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NESTING QUADRATIC LOGARITHMIC DEMAND SYSTEMS

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Abstract

We propose a new generalised rank-3 demand system which nests all known (and new) rank-3 and rank-2 demand systems derived from the Quadratic Logarithmic (QL) cost function. We investigate its statistical adequacy against commonly encountered alternatives using U.K. household data.

JEL Classification: D1
Keywords: Quadratic Logarithmic demand systems, rank-3 demand systems, individual household data.

1 Introduction

Empirical studies suggest that popular flexible functional form demand systems, such as the Almost Ideal (AI) model of Deaton and Muellbauer (1980) and the Translog (TL) model of Christensen, Jorgenson and Lau (1975) may not be statistically adequate for empirical demand analysis based on individual household data. This is because they do not contain higher order expenditure terms to capture nonlinearities in the utility effects pertaining to these data which have been found by a number of parametric and nonparametric studies to be significant for certain expenditure share equations. For this reason investigators have recently been using rank-3 demand systems derived from the Quadratic Logarithmic (QL) cost function, which are quadratic functions of the logarithm of expenditure or income, such as the Quadratic Almost Ideal Demand System ($QUAIDS$) of Banks, Blundell and Lewbel (1997) and the Almost Ideal Quadratic

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Logarithmic (*AIQL*) model of Fry and Pashardes (1992). Alternative rank-3 Quadratic Expenditure Systems (*QES*), which are quadratic functions of expenditure or income, have also been proposed by Howe, Pollak and Wales (1979) and Ryan and Wales (1999). Recent theoretical and empirical work suggesting that the rank of the demand system need not be greater than three have rendered rank-3 systems popular tools for empirical demand analysis[1].

With regard to demand systems which are quadratic functions of the logarithm of expenditure or income the issue of appropriate functional form still remains open. To address this question we introduce the *Generalized Quadratic Logarithmic (GQL)*, which is itself a rank-3 demand system based on the *QL* cost function. The advantage of this generalized specification is that it nests all known rank-2 and rank-3 demand systems and therefore allows for nested hypothesis testing. Also, it allows for the choice of functional form for the prices entering the *QL* cost function. Section 2 of the paper describes the *GQL* demand system, while section 3 reports results obtained from its application to individual household data drawn from the U.K. Family Expenditure Survey and tests restrictions imposed by less general rank-3 systems.

2 The GQL demand system framework

Assume that consumer preferences are described by the *QL* cost function (Lewbel 1990),

$$lnC(u,p) = a(p) + \frac{b(p)}{u^{-1} - e(p)} \tag{1}$$

where p is a price vector and u a utility index. The functions $a(p)$, $b(p)$ and $e(p)$ are some homogeneous time and household specific price indices, where the time and household subscripts are dropped for convenience.

The Hicksian budget share equations corresponding to (1) are

$$w_i = a_i(p) + \frac{b_i(p)}{u^{-1} - e(p)} + \frac{e_i(p)b(p)}{\left[u^{-1} - e(p)\right]^2}, \tag{2}$$

where the subscript $i = 1, ..., n$ denotes goods and $a_i(p)$, $b_i(p)$ and $e_i(p)$ are the derivatives of the corresponding price indices with respect to lnp. Writing $lnC(u,p) = lny$, where y is consumer expenditure and replacing the indirect utility function in (2) gives the Marshallian budget share equations corresponding to (1)

$$w_i = a_i(p) + \beta_i(p)\left[lny - a(p)\right] + \epsilon_i(p)\left[lny - a(p)\right]^2, \tag{3}$$

[1] Relevant papers include Lewbel (1991), Banks et al (1997), Lyssiotou, Pashardes and Stengos (1999a), Nicol (2000) and Lewbel (2000).

where $\beta_i(p) = b_i(p)/b(p)$ and $\epsilon_i(p) = e_i(p)/b(p)$.

An empirical demand system[2] is obtained by taking explicit functional forms for the $a(p), b(p)$ and $e(p)$ price indices. In the case of the $a(p)$ function we adopt the standard assumption that this has the translog form

$$a(p) = a_o + \Sigma_i a_i lnp_i + .5\Sigma_i\Sigma_j\gamma_{ij} lnp_i lnp_i \tag{4}$$

however, for the $b(p)$and $e(p)$ functions we consider the Box-Cox based forms

$$b(p) = \beta_o + \beta^{-1}[\left(\Pi_i p_i^{\beta_i}\right)^{\beta} - 1] \tag{5}$$

$$e(p) = [b(p)^{\theta}]\lambda(p) \tag{6}$$

where

$$\lambda(p) = \lambda_o + \lambda^{-1}[\left(\Pi_i p_i^{\lambda_i}\right)^{\lambda} - 1] \tag{7}$$

The parameter restrictions $\Sigma_i a_i = 1,\ \Sigma_i\beta_i = 0,\ \Sigma_i\lambda_i = 0$ and $\Sigma_i\gamma_{ij} = 0$ for all j are required for adding up; $\Sigma_j\gamma_{ij} = 0$ for all i for homogeneity; and $\gamma_{ij} = \gamma_{ji}$ for all i and j for symmetry.

The model described above is the *GQL* model that nests all other known demand systems based on the *QL* cost function. This is shown in Table 1 where the first section summarizes the *GQL* demand system and gives the budget share equations corresponding to it. The subsequent section in this table shows the parameter restrictions which must be imposed on the *GQL* model to yield the budget share equations of other rank-3 demand systems. The various models listed in Table 1 differ in the way the price indices $b(p)$ and $\lambda(p)$ are specified. The most commonly used demand system, the *QUAIDS*, assumes the first index to be Cobb-Douglas and the second to be log-linear and restricts $\theta = 0$. Similar to the *QUAIDS*, the *AIQL* model assumes the first to be Cobb-Douglas and the second to be log-linear but specifies these indices to interact with each other by restricting $\theta = 1$. This is in contrast with the *Quadratic Transedental Logarithmic (QTL)* model, a new demand system nested in *GQL*, that assumes both indices to be translog and similar to the *AIQL* model specifies the two indices to interact with each other by restricting $\theta = 1$. This latter feature, which both the *AIQL* and the *QTL* model possess (a) enables the nesting of the nonlinear rank-2 *Extended Almost Ideal*

[2] The properties required for the above demand system to be integrable are: (i) adding up: $\Sigma_i a_i(p) = 1$ and $\Sigma_i\beta_i(p) = \Sigma_i\epsilon_i(p) = 0$; (ii) homogeneity: $a_i(\xi p) = \xi a_i(p)$, $\beta_i(\xi p) = \beta_i(p)$, $\epsilon_i(\xi p) = \epsilon_i(p)$, for any scalar ξ;(iii) symmetry: $a_{ij}(p) = a_{ji}(p)$, $\beta_{ij}(p) = \beta_{ji}(p)$ and $\epsilon_{ij}(p) = \epsilon_{ji}(p)$; and (iv) negativity: $s_{ij} = \dfrac{\partial^2 C}{\partial p_i \partial p_j} = \dfrac{C}{p_i p_j} = \dfrac{\partial w_i(p,u)}{\partial lnp_j}$is negative semi-definite.

(EAI) model of Blundell, Pashardes and Weber (1993) and (b) has an extra parameter, λ_o, reflecting price normalization.

The *GQL* framework helps resolve the question which of the less general models above is more appropriate for empirical analysis by (i) allowing interaction between the $b(p)$ and $\lambda(p)$ indices through the parameter θ and (ii) defining these indices as Box-Cox transformations which include the Cobb-Douglas and log linear specifications as special cases.[3] This generalization is convenient for testing purposes and has economic intuition since it allows the effects of price changes on the budget shares to differ with the level of total expenditure y.

3 Empirical analysis

The empirical analysis is based on six categories of non-durable consumer expenditure: food, alcohol, fuel, clothing, other goods and services. Observations on these categories of expenditure and a large number of household characteristics (reflecting durable ownership, housing tenure, location, economic position, occupation, family composition etc.) for one and two adult households whose head is under retirement age and not self-employed are drawn from the annual UK Family Expenditure Survey (FES) for each year over the period 1970-1986. The total number of observations is 46, 325. The prices of goods over the same period are taken from the Retail Price Index (RPI) published by the H.M. Department of Employment.

The parameters of interest here are those reflecting price and expenditure effects. Empirical demand analysis based on micro data, however, also requires modelling preference heterogeneity between households through parameters capturing the effects household characteristics affecting consumer behavior such as those mentioned above. To focus on the parameters of interest here, first we remove preference heterogeneity and account for endogeneity of household expenditure using the procedure described in Lyssiotou, Pashardes and Stengos (1999b). Next we proceed with the empirical investigation of the Marshallian budget share system

$$w_{ih} = a_i + \Sigma_j \gamma_{ij} lp_j + \frac{b_i(p)}{b(p)} Y_h + \left\{ \theta \left[b(p)\right]^{\theta-2} b_i(p) \lambda\left(p\right) + \left[b(p)\right]^{\theta-1} \lambda_i(p) \right\} Y_h^2, \qquad (8)$$

where $a(p)$, $b(p)$, $\lambda\left(p\right), b_i(p)$, and $\lambda_i\left(p\right)$ are as defined in Table 1 and $Y_h = lny_h - a(p)$.

[3] Lewbel (1989) and Bollino and Violi (1990) considering generalisations of the b(p) index in the context of the linear logarithmic (rank-2) cost function $lnC(u,p) = a(p) + b(p)u$ show that selecting either the Cobb-Douglas or the log linear functional forms for the b(p) function is empirically inferior to a more general specification nesting these forms.

Table 2 reports pararameter estimates of interest and their standard errors for the *GQL, QTL, AIQL* and *QUAIDS* models, listed in terms of generality. It also reports test statistics for model comparison purposes. In comparing these models attention is given to: (i) the Box-Cox specification of the $b(p)$ and $\lambda(p)$ indices and (ii) the empirical importance of the extra parameter λ_o contained in the *QTL* and *AIQL*, but not the *QUAIDS* model.

The system parameters reported are of special interest here, as they differentiate the various quadratic logarithmic models. Looking at the pair of columns under the '*GQL*' heading, it is clear that all the system parameters in the *GQL* model are significantly different from 0 except the Box-Cox parameter (β) of the $b(p)$ index[4]. The θ parameter is 2.654 and significantly different from both 0 and 1. Therefore, neither of the three less general rank-3 models can be accepted against the more general *GQL* specification. Furthermore, the $b(p)$ index cannot be accepted to have the Cobb-Douglas form assumed by the most commonly used models (*QUAIDS* and *AIQL*) and the $\lambda(p)$ index cannot be accepted to have the log linear specifications assumed by all models. Statistical testing (p-value in Table 2) suggest rejection of all three nested alternative quadratic logarithmic models in favor of the *GQL* model, at the 5% significance level. Overall, the empirical analysis illustrates that the restrictions imposed by the most commonly used rank-3 quadratic logarithmic demand systems (*QUAIDS* and *AIQL*) are rejected against this more general specification. Future research may investigate the consistency of the *GQL* model with the properties implied by consumer theory and the implications of the choice of the alternative specifications for the analysis of consumer behavior and welfare.

[4]The parameter β_o is set equal to 1 for all demand systems. In the restricted less general models the Box Cox parameters β and λ are set to their limiting values as indicated in Table 1.

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Table 1: Quadratic Logarithmic Demand Systems

(i) Generalised Quadratic Logarithmic (GQL)

Cost function: $lnC(u,p) = a(p) + \dfrac{b(p)}{u^{-1} - [b(p)]^{\theta}\lambda(p)}$

where $a(p) = a_o + \Sigma_i a_{ki} lnp_i + .5\Sigma_i\Sigma_j\gamma_{ij} lnp_i lnp_i$

$b(p) = \beta_o + \dfrac{\left(\Pi_i p_i^{\beta_i}\right)^{\beta} - 1}{\beta}$ and $\lambda(p) = \lambda_o + \dfrac{\left(\Pi_i p_i^{\lambda_i}\right)^{\lambda} - 1}{\lambda}$.

Budget shares:

$$w_i = a_i + \Sigma_j \gamma_{ij} lnp_j + \frac{b_i(p)}{b(p)}[lny - a(p)] + \{\theta[b(p)]^{\theta-2} b_i(p)\lambda(p) + [b(p)]^{\theta-1}\lambda_i(p)\}[lny - a(p)]^2$$

where $b_i(p) = \beta_i(\Pi_j p_j^{\beta_j})^{\beta}$ and $\lambda_i(p) = \lambda_i(\Pi_j p_j^{\lambda_j})^{\lambda}$.

(ii) Rank-3 models nested in GQL

a. *Quadratic Transedental Logarithmic (QTL)*

Restrictions: $\theta = 1$, $\beta \to 0$ and $\lambda \to 0$.

Budget shares:

$$w_i = a_i + \Sigma_j \gamma_{ij} lnp_j + \frac{\beta_i}{\beta_o + \Sigma_j\beta_j lnp_j}[lny - a(p)] + \left(\lambda_i + \frac{\beta_i\lambda_o + \beta_i\Sigma_j\lambda_j lnp_j}{\beta_o + \Sigma_j\beta_j lnp_j}\right)[lny - a(p)]^2.$$

b. *Almost Ideal Quadratic Logarithmic (AIQL):* Fry and Pashardes (1992).

Restrictions: $\theta = 1$, $\beta \to 1$, $\lambda \to 0$ and $\beta_o = 1$.

Budget shares:

$$w_i = a_i + \Sigma_j \gamma_{ij} lnp_j + \beta_i[lny - a(p)] + [\lambda_i + \beta_i\lambda_o + \beta_i\Sigma_j\lambda_j lnp_j][lny - a(p)]^2.$$

c. *Quadratic Almost Ideal (QUAIDS):* Banks, Blundell and Lewbel (1997).

Restrictions: $\theta = 0$, $\beta \to 1$, $\lambda \to 0$, $\beta_o = 1$ and $\lambda_o = \tilde{\lambda}$ (*any real value*).

Budget shares:

$$w_i = a_i + \Sigma_j \gamma_{ij} lnp_j + \beta_i[lny - a(p)] + \frac{\lambda_i}{\Pi_j p_j^{\beta_j}}[lny - a(p)]^2.$$

Table 2: System Parameter Estimates and Test Statistics

Variable	Parameter	GQL Estimate	GQL T-ratio	QTL Estimate	QTL T-ratio	AIQL Estimate	AIQL T-ratio	QUAIDS Estimate	QUAIDS T-ratio
System param.	λ0	-0.14117	-5.16	-0.25153	-43.43	-0.29460	-25.94	-	-
	β	-0.10624	-0.35		fixed		fixed		fixed
	λ	-7.59828	-3.80		fixed		fixed		fixed
	θ	2.65400	2.30		fixed		fixed		fixed
System SSR (LL):		277770		277800		277806		277832	
Functional Form:	(p-value)			0.00186		0.00007		0	
No. Parameters		49		46		46		45	
No. Observations		46325		46325		46325		46325	

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