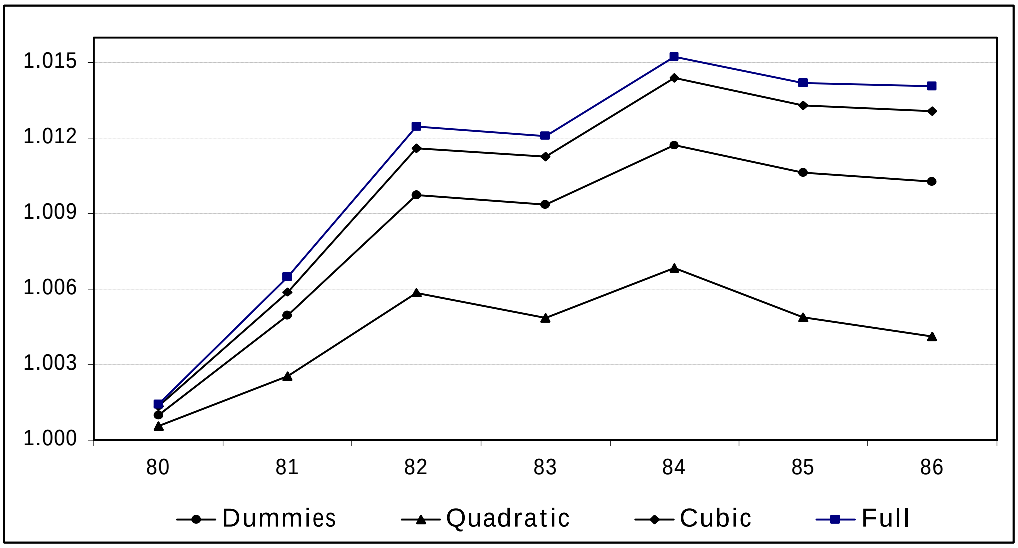
$$\beta_0 + \sum_i \left[\alpha_i + \sum_k \beta_{ik} Z_{hk} + \sum_{s=1} (\theta_{is} + \mu_{is} D_{<30}) X_{1h}^s + \sum_n \gamma_{in} \ln P_{\ell n} \right] \ln P_{i\ell}$$

and setting $P_{0i} = 0$ for the base period (6) can also be written as

$$\ln R_{ho} = \sum_i \left[\sum_k \beta_{ik} (Z_{hk} - Z_{ok}) + \sum_{s=1} (\theta_{is} + \mu_{is} D_{<30}) (X_{1h}^s - X_{1o}^s) \right] \ln P_{it}. \qquad (9)$$

The diagram of Figure 2 reports the relative equivalence scales calculated with (8) using the parameter estimates obtained from the alternative parameterization of the age effects described above. The relative equivalence scales obtained from using the parameter estimates of the 'full' model suggest that in the UK over the period 1980-86 households with head over 50 experienced a cost of living increase of 1.4% above the cost of living increase experienced by households with head under 30. This figure for the 'quadratic' model was only 0.4%, whereas for the 'dummies' and 'cubic' models 1.0% and 1.3%, respectively.

Figure 2: Relative equivalence scales for age differences



4 Conclusion

This paper investigates the effect of age and expenditure on consumer demand using an additive partially linear regression model where the effects of both these variables are estimated nonparametrically. Empirical results obtained from the application of this model to UK data suggest that age has more complicated effects than those generally assumed in empirical specifications of parametric demand systems. In particular, we have found that households with younger heads tend to behave differently than other households and this is not adequately captured in a demand system where only linear and quadratic age effects are included in the empirical specification. In the case of our sample an adequate empirical demand system requires either cubic age effects or dummies to capture differences in the behavior of households with head at the lower end of the age distribution.

The welfare implications of inadequately accounting for the age effects on consumer demand are illustrated using results obtained from alternative parameterization of these effects to compare differences in the cost of living increase between households over the period 1980-86. The results suggest that a system of Engel curves with only linear and quadratic age effects understates the impact of inflation on the cost of living of households with older head. This finding supports the inflation indexing of pensions and other old age benefits to a separate cost of living index reflecting the consumption costs of older consumers, a policy currently followed in the UK.

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