

Lahatte, Agénor; Miquel, Ruth; Laisney, François; Preston, Ian

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Demand Systems with Unit Values: A Comparison of Two Specifications

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Demand Systems with Unit Values: A Comparison of Two Specifications

Agénor Lahatte¹, Ruth Miquel¹, François Laisney² and Ian Preston³

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Abstract

The availability of quantity information along with expenditure information in some household surveys allows the estimation of price reactions on the basis of unit values. We compare two specifications that have been proposed in this context by Deaton (1990) and Crawford et al. (1997) in order to take account of quality effects reflected in the unit values. Using simulated data for a two-good model, and keeping Marshallian elasticities fixed, we compare true and pseudo-true quantity and quality elasticities. Expenditure elasticities are close, but we find large differences in price elasticities and even sign reversals. This suggests that, while convenient in the situation where prices are not observable, these specifications lack flexibility.

Key Words: Consumer demand, unit values, quality, pseudo-true values.

JEL Classification: D11, D12

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1 Université Louis Pasteur, Strasbourg.

2 Université Louis Pasteur, Strasbourg, and ZEW, Mannheim. laisney@zew.de

3 Institute for Fiscal Studies and University College London. ian_preston@ifs.org.uk

Summary

In empirical demand analysis based on household data it is usually difficult to estimate price reactions, because of insufficient information on price variation. However, many budget surveys present information on both expenditures and quantities purchased, which allows the computation of household-specific unit values, as ratios of expenditure over quantity. Since variation in these unit values can result from both variation in prices and household choices regarding the quality of the good purchased, the estimation of price reactions on the basis of such data requires the specification of a system of budget share and unit value equations for each good. We compare two such specifications currently used in the empirical literature, on the basis of simulated data. Contrary to the real world situation where unit data are used, we assume that prices are observed. Generating data for two goods from one model we compare the corresponding elasticities with those obtained from the estimation of the other model. We repeat the experiment the other way round and also introduce a more general model in order to generate data and estimate the two models under comparison. In spite of its simplicity, the experiment yields clear-cut answers: although expenditure elasticities are similar between models, we find large differences in price elasticities, and even sign reversals. This suggests that the tractability of the models studied — essential when prices are *not* observed — is paid by excessive inflexibility.

1. Introduction

The availability of quantity information along with expenditure information in some household surveys allows the estimation of price reactions on the basis of unit values, defined as the ratio of expenditure and quantity for each good. Deaton (1987, 1988, 1990) has proposed a strategy for estimating price reactions jointly with choice of unit values in data of this type. This entails the specification of a system of budget share and unit value equations, with the logarithms of total expenditure and (unobserved) prices as explanatory variables, and Deaton's specification (henceforth model (D)) is basically a first order Taylor approximation. Crawford et al. (1997) have developed an alternative approach which exploits the implicit links between quantity and unit value choices, resulting in a model which, in contrast to model (D), is consistent with demand theory (model (C)). Both specifications are currently used in empirical work, see for instance Ayadi et al. (1997) for model (D) and De Vreyer (1996) for model (C).

The purpose of this paper is to compare these two specifications: it may well be the case that the theory-consistent model (C) for the unit value equation is so badly misspecified that a first order Taylor expansion like (D) outperforms it in spite of its lack of internal consistency. We proceed as follows: choosing one of the models as the true model for a system with two goods, and a set of true values for its parameters, we compute the pseudo-true values of the parameters of the alternative model — i.e. the values minimising the Kullback contrast between the true joint distribution of the budget shares and unit values, and the distribution entailed by the alternative model. Keeping overall Marshallian elasticities fixed, we compare the way in which true and pseudo-true quantity and quality elasticities evolve as functions of the budget share w_1 of one of the two goods. We repeat the procedure by reverting the roles (true and pseudo-true) of the two specifications. We also introduce a non-linear generalisation for the specification of Crawford et al. (model (G)), and perform a third comparison between models (C) and (D), taking the true distribution of the data to belong to model (G).

While many more comparisons could be undertaken, this already provides clear-cut answers: expenditure elasticities remain close, but we find large differences in price elasticities, and even some sign reversals. This suggests that the tractability of these functional forms in the situation where prices are not observed is paid by excessive inflexibility.

Section 2 presents the three models (D), (C) and (G) and discusses the implied profiles of the various elasticities as functions of the budget share of one of the goods. Section 3 discusses the computation of pseudo-true values and Section 4 comments the graphs summarising the results.

2. Two Specifications and an Extension

We start with a brief exposition of Deaton's approach to modelling the determination of unit values. Goods are taken to be organised into m groups such as food, clothes, etc. Consumption within a group g is a vector of quantities q_g . A group quantity index Q_g is defined as $Q_g \equiv k_g \cdot q_g$, where k_g is a vector of aggregating units typically chosen by the data collector. Group spending is $x_g \equiv p_g \cdot q_g$, where p_g is the vector of group prices. We assume that relative prices within each group are fixed, so that $p_g = \pi_g p_g^0$, where π_g is defined as a scalar (Paasche) linear homogeneous price level for the group (for instance, the price for the aggregate "meat"), and p_g^0 is a vector representing the fixed within-group relative price structure (for instance, the relative prices of different types and qualities of meat).

For each household we can define a *unit value* for each group of goods, $V_g \equiv x_g/Q_g$. Given the definitions above, this leads naturally to the definition of a "quality" index ξ_g : since

$$\frac{x_g}{Q_g} = \frac{\pi_g p_g^0 \cdot q_g}{k_g \cdot q_g}, \quad (2.1)$$

we have $V_g \equiv \pi_g \xi_g$, with

$$\xi_g \equiv p_g^0 \cdot q_g / Q_g. \quad (2.2)$$

Note that a specification in terms of the logarithm of unit values translates

immediately into a specification in terms of the logarithms of the quality indices.

Model (D): Given the assumptions made by Deaton, the variables Q_g , x_g , ξ_g , V_g , as well as related variables such as budget shares, $w_g \equiv x_g/X$, will all be functions of X , the total expenditure, and π , the vector of (unobserved) group prices. Thus, Deaton (1990) specifies a fairly general first-order Taylor approximation in the form

$$\begin{aligned} w_g &= \alpha_g + \sum_h \delta_{gh} \ln \pi_h + \beta_g \ln X, \\ \ln \xi_g &= a_g + \sum_h d_{gh} \ln \pi_h + b_g \ln X. \end{aligned} \quad (2.3)$$

Crawford et al. (1997) show that, given Deaton's assumptions, there exist in fact cross-equation restrictions between the budget share and the unit value equations, stemming from the functional restrictions

$$\begin{aligned} Q_g &= H_g(\xi_g Q_g) \\ \xi_g &= h_g(\xi_g Q_g). \end{aligned} \quad (2.4)$$

Model (C): Crawford et al. propose to specify the budget share relationship, $w_g(X, \pi)$, and to derive a relationship between ξ_g and Q_g from an independent specification of (2.4), since the form of h_g is unrestricted. In particular, with a budget share equation as in (2.3) the specification of

$$h_g(\xi_g Q_g) = (\xi_g Q_g)^{B_g/(1+B_g)} \exp[A_g/(1+B_g)]$$

leads to the simple form

$$\ln \xi_g = A_g + B_g \ln Q_g. \quad (2.5)$$

Model (G): A common feature of models (D) and (C) is their linearity, which is central to the estimation strategies followed by Deaton (1990) and Crawford et al. (1997): the price vector π is not observed, and linearity allows the use of fixed effect techniques to sweep it away, given regional information and the assumption that π varies only *between*, but not *within*, regions. However, in this paper we do not focus on that estimation strategy, but rather on the properties of the two specifications above, and it is of interest to confront them with a more general specification, which does not need to satisfy linearity. A simple extension

of model (C) satisfying the cross-equation restrictions (2.4) is:

$$\ln \xi_g = \tilde{A}_g + \tilde{B}_g \ln (\xi_g Q_g) + \tilde{C}_g [\ln (\xi_g Q_g)]^2. \quad (2.6)$$

Note how we differentiate the notations for the parameters, so that their origin remains clear throughout: Greek letters refer to the parameters of the share equations, lower case (upper case [with tilde]) Latin letters to the parameters of the quality equation from model (D) (model (C) [model (G)]).

Elasticities: Since $w_g = \pi_g \xi_g Q_g$, the usual Marshallian elasticities derived from the share equation in (2.3) will be the sum of the elasticities of quantity and quality with respect to expenditure and prices, respectively. Thus, given the homogeneity relationship between expenditure and price elasticities, $e_g = e_{gg} + e_{gh} = 0$, all relevant information is contained in the form of the Marshallian price elasticities and the relationship between the elasticity of quantity w.r.t. each price and the corresponding Marshallian elasticity. This information is summarised in Table 1, where the notation λ_g used for model (G) is defined as $\lambda_g = 1 - \tilde{B}_g - 2\tilde{C}_g \ln (\xi_g Q_g)$:

Table 1: Marshallian elasticities and elasticities of quantity w.r.t. price

Marshallian	model (D)	model (C)	model (G)
$e_{gg}^M = -1 + \delta_{gg}/w_g$	$e_{gg}^D = e_{gg}^M - d_{gg}$	$e_{gg}^C = e_{gg}^M / (1 + B_g)$	$e_{gg}^G = e_{gg}^M \lambda_g$
$e_{gh}^M = \delta_{gh}/w_g$	$e_{gh}^D = e_{gh}^M - d_{gh}$	$e_{gh}^C = e_{gh}^M / (1 + B_g)$	$e_{gh}^G = e_{gh}^M \lambda_g$

A few comments are in order. The homogeneity property is satisfied not only by the Marshallian elasticities, but also by the quality and quantity elasticities. Quality elasticities are constant in model (D). Quantity elasticities in model (D) and all elasticities in model (C) depend only on model parameters and on w_g (linearly in w_g^{-1}). By contrast, elasticities for model (G) also depend on the product $\xi_g Q_g$ and are thus related in a more complicated way to w_g .

Of course there are also linear relationships between elasticities for models (D) and (C): for instance, we have:

$$e_g^C = (e_g^D + b_g) / (1 + B_g),$$

and the difference $e_g^C - e_g^D$ is linear in w_g^{-1} :

$$e_g^C - e_g^D = b_g - (1 + \beta_g/w_g) B_g / (1 + B_g).$$

Thus the difference $e_g^C - e_g^D$ increases or decreases with w_g according to the sign of $\beta_g B_g / (1 + B_g)$ while its magnitude also depends on b_g . This makes it clear that a meaningful investigation of the plausible magnitude of these differences requires the establishment of a relationship between the parameters above. This is the subject of the next section.

3. Computation of Pseudo-true Values

In the sequel we consider only two goods. Thus $w_2 = 1 - w_1$. We will assume that the distribution of w_1 given the vector Z of explanatory variables $(\ln \pi_1, \ln \pi_2, \ln X)$ is known. Denoting Y the vector of remaining endogenous variables $(\ln \xi_1, \ln \xi_2)$, and considering a parametric model for the conditional distribution of Y given Z , with densities $\{f(Y|Z, \theta); \theta \in \Theta\}$, the *pseudo-true value* θ^* of θ is defined as

$$\theta^* = \arg \max_{\theta \in \Theta} E_Z E_0 \ln f(Y|Z, \theta)$$

where E_0 denotes the expectation w.r.t. the *true* conditional distribution of Y given Z , and E_Z denotes the expectation w.r.t. the marginal distribution of Z (see e.g. Gouriéroux and Monfort, 1989).

Following Deaton (1990) we assume that the marginal distribution of Z is normal with expectation $(4.6, 0, 0)$ and a diagonal variance matrix with diagonal $(0.5, 0.1, 0.1)$. We also specify the conditional distribution of w_1 given Z as normal with variance 0.0005 and expectation

$$E(w_1|Z) = \alpha_1 + \delta_{11} \ln \pi_1 + \delta_{12} \ln \pi_2 + \beta_1 \ln X,$$

with the numerical values $\alpha_1 = 0$, $\delta_{11} = 0.046$, $\delta_{12} = -0.066$, $\beta_1 = 0.02$. These choices again follow Deaton's, with the exception that we choose the value of δ_{12}

so as to ensure zero degree homogeneity of the budget share.¹ With these choices we obtain the following ranges for the overall Marshallian elasticities:

Table 2: Range for Marshallian elasticities

w_1	e_1^M	e_2^M	e_{11}^M	e_{12}^M	e_{21}^M	e_{22}^M
0.05	1.40	0.98	-0.08	-1.32	-0.05	-0.92
0.85	1.02	0.87	-0.95	-0.08	-0.31	-0.56

We will describe case by case the assumptions concerning the distribution of $(\ln \xi_1, \ln \xi_2)$, but before that we outline the general procedure followed for the computation of pseudo-true values. The true model allows us to simulate any amount of data, and the use of a pseudo-ML estimator yields as precise an estimation as desired for the pseudo-true value. In order to economise on the number of simulations needed to achieve a given precision, we make use of the technique of antithetic variables (see e.g. Davidson and MacKinnon, 1993, 744-747).

In the sequel we will call “situation (X)” the situation where the true model is (X).

Situation (D): We specify the conditional distribution of $(\ln \xi_1, \ln \xi_2)$ given Z as normal with a diagonal variance matrix with diagonal $(0.1, 0.1)$ and expectation

$$\begin{aligned} E(\ln \xi_1 | Z) &= a_1 + d_{11} \ln \pi_1 + d_{12} \ln \pi_2 + b_1 \ln X, \\ E(\ln \xi_2 | Z) &= a_2 + d_{21} \ln \pi_1 + d_{22} \ln \pi_2 + b_2 \ln X, \end{aligned}$$

with numerical values $a_1 = a_2 = 0$, $b_1 = 0.5$, $b_2 = 0.2$, $d_{11} = d_{22} = 0.3$, $d_{12} = -0.8$, $d_{21} = -0.5$. In choosing these values we have taken account of the zero degree homogeneity of ξ_g , which results from the homogeneity of both p_g and Q_g .

The specification retained for the pseudo-model (C) is:

$$\ln \xi_g = A_g + B_g \ln Q_g + t_g, \quad g = 1, 2, \quad (3.1)$$

¹ Expressing the Slutsky matrix in terms of Marshallian elasticities we are able to check concavity of the corresponding cost function for each value of w_1 : we find that, for the chosen values of the parameters, concavity is satisfied for $w_1 < 0.9$. In interpreting the results we will thus focus on this range for w_1 .

where $(t_1, t_2)'$ is assumed bivariate normal with unrestricted covariance structure and zero expectation given Z . For a precision of 10^{-6} the number of simulations required was 1065. Technical details on the computation of the pseudo-true values, as well as a table recapitulating true and pseudo-true values, are given in the Appendix.

Situation (C): We generate data using (3.1) assuming $(t_1, t_2)'$ bivariate normal with zero expectation and diagonal variance matrix with diagonal (0.1, 0.1). The numerical values are $A_1 = 2$, $A_2 = 4$, $B_1 = 0.45$, $B_2 = 0.22$.

The data are simulated using the linear system

$$\begin{aligned} \ln \xi_g + \ln Q_g &= \ln w_g - \ln \pi_g + \ln X, \\ \ln \xi_g - B_g \ln Q_g &= A_g + t_g \end{aligned} \quad (3.2)$$

where the first equation results from the identity $w_g = \xi_g \pi_g Q_g / X$. The pseudo-model (D) is identical to the true model (D) above, except as regards the covariance structure, which is unrestricted. The number of simulations needed was 1649 (4149 without antithetic variables).

Situation (G): The data is generated using

$$\ln \xi_g = \tilde{A}_g + \tilde{B}_g \ln (\xi_g Q_g) + \tilde{C}_g [\ln (\xi_g Q_g)]^2 + t_g, \quad g = 1, 2, \quad (3.3)$$

and the same assumptions on the distribution of $(t_1, t_2)'$ as above. The numerical values chosen are $\tilde{A}_1 = 0$, $\tilde{A}_2 = 0$, $\tilde{B}_1 = 0.5$, $\tilde{B}_2 = 0.5$, $\tilde{C}_1 = -0.004$, $\tilde{C}_2 = -0.004$.

The data are simulated using the formulas

$$\begin{aligned} \ln \xi_g &= \tilde{A}_g + \tilde{B}_g (\ln w_g - \ln \pi_g + \ln X) + \tilde{C}_g (\ln w_g - \ln \pi_g + \ln X)^2 + t_g, \\ \ln Q_g &= -\tilde{A}_g + (1 - \tilde{B}_g) (\ln w_g - \ln \pi_g + \ln X) - \tilde{C}_g (\ln w_g - \ln \pi_g + \ln X)^2 - t_g \end{aligned}$$

obtained after simple algebraic transformations. The pseudo-models (D) and (C) are chosen as above. The numbers of simulations required were 2478 for model (D) and 707 for model (C).

4. Results

For each of the three situations above, we have produced a graph for each good and each type of elasticity (expenditure, own price, price of the other good)

while grouping quantity and quality elasticities. This yields a total of 18 graphs of which we reproduce only two here.² We show results for w_1 between 0.05 and 0.85. As noted below Table 1, the elasticities for model (G) do not depend solely on parameters and w_1 but also on $\ln(\xi_g Q_g)$, or equivalently on $\ln w_g - \ln \pi_g + \ln X$. Setting $\pi_1 = \pi_2 = 1$ this becomes $\ln w_g + \ln X$ and the expectation of the budget share for good 1 is $w_1 = \beta_1 \ln X$, which yields a value of $\ln X$ corresponding to each value of w_1 .

The main findings are the following. The expenditure elasticities for models (D) and (C) are close for both goods in all situations — the largest discrepancy, about 0.23, occurs for good 2 in situation (G) — with quantity elasticities between a half and two thirds of Marshallian elasticities. Quality elasticities for model (C) are almost constant for good 1 for $w_1 > 0.3$. For model (G), Figure 1 shows a profile of e_1 , the quantity expenditure elasticity for good 1, which is first decreasing then increasing as a function of w_1 , a profile which is a priori excluded for the other two specifications. Also noteworthy on Figure 1 is the fact that all elasticities for models (D) and (C) remain grouped, around a value of 0.55, whereas the relative importance of quantity and quality elasticities varies substantially for model (G), between 0.7 and 0.85 for the quantity elasticity and between 0.6 and 0.2 for the quality elasticity.

Own price elasticities show more important discrepancies, attaining 0.7 in absolute terms for the quantity elasticity of good 1 in situation (D). In that situation, the quality elasticities for both goods are of opposite signs for models (D) and (C), positive for the former, negative for the latter.

The discrepancies are also large for cross price elasticities, with a maximum of 0.7 for the quantity elasticity e_{12} in situation (D). As Figure 2 shows, sign reversals occur for the cross price elasticities of quantity: only e_{12}^D takes positive values, possibly a result of the constancy restriction for the quality elasticity in model (D). This also happens in situations (C) and (D). In situation (D) e_{21}^D and e_{21}^C have opposite signs for all values of w_1 (positive for the former, negative for the latter).

² The complete series of graphs will be provided upon request.

5. Conclusion

This very limited experiment leads to surprisingly clear-cut conclusions on two specifications used for the estimation of demand systems on the basis of unit values: these two models can yield strikingly different results as concerns the decomposition of price elasticities in quantity and quality elasticities. Whether the fact that we have restricted overall Marshallian elasticities to coincide does trigger these discrepancies or in the contrary helps the models track each other is not entirely clear to us, but our conjecture is rather in favour of the latter assumption.

The conclusion we draw from the exercise is that, while these two specifications are attractive for the estimation of price reactions when only unit values and regional information are available — and prices themselves remain unobserved, the search for more flexible but tractable specifications of the unit value equations should be rewarding.

6. Appendix: Technical details on the computation of the pseudo-true values

For ease of presentation we start with the case where model (C) is the true model.

Situation (C): Given a data set of size N we compute the ML estimate $\hat{\theta}_N$ of the parameters of model (D). For $N \rightarrow \infty$ this will converge to the pseudo true value θ^* . The system to be estimated is a system of seemingly unrelated regressions with identical regressors, and given the normality assumption, the ML estimator coincides with OLS equation by equation (see e.g. Oberhofer and Kmenta, 1974). Furthermore, the computation of the elasticities only requires knowledge of the slope parameters b_g, d_{gg}, d_{gh} for $g, h = 1, 2$. The only piece of information we still need to acquire to compute these is the covariance matrix $\text{cov}(\ln \xi, Z)$, which we approximate by simulation of the corresponding empirical moments.

Situation (D): Here we have the problem that t_g correlates with $\ln Q_g$:

indeed since $Q_g = Xw_g/(\pi_g\xi_g)$ we have

$$\begin{aligned} E(t_g \ln Q_g) &= E(t_g \ln X) + E(t_g \ln w_g) - E(t_g \ln \pi_g) - E(t_g \ln \xi_g) \\ &= E(t_g \ln w_g) - E(t_g \ln \xi_g), \end{aligned}$$

and there is no reason why this should be zero. A possibility to approximate the pseudo-true value of the slopes B_g is to compute the limit of the single equation instrumental variable estimator obtained with $\ln X$ as instrument. This is the product of $\text{cov}(\ln X, \ln Q_g)^{-1}$ and $\text{cov}(\ln \xi_g, \ln Q_g)$, which we approximate as above by simulation of the corresponding empirical moments.

Situation (G): The only change concerns the data generation, and the computation of pseudo-true values for models (D) and (C) proceeds as above. Table A.1 gives an overview of true and pseudo-true values in all situations. Note that the pseudo-true values for model (D) in situations (C) and (G) do satisfy the homogeneity constraints ($b_g + d_{gg} + d_{gh} = 0$, $g, h = 1, 2$), as expected.

Table A.1: True and pseudo-true values of slope parameters

param.	b_1	b_2	d_{11}	d_{12}	d_{21}	d_{22}	B_1	B_2	\bar{B}_1	\bar{B}_2	\bar{C}_1	\bar{C}_2
(D)	.5	.2	.3	-.8	-.5	.3	.67	.26				
(C)	.39	.18	-.14	-.25	-.01	-.17	.45	.22				
(G)	.58	.18	-.20	-.38	-.01	-.17	1.08	.72	.45	.22	-.004	.004

Italics: pseudo-true

N.B. The values for the intercepts A_g and \tilde{A}_g , $g = 1, 2$, are not shown, because they play no role in the computation of the elasticities.

Figure 1: Expenditure elasticities, good 1, situation (G)

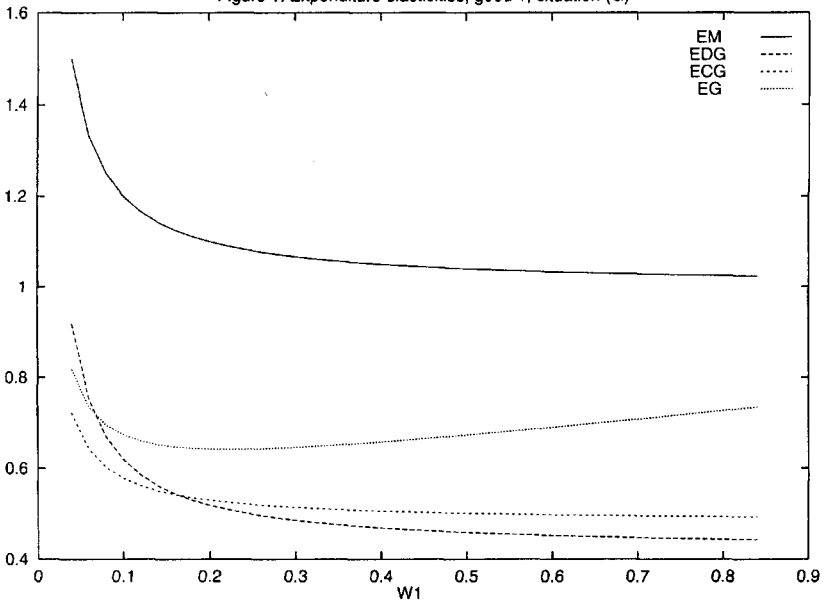
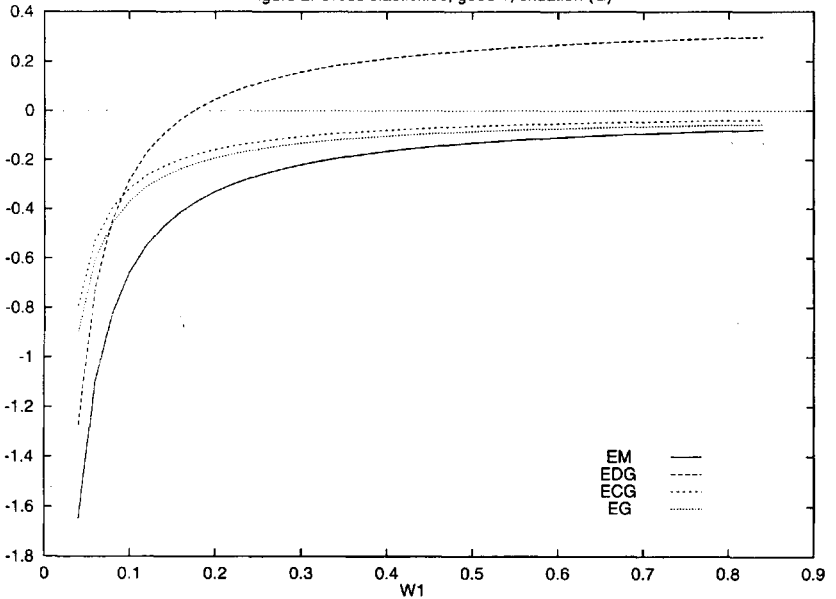


Figure 2: Cross elasticities, good 1, situation (G)



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Figure 1: Expenditure elasticities, good 1, situation (G)

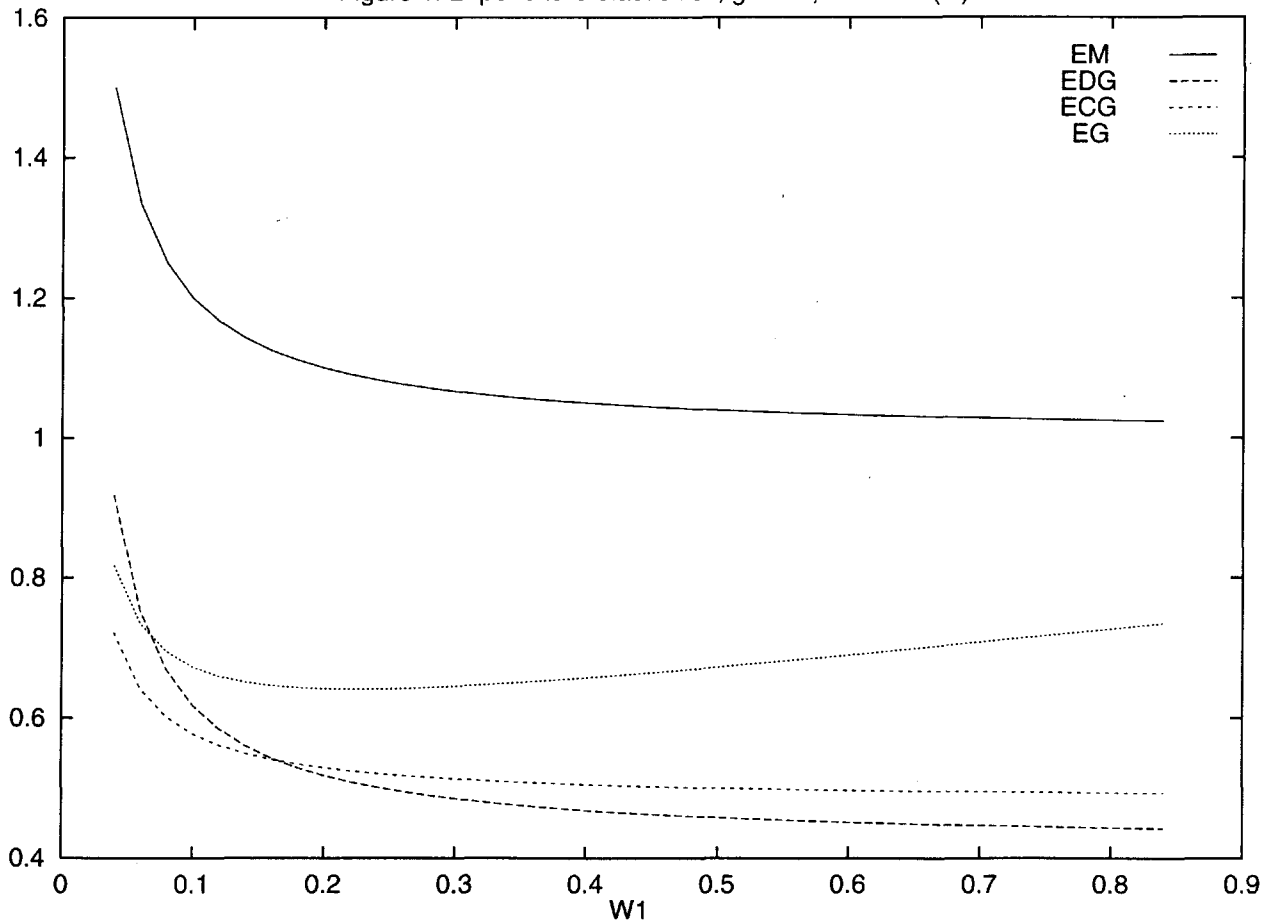


Figure 2: Cross elasticities, good 1, situation (G)

