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Calculating marginal effects in models for zero expenditures in household budgets using a Heckman-type correction

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Using the Heckman approach, either in single-equation or multi-equation settings, general expressions are derived for calculating marginal effects and elasticities. In the conventional calculation of marginal effects, terms related to the change in the inverse of Mills ratio are omitted. Using data from the 1987–88 Nationwide Food Consumption Survey, we calculate income and household size elasticities for 12 food commodities. We compare the magnitudes and signs of the elasticities using the conventional expressions of marginal effects and our derived expressions. Bottomline, sizeable differences, especially in single-equation applications, can occur in calculating marginal effects if one fails to account for changes in the inverse of the Mills ratio.

I INTRODUCTION

Using household budget data, one is very likely to encounter zero expenditures. The shorter the survey period and the more narrowly defined the commodity, the greater the proportion of households likely to report zero expenditure of one particular product Non-purchases may be due to sufficient household inventory, responses to economic forces, or to non-preference. The use of household budget data may lead to econometric problems In particular, for censored responses, the use of least squares may produce bias in the parameter estimates

A fair amount of work in demand analysis has been geared to the zero-expenditure problem, particularly in the last decade The traditional approach has been to use a Tobit procedure that allows for a discrete mass point for observations, as well as a continuous range of values for the dependent variable (Tobin, 1958) This method has been employed in a variety of studies (e.g. McCracken and Brandt, 1987; Lane, 1978)

Cragg (1971) developed several generalizations of the Tobit model that allow the decision process to have two steps. Haines *et al* (1988) used the Cragg procedure, termed the double-hurdle model in the literature, to examine consumption patterns of various food groups. This model has also been used by Blaylock and Blisard (1992) in considering tobacco expenditures, by Blisard and Blaylock (1993) to estimate the demand for butter; and by Yen (1993) to examine food-away-from-home expenditures Cheng and Capps (1988), in analysing expenditure patterns for finfish and shellfish, applied a Heckman-type sample selectivity correction to the analysis of consumption decisions as a two-step process Heien and Wessells (1990) and Heien and Durham (1991) generalize the Heckman specification to a system of equations. Suffice it to say that the problem of zero expenditures has received widespread attention in recent times.

In this paper, we deal exclusively with the Heckman approach in the estimation of single equations and of a system of equations Using this approach, we derive general expressions for calculating marginal effects and elasticities These derivations are a unique contribution to the literature We contend that in the conventional calculation of marginal effects, terms related to the change in the inverse of Mills ratio are omitted

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The paper is organized as follows. We revisit the Heckman procedure for single equations and for a system of equations. Subsequently, we derive the expressions for calculating marginal effects and elasticities. Using the 1987–88 Nationwide Food Consumption Survey (1987–88 NFCS), we then estimate expenditure functions for 12 food commodities, and we calculate income and household size elasticities. Finally, we compare the magnitudes and signs of the elasticities using the conventional calculation and using our calculation.

II. HECKMAN PROCEDURE FOR SINGLE EQUATIONS

In single-equation applications, the Heckman two-step procedure has been employed by Buse (1986), Cheng and Capps (1988) and Jensen *et al.* (1992) to circumvent the zero-expenditure problem. In the first stage, probit analysis is used to determine the inverse of the Mills ratio (MR_{hi}) for the hth household for the ith commodity. The probit analysis employs all available observations; the dependent variable equals one if the household makes a purchase; otherwise the dependent variable is zero. The second stage involves the use of the estimated inverse Mills Ratio ($\hat{M}R_{hi}$) as an additional regressor in the estimation equation involving the continuous, non-zero dependent variable. The appropriate estimation technique in the second-stage is either ordinary (OLS) or generalized least squares (GLS). The OLS procedure produces consistent estimates; but the GLS procedure, when implementation is possible (Heckman, 1976, pp. 480–83), improves the precision of the estimates. The GLS procedure circumvents the potential heteroscedasticity problem inherent in the Heckman procedure.

Mathematically, we can characterize the probit-based Heckman-type selectivity correction as follows. In the first-stage, let Z_{hi} denote an indicator variable that takes a value of one if expenditure occurs for the ith commodity by the hth household and zero otherwise Denoting the normal cumulative distribution function (CDF) by Φ, we have

$$\Pr[Z_{hi} = 1] = \Phi(W_h \gamma_i)$$

and

$$\Pr[Z_{hi} = 0] = 1 - \Phi(W_h \gamma_i) \quad i = 1, \ldots, n; h = 1, \ldots, H \quad (1)$$

where W_h is a vector of regressors, related to this purchase decision, and γ_i is the coefficient vector. The first-stage estimation provides estimates of γ_i and the inverse of the Mills ratio defined as

$$\hat{M}R_{hi} = \begin{cases} \dfrac{\phi(W_h\hat{\gamma}_i)}{\Phi(W_h\hat{\gamma}_i)} & \text{for } Z_{hi} = 1 \\ \dfrac{\phi(W_h\hat{\gamma}_i)}{1 - \Phi(W_h\hat{\gamma}_i)} & \text{for } Z_{hi} = 0 \end{cases} \quad (2)$$

In the second stage, let Y_{hi} denote the expenditure of household h on commodity i. Then

$$E[Y_{hi}|Z_{hi} = 1] = X_h\beta_i + \alpha_i \frac{\phi(W_h\hat{\gamma}_i)}{\Phi(W_h\hat{\gamma}_i)} = X_h\beta_i + \alpha_i \hat{M}R_{hi} \quad (3)$$

X_h is a vector of regressors related to the magnitude of the expenditure on the ith commodity. Importantly, only the non-zero observations on Y_{hi} are used in the second-stage.

Marginal effects

Let X_{hj} denote the jth regressor that is common to both W_h and X_h,, the vector of regressors in stage 1 and stage 2 equations, respectively. Using Equation (3), the estimated marginal effect of a change in the jth regressor is given by

$$\hat{M}E_{hj} \frac{\partial E[Y_{hi}|Z_{hi} = 1]}{\partial X_{hj}} = \hat{\beta}_{ij} + \hat{\alpha}_i \frac{\partial}{\partial X_{hj}} (\hat{M}R_{hi}) \quad (4)$$

It is evident from Equation (4) that the marginal effect of the jth regressor is composed of two parts: (i) a change in X_j which affects the probability of consuming the ith commodity; this effect is captured by the second term in the right-hand side of Equation (4); and (ii) a change in X_j which affects the expenditure on the ith commodity; this effect, however, is conditional upon the household choosing to consume the ith commodity. This second effect is captured by $\hat{\beta}_{ij}$ in Equation (4). In the conventional marginal effect expression, only the second effect, i.e. $\hat{\beta}_{ij}$, is considered. The degree and direction of the attendant bias in the calculation of marginal effects depends on the magnitude and sign of the second term of the right-hand side of Equation (4).

After some simplification, the marginal effect expression becomes

$$\hat{M}E_{hj} = \hat{\beta}_{ij} - \hat{\alpha}_i \hat{\gamma}_{ij} \{W_h \hat{\gamma}_i \hat{M}R_{hi} + (\hat{M}R_{hi})^2\} \quad (5)$$

Equation (5) represents the appropriate general expression for calculating marginal effects in single equations using the Heckman-type correction. Note that $\hat{M}E_{hj} \neq \hat{\beta}_{ij}$; the only time $\hat{M}E_{hj} = \hat{\beta}_{ij}$ holds is when $\hat{\alpha}_i = 0$. It is readily verified that $\hat{\alpha}_i = 0$ if and only if the covariance between the errors of the first and second stage estimation equations is equal to zero. In almost all cases of interest this situation is highly unlikely.

Also note that $\partial E[Y_{hi}|Z_{hi} = 1]/\partial X_{hj}$ will vary by observation. Therefore, we propose to evaluate $\partial E[Y_{hi}|Z_{hi} = 1]/\partial X_{hj}$ at the sample means That is

$$\left.\frac{\partial E[Y_{hi}|Z_{hi}]}{\partial X_{hj}}\right|_{\text{sample mean}} = \hat{\beta}_{ij} - \hat{\alpha}_i \hat{\gamma}_{ij} ((\bar{W}\hat{\gamma}_i)\bar{\hat{M}}R_i + \bar{\hat{M}}R_i^2) \quad (6)$$

where $\bar{W}$ denotes the vector of sample means of the regressors in the stage 1 equations and $\bar{\hat{M}}R_i = \phi(\bar{W}\hat{\gamma}_i)/\Phi(\bar{W}\hat{\gamma}_i)$, the inverse of the Mills ratio evaluated at the sample means.

III. HECKMAN PROCEDURE FOR A SYSTEM OF EQUATIONS

Heien and Wessells (1990) and Heien and Durham (1991) extend the Heckman approach to a system of equations. In this procedure, all H observations are used in the second-stage estimation. It requires using the appropriate formulation for the inverse Mills for observations for which $Z_{hi} = 0$ and $Z_{hi} = 1$, that is

$$E[Y_{hi}|Z_{hi} = 1] = X_h\beta_i + \alpha_i \frac{\phi(W_h\hat{\gamma}_i)}{\Phi(W_h\hat{\gamma}_i)}$$

$$E[Y_{hi}|Z_{hi} = 0] = X_h\beta_i + \alpha_i \left[\frac{\phi(W_h\hat{\gamma}_i)}{1 - \Phi(W_h\hat{\gamma}_i)}\right] \quad (7)$$

$$\in i = 1, \ldots, m$$

Importantly, all m commodity equations are estimated as a system, each having the same set of regressors except for the m inverse Mills ratios Consequently, a seemingly unrelated regression (SUR) procedure is appropriate because the disturbance terms of the respective equations may be contemporaneously correlated. Given that the right-hand side variables are not the same in each relationship, gains in efficiency can be expected with the SUR procedure relative to the use of ordinary least squares.

Marginal effects

Let X_{hj} again denote a regressor that is common to both W and X, the regressors in the stage 1 and stage 2 equations respectively. The marginal effects, evaluated at the sample means are given as

$$\hat{\text{ME}}^{\text{A}}_{hj} = \frac{\partial E[Y_{hi}|Z_{hi} = 1]}{\partial X_{hj}}\bigg|_{\substack{\text{sample}\\ \text{mean}}}$$

$$= \hat{\beta}_{ij} - \hat{\alpha}_i\hat{\gamma}_{ij}\{\bar{W}\hat{\gamma}_i\bar{\hat{\lambda}}^{\text{A}}_i + (\bar{\hat{\lambda}}^{\text{A}}_i)^2\} \quad (8)$$

and

$$\hat{\text{ME}}^{\text{B}}_{hj} = \frac{\partial E[Y_{hi}|Z_{hi} = 0]}{\partial X_{hj}}\bigg|_{\substack{\text{sample}\\ \text{mean}}}$$

$$= \hat{\beta}_{ij} - \hat{\alpha}_i\hat{\gamma}_{hj}\{\bar{W}\hat{\gamma}_i\bar{\hat{\lambda}}^{\text{B}}_i - (\bar{\hat{\lambda}}^{\text{B}}_i)^2\} \quad (9)$$

where

$$\bar{\hat{\lambda}}^{\text{A}}_i = \frac{\phi(\bar{W}\hat{\gamma}_i)}{\Phi(\bar{W}\hat{\gamma}_i)} \quad \text{and} \quad \bar{\hat{\lambda}}^{\text{B}}_i = \frac{\phi(\bar{W}\hat{\gamma}_i)}{1 - \Phi(\bar{W}\hat{\gamma}_i)} \quad (10)$$

To compute the marginal effect of X_{hj} on $E[Y_{hi}]$, we propose to take the weighted average of $\hat{\text{ME}}^{\text{A}}_{hj}$ and $\hat{\text{ME}}^{\text{B}}_{hj}$

$$\hat{\text{ME}}_{hj} = \theta_i\hat{\text{ME}}^{\text{A}}_{hj} + (1 - \theta_i)\hat{\text{ME}}^{\text{B}}_{hj} \quad (11)$$

where θ_i is the proportion of observations for which $Z_{hi} = 1$. This

$$\hat{\text{ME}}_{hj} = \hat{\beta}_{ij} - \hat{\alpha}_i\hat{\gamma}_{ij}[\theta_i(\bar{W}\hat{\gamma}_i\bar{\hat{\lambda}}^{\text{A}}_i + (\bar{\hat{\lambda}}^{\text{A}}_i)^2) + (1 - \theta_i)(\bar{W}\hat{\gamma}_i\bar{\hat{\lambda}}^{\text{B}}_i - (\bar{\hat{\lambda}}^{\text{B}}_i)^2)] \quad (12)$$

Again, in general, $\hat{\text{ME}}_{hj} \neq \hat{\beta}_{ij}$. Equation (12) represents the appropriate general expression for calculating marginal effects in a system of equations using the Heckman-type correction. $\hat{\beta}_{ij}$ represents the conventional expression for calculating the marginal effect of the jth commodity.

IV. EMPIRICAL ANALYSIS

To determine the extent to which the marginal effects differ by taking into account the change in the inverse Mills ratio with respect to X_{hj}, it is necessary to consider empirical analysis. In this light, we examine 12 expenditure relationships for food commodities using data from the 1987–88 Nationwide Food Consumption Survey (1987–88 NFCS). The food commodities are: (1) food away from home; (2) beef; (3) pork; (4) chicken; (5) fish; (6) cheese; (7) milk; (8) fruit; (9) vegetables; (10) breakfast cereals; (11) bread; and (12) fats and oils.

Data

The data set for this analysis is the household portion of the 1987–88 NFCS basic sample, targeted at all private households in the 48 contiguous states. The households were selected using a self-weighting, multistage, stratified selection procedure; the survey was designed to provide four independent, but continuous, seasonal (spring, summer, fall and winter), samples and to provide a sample of 6000 households However, only 4495 completed acceptable interviews (Lutz *et al.*, 1992).

Information was collected on various socioeconomic and demographic characteristics of the household as well as detailed records on the money value, quantity, and types of foods used by the household over a 1 week period. Socioeconomic and demographic characteristics considered in this paper were: (1) region; (2) urbanization; (3) race; (4) income; and (5) household size. These variables are common to analyses of expenditure or Engel functions. The sample size used for estimation purposes was 3896. The entire sample of 4495 households could not be used because some households either did not report income figures or had non-responses in other categories Also, this analysis considered only housekeeping households; that is, those households with at least one person having eaten ten or more meals from the household food supply during seven days prior to the interview. Thus, we excluded non-housekeeping households

The specification for a particular equation in the second-stage of this analysis is given as

$$\begin{aligned} \text{EXP}_{ih} = a_0 &+ a_1\text{NE} + a_2\text{MW} + a_3\text{WEST} + a_4\text{CC} \\ &+ a_5\text{SUB} + a_6\text{BLACK} + a_7\text{ASIAN} \\ &+ a_8\text{INCOME} + a_9\text{HSIZE} \\ &+ a_{10}\hat{\text{MR}}_{ih} + \varepsilon_{ih} \end{aligned} \qquad (13)$$

where EXP_{ih} = the expenditure of the ith item by the hth household; NE = 1 if the household resides in the north-east; 0 otherwise; MW = 1 if the household resides in the mid-west; 0 otherwise; west = 1 if the household resides in the west; 0 otherwise; CC = 1 if the household resides in a central city, that is, a city which has a population of 50 000 or more; 0 otherwise, SUB = 1 if the household resides in a suburban area; 0 otherwise; BLACK = 1 if the race of the household is black; 0 otherwise; ASIAN = 1 if the race of the household is ASIAN/Pacific Islanders; 0 otherwise; INCOME = household income before taxes in dollars; HSIZE = household size, the number of persons in the household including roomers, boarders; and $\hat{\text{MR}}_{ih}$ = inverse of Mills ratio from a first-stage probit regression.

In the first stage, the decision to consume is a dichotomous choice problem, whose specification is assumed to be

$$Y_{ih} = \Phi\,(\text{region, urbanization, race, income, household size}) \qquad (14)$$

where $Y_{ih} = 1$ if the hth household consumes the ith food item and 0 otherwise. Thus, the variables which enter the model in (13) also are in the second-stage relation in (14) This 'overlap' of variables in the decision to consume is important in calculating marginal effects

Socioeconomic and demographic characteristics are represented by dummy variables. To avoid singularity due to the use of the binary variables, we arbitrarily drop one of the categories from each demographic group. Reference households correspond to those that: reside in the south; reside in non-metropolitan areas; and are white. Descriptive statistics of the dependent variables used in the analysis are exhibited in Table 1. The number of zero-expenditure observations runs from 10% to 50%. Nine out of ten housekeeping households consumed milk, while one out of two consumed fish. Roughly four out of five housekeeping households made purchases for food away from home; beef; fruit; vegetables; and bread Three out of four made purchases for fats and oils and cheese; two out of three consumed pork; chicken; and breakfast cereals. Because these commodities are still aggregate in nature, the number of zero-expenditure observations is not necessarily sizeable, with the possible exception of fish.

Roughly 21% of the households reside in the north-east; 26% in the mid-west; 18% in the west; and 35% in the south. About 23% reside in central cities, 47% in suburban areas; and 30% in non-metropolitan areas. 11% of the sample is black, 1% is Asian; and 88% is white. The average before-tax income level is about $27 700, and the average household size is 2.7 members.

In the interest of brevity, the parameter estimates of the probit regressions are not reported here, but are available on request from the authors. Goodness-of-fit measures such as McFadden's R-square and the percentage of correct predictions are given in Table 2. Household size was a significant determinant in all probit regressions; region was statistically important in the decision to consume except for breakfast cereals and fats and oils, urbanization was a key determinant except for cheese and milk; race was a statistically important factor except for beef and vegetables; income, however, was significant only in the probit regressions pertaining to food away from home, fish, cheese; fruit; vegetables; bread, and fats and oils.

Table 1 *Descriptive statistics of the dependent variables used in the analysis*

Dependent variable	Percentage of non-zero observations	Mean[a]	Standard deviation	Min[a]	Max[a]
Food away from home	81.3	27.23	33.63	0	350
Beef	83.1	6.35	6.95	0	92
Pork	66.8	3.64	5.27	0	142
Chicken	64.4	2.40	3.50	0	100
Fish	51.6	2.73	5.65	0	70
Cheese	74.3	2.17	2.43	0	27
Milk	90.5	3.27	3.23	0	38
Fruit	77.2	3.03	3.61	0	57
Vegetables	82.5	3.29	3.35	0	31
Breakfast cereals	70.4	2.02	2.36	0	23
Bread	82.1	1.58	1.44	0	14
Fats & oils	75.0	1.57	1.57	0	19

[a] In US dollars

We have not presented the estimates for the second-stage relationships, either for single-equation or system of equation applications. These results are available from the authors. We focus on comparing the marginal effects of income and household size with and without taking into account changes in the inverse Mills ratio. Also, we report these marginal effects (see Tables 3 and 4) in terms of income and household size elasticities, evaluated at the sample means.

For the single-equation application, there may be sizeable differences in the magnitudes of the income elasticities and household size elasticities. To illustrate, for food away from home, without taking into account changes in the inverse of Mills ratio (referred to as without correction in Tables 3 and 4), the income elasticity for food away from home was estimated to be 0.3398. But, with the correction (that is, taking into account changes in the inverse of Mills ratio), the income elasticity was estimated to be 0.6721. Similarly, the income elasticities for fish, fruit, and vegetables changed noticeably by taking into account the inverse of Mills ratios. Without (with) the correction, the income elasticity for fish was 0.3404 (0.4744); for fruit 0.793 (0.2705); and for vegetables 0.944 (0.2207). Changes were also evident for pork (0.201 to 0.0448); breakfast cereals (−0.0277 to −0.0119); and for fats and oils (0.0264 to 0.0450). The income elasticities for beef, chicken, cheese, milk, and bread were not noticeably affected by accounting for the inverse Mills ratio. Also, the income elasticity may rise or fall by accounting for the inverse Mills ratio. For eight of the 12 commodities, the income elasticities rose, while for four of the 12 commodities, the income elasticities fell.

Except for cheese, the household size elasticities were very much affected by making the correction in the marginal effects. For food away from home and for fish, the household size elasticity changed from −0.0739 to 0.2059 and from −0.0810 to 0.1738, respectively. So, in some cases, sign changes in the marginal effects may occur with the corrections. For beef, pork, fruit, vegetables, and fats and oils, the household size elasticities rose in magnitude, while for chicken, milk, breakfast cereals, and bread, they fell in magnitude.

For the system of equations, the patterns in the changes of income and household size elasticities were similar to those in the single-equation applications (see Table 4). In most cases, the respective elasticities were larger by accounting for the inverse of the Mills ratio. Importantly, however, the differences in the magnitudes of the elasticities were noticeably smaller than those in the single-equation approach.

Table 2 *Goodness of fit measures from the first-stage probit regressions*

Commodity	McFadden R-square[a]	% of correct predictions[b]
Food away from home	0.149	0.8172
Beef	0.0891	0.8311
Pork	0.0511	0.6855
Chicken	0.0479	0.6552
Fish	0.0230	0.5746
Cheese	0.0718	0.7494
Milk	0.1047	0.9058
Fruit	0.0419	0.7720
Vegetables	0.0470	0.8259
Breakfast cereals	0.0810	0.7166
Bread	0.1283	0.8236
Fats & oils	0.1009	0.7582

[a] 1 − [log of the likelihood function evaluated at the maximum likelihood estimates/log of the likelihood function when all coefficients, except the constant, are set to zero]
[b] An observation is predicted to be 1 if the predicted probability is 0.5 or greater, otherwise the observation is predicted to be 0.

Table 3 *Calculation of income and household size elasticities with and without taking into account the inverse of one Mills ratio. Heckman procedure: single-equation application*

Commodity	$\bar{R}^2$	Income elasticity without correction	Income elasticity with correction	Household size elasticity without correction	Household size elasticity with correction
Food away from home	0.1720	0.3398	0.6721	−0.0739	0.2059
Beef	0.1070	0.1302	0.1229	0.0943	0.6818
Pork	0.0896	0.0201	0.0448	0.1306	0.7770
Chicken	0.0632	0.2213	0.1953	0.8722	0.4984
Fish	0.0434	0.3404	0.4744	−0.0810	0.1738
Cheese	0.1050	0.0995	0.0999	0.6121	0.6141
Milk	0.2752	0.0144	0.0131	1.2148	0.9099
Fruit	0.0695	0.0793	0.2705	0.2121	0.3508
Vegetables	0.0733	0.0944	0.2207	0.0628	0.2406
Breakfast cereals	0.2114	−0.0277	−0.0119	1.4140	0.9418
Bread	0.1627	0.0596	0.0514	0.8404	0.5618
Fats & oils	0.0728	0.0264	0.0450	0.3760	0.4929

Table 4. *Calculation of income and household size elasticities with and without taking into account the inverse of the Mills ratio Heckman procedure: system of equations*

Commodity	$\bar{R}^2$	Income elasticity without correction	Income elasticity with correction	Household size elasticity without correction	Household size elasticity with correction
Food away from home	0.2908	0.4160	0 4938	0.1005	0.1666
Beef	0 2513	0 1102	0.1088	0 4031	0 5244
Pork	0.2652	0 0343	0 0387	0 4526	0 5675
Chicken	0.2430	0.1357	0.1417	0.3368	0.4240
Fish	0 0785	0.3208	0 3241	0 2203	0.2263
Cheese	0.3285	0 0665	0.0909	0.4134	0 5133
Milk	0 3452	− 0.0010	− 0.0007	0.8471	0 9148
Fruit	0 2564	0.1498	0 1931	0 2497	0.2809
Vegetables	0.2548	0 1527	0.1811	0.1782	0.2181
Breakfast cereals	0 4249	− 0 0176	− 0 0228	0.6694	0 8224
Bread	0.3582	0 0352	0.0391	0 4465	0 5789
Fats & oils	0.3338	0.0258	0.0471	0 3252	0.4585

V. CONCLUDING COMMENTS

The pattern of zero expenditures in analyses of Engel or expenditure functions has received widespread attention in recent times. The Heckman procedure is a way to deal with this problem to provide consistent estimates. Using this approach, we derived appropriate general expressions for calculating marginal effects and elasticities. Using our derived expressions and the 1987–88 NFCS, empirically, we calculated income and household size elasticities for 12 food commodities. We made these calculations using the Heckman procedure for single equations and for systems of equations.

Bottomline, in single-equation applications, it is very important to take into account the inverse of the Mills ratio when calculating marginal effects using a Heckman-type correction. The same is true for systems applications, but to a lesser degree.

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