An Ordered Tobit Model of Market Participation: Evidence from Kenya and Ethiopia

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Do rural households in developing countries make market participation and volume decisions simultaneously or sequentially? This article develops a two-stage econometric method to test between these two competing hypotheses regarding household-level marketing behavior. The first stage models the household's choice of whether to be a net buyer, autarkic, or a net seller in the market. The second stage models the quantity bought (sold) for net buyers (sellers) based on observable household characteristics. Using household data from Kenyan and Ethiopian livestock markets, we find evidence in favor of sequential decision making, the welfare implications of which we discuss.

Key words: market participation, agricultural household models, discrete choice and limited dependent variables, livestock markets, transactions costs.

Do rural households in developing countries make market participation and volume decisions simultaneously or sequentially? That is, does the household decide whether to be a net buyer, autarkic, or a net seller, and then decide how much to buy or sell only once it gets to market and discovers additional market information, conditional on having chosen not to be autarkic, or does the household head make both decisions before leaving for market? This seemingly innocuous question addresses a critical issue of market power that has bedeviled development economists for decades. If households make participation and volume decisions simultaneously, they effectively precommit to a volume before learning information available to them only once they arrive at market.[1] This *ex ante* decision making effectively gives the traders with whom the household interacts market power by rendering the household's demand (supply) inelastic with respect to new market information (e.g., prices) they discover, leaving poor precommitted households vulnerable to exploitation by astute traders. If, however, households make marketing decisions sequentially, then they retain greater flexibility once they arrive in a market, making their purchases or sales volume decisions *ex post* based on new information discovered at market, thereby reducing traders' capacity to extract much or all the gains from trade. Given long-standing popular assumptions that traders exert market power over sellers and buyers in rural dyadic markets, it seems appropriate to test this hypothesis directly while estimating household market participation behavior. This article is, to the best of our knowledge, the first to accomplish that objective.

The literature on market participation has been thin, especially in developing country settings where significant frictions make this question most salient. Goetz (1992) studied the participation of Senegalese agricultural households in grain markets, using a probit

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[1] This lack of information arises due to households' remoteness from markets combined with rudimentary communications with market towns and considerable intraday, much less day-to-day, volatility in market prices (Barrett and Luseno, 2004).

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model of households' discrete decision to participate in the market (either as buyers or as sellers, without distinction) followed by a second-stage switching regression model of the continuous extent of market participation decision (i.e., transaction volume). Key, Sadoulet, and de Janvry (2000) developed a structural model to estimate structural supply functions and production thresholds for Mexican farmers' participation in the maize market, based on a censoring model with an unobserved censoring threshold. Their model differentiates between the effects of fixed and proportional (i.e., variable) transactions costs. Holloway, Barrett, and Ehui (2005) used a Bayesian double-hurdle model to study the participation of Ethiopian dairy farmers in the milk market when nonnegligible fixed costs lead to nonzero censoring, as in Key, Sadoulet, and de Janvry, but distinguishing between the discrete participation decision and the continuous volume marketed decision, as in Goetz.

These extant articles on household marketing behavior in developing countries thus begin from fundamentally different assumptions on the nature of households' market participation choices. Goetz and Holloway, Barrett, and Ehui explicitly assume sequential choice: households initially decide whether or not to participate in the market, then decide on the volume purchased or sold conditional on having chosen market participation. Key, Sadoulet, and de Janvry, by contrast, implicitly model the household as making the discrete market participation choice simultaneously with the continuous decision as to volumes purchased or sold. None of the previous articles allows for the possibility that households could make marketing decisions either sequentially or simultaneously.

Our contribution is thus threefold. First, and of most general value, we introduce a method that nests within it both the simultaneous and the sequential formulations of household marketing behavior, allowing for direct testing of which assumption the data most support. The estimation method we introduce can be applied to a relatively broad range of problems, as we briefly discuss in the concluding section. Second, we add new empirical results to the thin literature on market participation, in our case looking at pastoralists' participation in livestock markets in southern Ethiopia and northern Kenya. This new application adds insights from markets for assets—livestock—to the extant literature on grain and milk marketing. Finally, our data also permit us to offer some interesting, albeit tentative, empirical insights related to possible behavioral anomalies in household marketing behavior.

The rest of the article is structured as follows. In the next section, we lay out a simple theoretical model of household marketing behavior, highlighting the implications of different assumptions about households' (discrete) participation and (continuous) volume decisions. We then present the ordered tobit estimator, a two-stage econometric model that treats both sales and purchases as censored dependent variables, but models the actual participation decision as an ordered decision by partitioning the real line into three mutually exclusive and collectively exhaustive positions *vis-à-vis* the market: net buyer, autarkic, and net seller. After briefly describing the data, we then report the estimation results from applying this novel method to study livestock marketing behavior among a population of herders in East Africa. The concluding section focuses on both the policy and the welfare implications of our empirical findings and on prospective other uses of the ordered tobit estimator.

A Theoretical Model of Market Participation

In this section, we develop a theoretical framework that allows determining whether households make simultaneous or sequential marketing decisions. In order to do so, we set up a simple dynamic agricultural household model. In the interest of parsimony, we break each time period, t, into two subperiods. In $r = 0$, the household makes the discrete participation decision at home, not yet knowing information available only at the market. If marketing choices are simultaneous, the net sales or purchases volume decision is likewise made in $r = 0$. In $r = 1$, those households that have chosen to participate in the market as either net buyers or net sellers have arrived at the market, received additional information, and, if choice is sequential, make their continuous net sales or purchases volume decision.

Under the maintained hypothesis that market behavior is driven by a household's objective of maximizing the discounted stream of consumption, one can focus on the choice problem that relates optimal (nonnegative) quantities bought and sold, Q^{b^*} and Q^{s^*} respectively, to household attributes and the environmental factors that condition consumption and marketing behaviors. For a representative household, let C_{rt} be consumption over subperiod r in period t, W_{rt} be liquid but nonproductive household wealth at the beginning of the period, H_{rt} reflect the beginning period size of a household's herd, and A_{rt} equal the amount of cultivable land it operates. The productive assets—herd and land size—generate income over period t according to the mapping $Y_{rt} = y(H_{rt}, A_{rt})$, where income is measured in units of the numéraire consumption good. The household may also incur exogenous obligatory, norms-driven ceremonial expenses, X_{rt} (likewise measured in consumption good units), associated with births, baptisms, circumcisions, marriages, and deaths.

Under the assumption of sequential choice, household livestock marketing behavior can be described by

$$(1) \qquad \max_{C_{rt}, I_{rt}^{j}, Q_{rt}^{j}} \mathrm{E}_{rt} \sum_{r=0}^{1} \sum_{t=0}^{\infty} \delta^{t} U(C_{rt}) \, \forall j \in \{b, s\}$$

subject to

$$(2) \qquad C_{rt} \le y(H_{rt}, A_{rt}) + W_{rt} - X_{rt} - (1-r)\left(I_{rt}^{s} + I_{rt}^{b}\right) fc_{rt} + p_{rt}^{*s} I_{rt}^{s} Q_{rt}^{s} - p_{rt}^{*b} I_{rt}^{b} Q_{rt}^{b}$$

$$(3) \qquad H_{1t} = H_{0t} + g(H_{0t}, e_{1t}) \ge 0$$

$$(4) \qquad H_{0t+1} = H_{1t} + g(H_{1t}, e_{0t+1}) + I_{1t}^{b} Q_{1t}^{b} - I_{1t}^{s} Q_{1t}^{s} \ge 0$$

$$(5) \qquad W_{1t} = W_{0t} - X_{0t} - C_{0t} + y(H_{0t}, A_{0t}) - \left(I_{0t}^{s} + I_{0t}^{b}\right) fc_{0t} \ge 0$$

$$(6) \qquad W_{0t+1} = W_{1t} - X_{1t} - C_{1t} + y(H_{1t}, A_{1t}) + p_{1t}^{*s} I_{1t}^{s} Q_{1t}^{s} - p_{1t}^{*b} I_{1t}^{b} Q_{1t}^{b} \ge 0$$

where E is the expectation operator, δ is the household's discount rate, $g(H_{rt}, e_{rt})$ represents within-period herd growth as a function of herd size at the beginning of the period and current local environmental conditions e_{rt}, fc_{rt} summarizes nonnegative fixed costs, including the cost of the person's transport to and from market, search, screening, and negotiation costs, etc., and the indicator variable $I_{rt}^{b} = 1$ if the household chooses to be a net buyer ($Q^{b*} > 0$, $I_{rt}^{b} = 0$ otherwise) and $I_{rt}^{s} = 1$ if it chooses to be a net seller ($Q^{s*} > 0$, $I_{rt}^{s} = 0$ otherwise) with the complementary slackness condition that $I_{rt}^{b} \cdot I_{rt}^{s} = 0$ to allow the possibility that a household remains autarkic.

If choice is sequential, then $I_{0t}^{b} = I_{1t}^{b}$ and $I_{0t}^{s} = I_{1t}^{s}$, with $Q_{0t}^{b} = Q_{0t}^{s} = 0$, that is, market participation choices are made only in $r = 0$ and purchases or sales volume decisions are made only in $r = 1$. In this formulation, the information set differs between these two decisions as the household does not yet know the shadow price, p_{1t}^{*}, it will face. Furthermore, the law of motion on liquid household wealth between periods—as distinct from within-period—no longer include the fixed costs of market participation, since those are paid in $r = 0$, when the household makes the discrete market participation choice.

Our model is essentially the dynamic generalization of the structural model presented in Key, Sadoulet, and de Janvry (2000). The p^{*j} are the shadow prices for purchases ($j = b$) and sales ($j = s$). As in de Janvry, Fafchamps, and Sadoulet (1991), the household pays a transaction cost (e.g., market taxes and transport fees) per unit of vc, so that when the market price is equal to p^{m},

$$(7) \qquad p_{rt}^{*b} = (1 + vc_{rt}) p_{rt}^{m}$$

$$(8) \qquad p_{rt}^{*s} = (1 - vc_{rt}) p_{rt}^{m}.$$

Controlling for random variation in prices described by the mean zero stochastic term z^{k} for $k \in \{p, fc, vc\}$—future market prices, fixed costs, and variable costs follow a random walk:

$$(9) \qquad p_{rt+1}^{m} = p_{rt}^{m} + z_{rt}^{p}$$

$$(10) \qquad fc_{rt+1} = fc_{rt} + z_{rt}^{fc}$$

$$(11) \qquad vc_{rt+1} = vc_{rt} + z_{rt}^{vc}.$$

Rewriting this dynamic optimization problem as a Bellman equation (not shown), one can derive the reduced form of the household's optimum decisions as

$$(12) \qquad I_{0t}^{b*} = i^{b}\left(A_{0t}, H_{0t}, W_{0t}, X_{0t}, e_{0t}, p_{1t-1}^{m}, fc_{0t}, vc_{1t-1}\right)$$

$$(13) \qquad I_{0t}^{s*} = i^{s}\left(A_{0t}, H_{0t}, W_{0t}, X_{0t}, e_{0t}, p_{1t-1}^{m}, fc_{0t}, vc_{1t-1}\right)$$

$$(14) \qquad Q_{1t}^{b*} = i^{b}\left(A_{1t}, H_{1t}, I_{0t}^{b}, W_{1t}, X_{1t}, e_{1t}, p_{1t}^{m}, vc_{1t}, z_{1t}^{k}\right)$$

$$(15) \qquad Q_{1t}^{s*} = i^{s}\left(A_{1t}, H_{1t}, I_{0t}^{s}, W_{1t}, X_{1t}, e_{1t}, p_{1t}^{m}, vc_{1t}, z_{1t}^{k}\right).$$

The relationship between the purchase or sales quantities and the discrete market participation choice is a form of selectivity correction akin to that on which Goetz (1992) focused. Here, however, we distinguish between net buyers and net sellers. Because net buyers and net sellers can be strictly ordered along the real line describing net sales ($S_{rt} \equiv Q_{rt}^{s*} - Q_{rt}^{b*}$) positions, we can treat the $\{I_{rt}^{b*}, I_{rt}^{s*}\}$ pair as an ordinal variable: $\{I_{rt}^{b*} = 1, I_{rt}^{s*} = 0; I_{rt}^{b*} = 0, I_{rt}^{s*} = 0; I_{rt}^{b*} = 0, I_{rt}^{s*} = 1\}$, equivalent to net buyers, autarkic households, and net sellers, respectively.

The simultaneous choice model is nested within the sequential specification above. When the household makes its marketing and volume decision simultaneously, subperiods disappear and one is left only with the following two marketing behavioral equations:

$$(16) \quad Q_t^{b*} = q^b\big(A_t, H_t, W_t, X_t, e_t, fc_t, p_t^m, vc_t, \delta\big)$$

and

$$(17) \quad Q_t^{s*} = q^s\big(A_t, H_t, W_t, X_t, e_t, fc_t, p_t^m, vc_t, \delta\big).$$

The theoretical predictions of both the sequential and simultaneous choice models are several. First, one would expect that $Q_t^{b*}(Q_t^{s*})$ is decreasing (increasing) in A_t, that is, if a household cultivates, its mobility is restricted, thereby limiting the size of the herd it can manage sustainably, given local forage and water resources. Second, because income is increasing in herd size (i.e., income is not a stationary process), the usual Friedmanite consumption smoothing behavior breaks down. As long as $E[\partial g(H_t, e_t)/\partial H_t] > 0$ (i.e., expected herd growth is increasing in herd size), households have an incentive for herd accumulation that will limit their use of livestock to smooth consumption (McPeak, 2004). This can lead to both a positive (negative) relation between *ex ante* herd size and livestock sales (purchases) and a potentially negative (positive) relation between livestock sales (purchases) and income from sources other than livestock sales. Third, given the liquidity constraints these households face, they can only satisfy current consumption from asset sales. Thus livestock sales (purchases) could be increasing (decreasing) in household demographic shocks that necessitate ceremonial expenditures, X_t, and sales could be negatively related to price (i.e., the supply curve could bend backward) as households liquidate only as many animals as are necessary, given prevailing prices, to meet immediate expenditure needs. Fourth, both sales and purchases should be decreasing in fixed and variable costs. Fifth, there should be a positive relationship between wealth and purchases since the budget constraint limits poorer households' capacity to buy livestock.

There are, however, significant differences between the simultaneous and sequential choice models. First, when household choice is simultaneous, the fixed costs of market participation (*fc*) become an argument of the optimum marketing decisions Q^{b*} and Q^{s*}. This means that conditional on finding that the data support the sequential formulation of the household marketing choice, tests of the exclusionary hypothesis that fixed costs are unrelated to quantities sold or purchased thus serve as tests of the prospective behavioral anomaly that households take fixed costs into account when standard microeconomic theory posits they do not. Second, because households do not precommit to sales volumes prior to receiving full, current information on prices in the sequential choice model, one would expect greater price elasticity of demand under the sequential marketing decisions model than under the simultaneous decisions model.

The distinction between whether a household makes its market participation and purchase or sales volume decisions simultaneously or sequentially has significant implications for several relationships of interest in market participation studies. Most especially, if herders choose how much to sell or how much to buy at the same time they choose whether to sell or to buy, that is, before they get to market and know the prevailing market price, then they are more likely to exhibit price inelastic demand and supply for animals and to be more vulnerable to exploitation by traders. However, if herders first choose whether they will be buyers, sellers, or nonparticipants, then, conditional on their choosing to be buyers or sellers, they go to market, uncover more details about the conditions under which they can transact, and subsequently decide how much to buy or sell, the sequential nature of household marketing choice reduces the likelihood of trader exploitation of herders. We exploit the two specifications—simultaneous and sequential—of the dynamic agricultural household model outlined above in order to determine whether households make *ex ante* or *ex post* marketing decisions. The simultaneous choice model described by equations (16) and (17) is estimable as a bivariate tobit model, but in order to estimate the sequential choice model described by equations (12)–(15), one must define a likelihood function that reflects the first-stage ordered participation and the second-stage continuous volume decisions.

An Econometric Model of Market Participation

This section develops the ordered tobit model we implement in the next section. The motivation for the model comes from the prospective sequencing and jointness of the household's marketing decisions, as just described. The key insight is that because a household's net sales (sales minus purchases) volume spans the real line,[2] one can divide the continuous market participation outcome into three distinct categories: net buyer (households whose net sales are negative), autarkic (households whose net sales are equal to zero), and net seller (households whose net sales are positive) households. Because these three categories are logically ordered, and since it is informative to distinguish between net buyers and net sellers rather than to just lump them together as "market participants," we can first estimate an ordered probit participation decision, then estimate a censored model of net sales or net purchases volume. By estimating the ordered tobit and then comparing it to a bivariate tobit model using a test of nonnested hypotheses, we can then establish whether the discrete participation and continuous volume decisions are made sequentially or simultaneously.

Our ordered tobit[3] specification allows us to study fixed and variable transactions costs separately, as do Key, Sadoulet, and de Janvry (2000), but using an estimator that we find converges more readily than does their somewhat more cumbersome likelihood function. This approach also allows for nonzero censoring points at the first stage, that is, the thresholds below and above which a household will find it worthwhile to be a net buyer or a net seller, respectively, as in Key, Sadoulet, and de Janvry (2000) and Holloway, Barrett, and Ehui (2005).

The Ordered Tobit Model

The specification of the ordered tobit model is as follows. Let y_{1i} denote the category—net buyer ($y_{1i} = 0$), autarkic ($y_{1i} = 1$), or net seller ($y_{1i} = 2$)—to which household i belongs. The specification of the first-stage decision is that of an ordered probit. The innovation comes at the second stage. Let $y_{2i} > 0$ be the total units of livestock purchased by household i and let $y_{3i} > 0$ be the total units of livestock sold by household i. Note that these two variables define clear, mutually exclusive subsets of the data. As per the complementary slackness condition of the previous section, a household cannot simultaneously be a net buyer and a net seller.

We could treat the full problem under the maintained hypothesis of simultaneous choice by estimating a bivariate tobit, with one equation for net buyer households and one for net sellers households. Following the earlier theoretical discussion, however, one would prefer to allow the possibility of sequential decision making. It would therefore be better to estimate an ordered probit in the first stage and then append two linear regressions to the $y_1 = 0$ and $y_1 = 2$ categories: one for net buyers and one for net sellers, respectively, and then test whether or not the ordered tobit specification is better supported by the data relative to the bivariate tobit. This effectively allows direct testing of the hypothesis that household market participation and volume decisions are made sequentially versus the null that they are made simultaneously.

In the following empirical analysis, x_1 is the vector of first-stage regressors, x_2 is the vector of second-stage regressors thought to affect the volume of purchases by net buyers, and x_3 is the vector of second-stage regressors thought to affect the volume of sales by net sellers. The result is an ordered probit combined with two of what Amemiya (1985) refers to as Type II tobit models. Therefore, what we estimate is more precisely an ordered Heckit, but this is just a special case of the more general ordered tobit. We estimate the model by limited information maximum likelihood, using Heckman's two-step approach. We nonetheless present the full information maximum likelihood specification here in order to remain as general as possible. We also adapted the Heckman correction for

[2] In the presence of nonzero censoring points, regions between zero and the censoring points may have zero density.

[3] Klein and Sherman (1997) also combine the ordered probit and tobit estimators but in reverse order. They first estimate a censored regression and then use the parameters from that first stage to fit an ordered response model. Our approach thus differs significantly from theirs.

standard errors to our model, which we present in the Appendix.

The log-likelihood for our ordered tobit estimator is

(18)

$$\ell(\alpha', \beta', \sigma') = \sum_{i=1}^{N} \Bigg\{ I(y_{1i} = 0) \times \Bigg[\ln \Phi\Bigg(\frac{\alpha_1 - x_{1i}\beta_1 + (y_{2i} - x_{2i}\beta_2)\rho_{12}/\sigma_2}{\sqrt{1-\rho_{12}^2}} \Bigg) - \frac{1}{2}\Bigg(\frac{y_{2i} - x_{2i}\beta_2}{\sigma_2}\Bigg)^2 - \ln\left(\sqrt{2\pi}\sigma_2\right) \Bigg] + I(y_{1i}=1)[\ln[\Phi(\alpha_2 - x_{1i}\beta_1) - \Phi(\alpha_1 - x_{1i}\beta_1)]] + I(y_{1i} = 2) \times \Bigg[\ln \Phi\Bigg(\frac{x_{1i}\beta_1 - \alpha_2 + (y_{3i} - x_{3i}\beta_3)\rho_{13}/\sigma_3}{\sqrt{1-\rho_{13}^2}} \Bigg) - \frac{1}{2}\Bigg(\frac{y_{3i} - x_{3i}\beta_3}{\sigma_3}\Bigg)^2 - \ln\left(\sqrt{2\pi}\sigma_3\right) \Bigg] \Bigg\}$$

where α is a (2×1) vector of unknown threshold parameters, $\beta = (\beta_1, \beta_2, \beta_3)$ is a $([K + L + M] \times 1)$ vector of parameters, σ is a (2×1) vector of variance parameters, one for each linear component, that is, net purchases and net sales, and $\Phi(\cdot)$ is the standard normal cumulative distribution function. Thus, the model estimates $K + L + M + 4$ parameters by maximum likelihood.

The three error terms in the model, ε_1, ε_2, and ε_3, follow a trivariate normal distribution, that is, $\varepsilon \sim N(\underline{0}, \Sigma)$, where $\underline{0}$ is a (3×1) vector of zeros and Σ is the (3×3) variance–covariance matrix between the equations of the ordered tobit model. The error terms of each equation are correlated via the ρ_{ij} coefficients, where $i, j \in \{1, 2, 3\}$.

The ordered tobit model has been the subject of very little published work. Groot and van den Brink (1999) study overpayment and earnings satisfaction, developing a computationally similar but atheoretical model.[4] Ranasinghe and Hartog's (1997) unpublished working paper explores investment in post-compulsory education in Sri Lanka. Finally, Greene (2003) discusses a model similar to ours, that is, first-stage ordered probit, second-stage linear regression, except his second stage only consists of one linear regression. Yet, the prospective applications of this model are many, and it is rather easy to estimate with any statistical package that accommodates maximum likelihood.

Data and Descriptive Statistics

We study livestock market participation by pastoralists in a large, contiguous area of Northern Kenya and Southern Ethiopia. Observers have long been puzzled by the limited use of livestock markets by East African pastoralists who hold most of their wealth in the form of livestock, who face considerable income variability, and who regularly confront climatic shocks that plunge them into massive herd die-offs and loss of wealth (Desta, 1999; Little et al., 2001; Barrett, Bellemare, and Osterloh, 2006; Lybbert et al., 2004). It would seem that opportunistic use of markets would permit herders to increase their wealth by buying when prices are low and selling when prices are high and to smooth consumption through conversion between livestock and cash useful for purchasing food. Yet such behavior seems relatively rare (Barrett, Bellemare, and Osterloh, 2006; Lybbert et al., 2004; McPeak, 2004).

The data come from a study of risk management among East African pastoralists and consist of a panel of 337 pastoralist households from eleven sites in the arid and semiarid lands of Northern Kenya and Southern Ethiopia. Each household was observed quarterly between June 2000 and June 2002. Further details on the surveys, sites, and instruments are available in Barrett et al. (2004).

We pool all nine time periods together and treat the data set as a cross section, first because of the highly unbalanced nature of our panel, and second due to the inherent complexity that an extension of the ordered tobit to a panel setting would involve.[5] The descriptive statistics presented here thus treat household i in period t and household i in period s as two distinct observations for $s \neq t$. The implications of pooling all observations are as follows. If we could exploit the panel nature of our data set and a fixed effects structure were appropriate, our approach would suffer

[4] Groot and van den Brink (1999) use an estimator similar to ours but incorporating a Type I rather than a Type II tobit.

[5] The number of observations per time period ranged from 233 to 255, reflecting a mixture of attrition and interruption.

Table 1. Full-Sample Descriptive Statistics

	$N = 2{,}037$	
Variable	Mean	Std. Dev.
Female household head dummy	0.3068238	0.4612888
Household head age (years)	48.80511	14.70051
Dependency ratio	0.4827757	0.1998441
Household size (persons)	7.260187	3.748484
Land (hectares owned)	1.412248	2.569049
Assets (Ksh)	19,760.9	196087
Births (persons)	0.0618557	0.2409524
Deaths (persons)	0.0166912	0.1319204
Income (Ksh, including food aid)	11,818.03	22,395.67
Herd size (TLUs)	19.2374	29.29284
Percent female (TLUs)	0.6766991	0.2448751
Encumbered males (TLUs)	0.4650221	2.928111
Encumbered females (TLUs)	0.8929848	4.501852
Avg. price of large stock (Ksh)	5,558.806	2,664.602
Avg. price of small stock (Ksh)	790.6819	424.0051
Animal births (TLUs)	1.194113	3.294443
Net buyer dummy	0.0382916	0.1919465
Autarkic dummy	0.6843397	0.4648924
Net seller dummy	0.2773687	0.4478099
Net sales (TLUs)	0.2229602	1.457145
Fixed costs (Ksh)	126.4936	245.4636
Variable costs (Ksh/TLU)	96.01313	135.4184
Sales (net sellers)	0.9925133	1.828466
Purchases (net buyers)	1.366667	4.883537

from an omitted variables problem, which would bias parameter estimates at both stages. If, however, a random effects structure were appropriate, our estimated coefficients would be unbiased, but the standard errors around them would be too small, thus leading to over-rejection of null hypotheses. One would assume a priori that a random effects approach would apply to these data, since the households were randomly selected from the sampling frame.[6] Nevertheless, the pooling of all longitudinal observations is a clear shortcoming of our approach. It is unfortunately the best we can do given the data at hand.

Table 1 provides descriptive statistics. Almost 70% of the households are male-headed, with an average size of 7.3 people and a dependency ratio of nearly 0.5.[7] Most households own livestock, with an average herd size of about 20 tropical livestock units (TLU), a standard measure for aggregating across ruminant species such as camels, cattle, goats, and sheep.[8] Herds reproduce, on average, at a rate of about 6.5% annually (animal births/total herd size). Pastoralists have a strong preference for holding cows for milk and calves, so herds are more than two-thirds female, on average.

Property rights in livestock can be complex. Households often give or lend animals to one another without surrendering all rights in the animal. For example, it is common for a household to "own" an animal given to it by a relative, yet the household is not permitted to sell or slaughter the animal nor to give it to anyone outside the clan or village. While these encumbered or restricted property rights may matter to marketing decisions, especially with respect to purchasing cows (for which restricted gifts may be a substitute) or selling bulls, they affect less than 10% of a household's herd, on average. Mean land holdings are small, at about 1.4 ha, much of which goes uncultivated any given year due to insufficient rainfall. Other assets owned by the household include bicycles, radios, wooden beds, tables and other furniture, watches, lanterns, ploughs, small shops or other businesses, nonlocal breed animals, vehicles, and urban property, all valued in Kenyan shillings (Ksh).[9] The value of these assets amounts to a bit more than U.S.$35 per capita, while household income (the sum of the market value of milk and crop production, sales of firewood, charcoal, crafts and hides, and wage and salary earnings) over the preceding quarter averaged around $1.75 per day, or less than $0.24 daily per capita income, underscoring the poverty these herders suffer.

Variable cost expenditures on market participation represent a surprisingly modest share of price:[10] costs related to per animal transport costs and market fees add (for buyers, subtract for sellers) only about 12% to the small

[6] Recall that a fixed effects estimator is *a priori* applicable when one observes all sampling units in the population, whereas a random effects estimator is conceptually appropriate when studying a random sample of individuals in a population.

[7] A household's dependency ratio is calculated by dividing the number of individuals under 15 years of age plus the number of individuals over 64 years of age by the total number of individuals in the household.

[8] One TLU equals 0.7 camel, 1 cattle, 10 goats, or 11 sheep.

[9] For Ethiopian households, we use 1 Ethiopian birr = 8.75 Ksh. Note that U.S.$1.00 ≅ Ksh 75.

[10] In our analysis, fixed fees include accommodations, food, and transportation for the herder as well as bribery, security expenditures, and medications. Variable fees are fees per animal paid to county or municipal authorities as well as district veterinary officer inspection and other veterinary fees.

Table 2. Bivariate Tobit Estimation Results

	Quantity Bought		Quantity Sold	
Variable	Coefficient	Std. Err.	Coefficient	Std. Err.
Household head gender	1.526364	1.001167	−0.1930418	0.146936
Household head age	0.2963331**	0.1515074	−0.0737349***	0.0258084
Household head age squared	−0.0029066**	0.0014053	0.0006811***	0.000239
Household size	−0.0424101	0.1271381	0.0093567	0.0190557
Dependency ratio	−3.527704*	2.000703	0.243366	0.3242443
Births	0.9750697	1.342157	0.0311499	0.2021928
Deaths	2.152439	2.717678	0.6644136*	0.3773919
Household assets	7.21*e*-06***	2.61*e*-06	3.68*e*-06***	1.94*e*-07
Land	0.2239154	0.1550544	0.0659076**	0.0266245
Income	0.0001149*	0.0000647	−0.0000165*	8.44*e*-06
Herd size	0.0431043	0.0317213	0.0056346*	0.0032272
Percent female (TLUs)	4.052207**	1.651769	0.0064873	0.2972863
Encumbered males	−0.0581539	0.4372356	0.0133173	0.0187927
Encumbered females	−0.1561055	0.2140918	−0.0043805	0.0124091
Fixed costs	−0.0050478**	0.002457	0.0005547**	0.0002498
Variable costs	0.0101344**	0.0052924	−0.0005345	0.0006172
Log avg. price large stock	−1.894086**	0.85668	−0.0863504	0.1475813
Log Avg. price small stock	−1.710362	1.074863	−0.0728132	0.1343425
Constant	22.23479**	10.36375	4.120857**	1.648611
$\rho(\varepsilon_b, \varepsilon_s)$	−0.5931155***			

stock (goat or sheep) price and less than 2% to the large stock (camel and cattle) price. Fixed costs represent a higher share of price, however. Costs associated with transport and lodging expenditures for the individual who sells or buys animals and any market fees unrelated to volumes sold or purchased are about 30% larger than variable costs per TLU.

Results and Analysis

This section first presents estimation results for a bivariate tobit model consistent with the simultaneous choice model outlined earlier. Then, we present estimation results from the ordered tobit model that allows the possibility of sequential household choice. Finally, we test the null hypothesis that a simultaneous choice model suffices for describing the livestock marketing behavior of our sample households using Davidson and MacKinnon's (1993) *J*-test of nonnested hypotheses.

Bivariate Tobit Results

We estimate the bivariate tobit model—that is, one tobit for net buyer households, another for net seller households—under the maintained hypothesis that discrete participation and continuous volume decisions are made simultaneously. The two tobits share the autarkic observations in common. Table 2 reports the estimated bivariate tobit coefficients. Note that we omit the coefficient estimates for the quarterly seasonal (March to June, June to September, and September to December) and location dummies included to account for climatic, range, security conditions, and other unobserved spatial or temporal characteristics common to all households in the relevant subsample.

Given that income is a function of sales proceeds, household income is likely endogenous. We instrumented for income using the household head's education, time and location interaction terms, beginning period herd size, and land assets. See Appendix, table A1 for instrumenting equation estimation results.[11] Education is a good instrument for income given that higher educational attainment is usually associated with off-farm employment. The instrumenting regression had an adjusted R^2 of 0.2630, so we can rule out overfitting. We use the same instrumenting equation results for income in the ordered tobit below.

One might also think a priori that a household's norms-driven ceremonial expenses, the amount of land it controls, and the variable costs it faces when buying or selling livestock might also be endogenous to its net sales and/or

[11] In the interest of brevity, we omit reporting estimated coefficients for time-and-location interaction terms.

net purchases of livestock. However, expenses on baptisms and marriages usually occur only at certain times of the year, planned well in advance. In other words, these expenses are predetermined relative to the quarterly frequency marketing data we study. The amount of cultivable land (not grazing or pasture land) under the control of the household is similarly effectively exogenous in these sites. In Ethiopia, all land is formally owned by the state and occasionally (and somewhat unpredictably) redistributed, so that a household does not have a choice of land holding that might be correlated with some unobservable that is causally connected to livestock marketing patterns. In Kenya, most land is allocated by clans, and a similar argument holds. Finally, variable costs are transportation and market fees. Transportation fees are set in a relatively competitive market, and market fees are set by local governments, so that households are price takers for both. Moreover, we use average variable costs per animal, not total variable costs, since the latter could be spuriously correlated with net sales or net purchases.

Given limitations of space, and because the bivariate tobit is only instrumental in our approach, we turn directly to a discussion of the variables of greatest interest: prices and transactions costs. Variable costs are positively associated with the number of animals bought, a puzzling result since one would expect the volume of trade to be strictly decreasing in variable costs.[12] Fixed market participation costs decrease the number of animals bought but increase the number of animals sold. The former effect is consistent with the existence of binding liquidity constraints that reduce the number of animals a herder can afford to purchase the more she must spend on fixed costs *ex ante*. The latter effect is consistent with the walking bank hypothesis that the herder sells as many animals as are needed to meet immediate cash needs and that number increases with the fixed costs the herder must incur. Alternatively, these results could reflect the well-known behavioral anomaly that people take sunk costs into consideration at the margin even when standard microeconomic theory suggests they do not. Under this hypothesis, buyers seek to limit their expenditures and sellers try to recover them by considering sunk costs at the margin. Pastoralists appear highly responsive to prices on the demand side, with demand for both large and small stock decreasing in prices (albeit not significantly so for small stock). Under the maintained assumption of simultaneous choice, however, herders appear nonresponsive to price on the supply side. Since herders sell far more often than they buy, the implication of the estimation results under the assumption of simultaneous choice is that herders can be exploited by traders.

Ordered Tobit Results

We now explore whether these estimation results change if we relax the assumption that households make simultaneous marketing decisions by employing the ordered tobit model to estimate the more general, sequential choice model.[13] Given that both linear components include a selection term—the usual inverse Mills ratio (IMR)—we apply Heckman's correction to the variance–covariance matrices for each of the second-stage regressions. The only difference between our method and that of Heckman comes from the first stage, and in that sense, our model offers a modest extension to Heckman (1979).

The ordered probit model of discrete market participation yields intuitive results (table 3). The nonzero censoring points are of opposite signs, with the lower censoring threshold at −1.59 TLU net purchases and the upper threshold at 0.95 TLU net sales, each statistically significantly different from zero. These estimates suggest that purchases or sales of less than 1 TLU are generally uneconomical, given the monetary and nonmonetary costs of market participation in this region. People are more willing to enter the market for smaller volume sales than purchases, likely reflecting the fact that sales of livestock are essentially means by which households meet immediate cash needs related to payment of school fees, food purchases, and ceremonial or emergency health expenses.

Female-headed households are more likely to be autarkic than to be net sellers and are

[12] Given motorized transport and inspection bottlenecks in the region, it is possible that variable transport costs and inspection and certification fees are endogenous to aggregate market demand—while still exogenous to individual marketing decisions—increasing at those times when households most want to restock. Our data, however, do not include information on aggregate market transactions, making it infeasible to control for this possibility, which could explain the anomalous result.

[13] We estimate the ordered tobit by limited information maximum likelihood, that is, using Heckman's two-step estimator, rather than a simultaneous estimator, following the recommendations of Puhani (2000) given collinearity in our sample data.

Table 3. Estimation Results for the First Stage of the Ordered Tobit

Variable	Coefficient	Std. Err.
Household head gender	−0.1199407***	0.0641554
Household head age	0.0071154	0.0115469
Household head age squared	−0.0000848	0.0001079
Household size	0.0180623	0.0213252
Children	0.0091998	0.0395143
Dependency ratio	0.1057024	0.2600769
Births	0.2543608**	0.1138981
Deaths	0.1213393	0.2086002
Household assets	−3.91e-08	1.98e-07
Land	0.010639	0.0141761
Income	2.95e-06	4.71e-06
Herd size	0.0028195	0.0018374
Percent female (TLUs)	0.1717806	0.1297437
Encumbered males	0.0161459	0.0144535
Encumbered females	−0.0059672	0.0083052
Fixed costs	0.0005797**	0.0002375
Fixed costs squared	−2.23e-07*	1.34e-07
Animal births	0.0268813**	0.0121053
α_1	−1.586686***	0.331772
α_2	0.951289***	0.3310051

more likely to be net buyers than to be autarkic, *ceteris paribus*. Human births positively affect the categorical outcome, again consistent with the notion that exogenous demographic shocks associated with culturally mandated expenditures affect livestock marketing patterns. Animal births likewise exert a positive effect on the ordered market participation variable. The more animal births a household herd enjoys in a period, the more likely it is to be autarkic instead of being a net buyer and the more likely it is to be a net seller instead of being autarkic. Wealth and income have no statistically significant effect on the discrete market participation decision in the first stage of the ordered tobit.

The fixed costs of market participation exert an increasing, concave effect on market participation up through almost the 75th percentile of the data, at which point the effect turns negative. This implies that over most of the range of fixed costs observed in these data, the marginal effect is greatest with respect to purchase decisions, moving households from net purchases to autarky. However, when fixed costs are extremely high—beyond about Ksh415—this encourages households to move from net seller positions to autarky.

The second-stage net purchase and net sales volume choices conditional on expected market participation likewise make sense, repeating many of the more intuitive results from the bivariate tobit model (table 4). Pronounced and intuitive life cycle effects emerge, as households buy more and sell less up through about age 50—roughly the mean in these data—and then switch to selling more and buying less. Livestock sales (purchases) are decreasing (increasing) in household nonlivestock income. When income is high, they sell fewer animals and when income is low, they sell more, *ceteris paribus*. Sales and purchases are both increasing in households' nonlivestock assets as wealthier people sell in larger volumes than poorer households with equal probability of market participation. Household land holdings are positively related to sales because pastoralists who own land have effectively sedentarized themselves, reducing the herd sizes they can manage within a fixed space subject to considerable intertemporal variability in forage and water availability. Herd size matters to livestock marketing patterns. Households with larger herds sell slightly more animals, although this effect, while statistically significant, is small in magnitude, indicating that marketing is not used to regulate herd sizes (Lybbert et al., 2004).

The data do not support our hypothesis that complex indigenous livestock gifting and loaning institutions that encumber some animals in many households' herds impede livestock marketing behavior. Nor does it appear that the gender mix of a household's herd matters to market participation or transactions volumes.

The multifunctional nature of livestock holding in pastoralist regions again becomes evident when we consider the estimated effect of livestock prices on net sales and purchases. Larger stock (camels and cattle) are productive assets held for long-term equity growth. Net sales decrease modestly with price, while net purchases decrease sharply as prices rise, with price elasticities of supply and demand of $\eta_s = -0.10$ and $\eta_b = -2.73$, respectively, at the sample means. Herders are highly price responsive on the buyer side but much less price responsive on the seller side. Moreover, the backward-bending estimated supply curve is consistent with the walking bank model of livestock management. Herders tend to liquidate animals, as needed, to meet immediate cash needs (Barrett, Bellemare, and Osterloh, 2006), thus the number they sell falls as price increases. Note that the estimated

Table 4. Estimation Results for the Second Stage of the Ordered Tobit

	Quantity Bought			Quantity Sold	
Variable	Coefficient	Std. Err. (Heckman)	Std. Err.	Coefficient	Std. Err. (Heckman)
Household head gender	1.285796	92.742948	1.769402	−0.0364986	0.39662522
Household head age	0.3882739	1.7234782	0.1999706	−0.077481***	0.00725739
Household head age squared	−0.003572***	0.00014832	0.0019399	0.0007297***	6.282e-07
Household size	−0.8324656	2.7430249	0.2501537	−0.0112788	0.01122807
Dependency ratio	−16.89952	351.27406	2.831598	0.1481089	1.4769656
Births	−3.723545	333.92481	2.065978	−0.1305168	1.3862985
Deaths	2.052634	730.83915	3.946894	0.6257654	3.0944864
Household assets	0.0000355***	9.303e-10	0.0000116	3.53e-06***	3.904e-12
Land	−0.3305331	3.3383848	0.2524294	0.0732192***	0.01445112
Income	0.0001777***	2.958e-07	0.0001129	−0.000012***	1.239e-09
Herd size	−0.0579812	0.11704397	0.069558	0.0026422***	0.00042646
Percent female (TLUs)	4.324919	279.42664	2.471809	−0.0216494	1.1846152
Encumbered males	0.1230207	6.3491891	0.8751133	−0.0032226	0.02502689
Encumbered females	−0.1867259	1.6364485	0.42887	−0.0013632	0.00653026
Fixed costs	−0.026322***	0.00056822	0.0056752	0.0001716***	2.035e-06
Variable costs	0.0456513***	0.00006896	0.0102437	−0.000081***	5.852e-07
Log avg. price large stock	−3.73215***	0.84147319	1.121651	−0.100242***	0.00929865
Log avg. price small stock	0.3518346	1.6675088	1.578528	−0.126123***	0.01777674
Inverted mills ratio (IMRs)	19.86553	3,598.7754	6.277778	−1.277819	20.417661
Constant	−13.17884	10,202.617	17.87172	6.321585	66.95251
Price elasticity	−2.730837	–	–	−0.100998	–
ρ_{12}	0.1512***				
ρ_{13}	0.2834***				

price effects under the ordered tobit model are statistically significantly different from zero and of larger magnitude than under the bivariate tobit model, consistent with the basic point made earlier that sequential decision making implies greater price elasticity of herder demand and supply and, thus, less opportunity for traders to exercise market power.

The estimated effects of transactions costs are qualitatively unchanged from those under the bivariate tobit model. Variable costs appear to exert a small, significant negative effect on sales volumes (this effect was statistically insignificant in the bivariate tobit model), as one would expect, but an anomalous positive effect on purchase volumes. Meanwhile, fixed costs appear to affect purchase (sales) volumes negatively (positively) and significantly. Recall that the theoretical model based on sequential choice predicts that fixed costs should have no effect whatsoever on the continuous volume decision, only on the discrete participation decision, which was indeed affected by fixed costs. This thus seems to offer a bit more evidence in support of the behavioral anomaly hypothesis, although we still cannot identify that effect separately from a liquidity constraint effect.

One concern in the ordered tobit model estimates is the large standard errors for the net buyer component. This arises from lack of effective identification available in the data. We have only two variables (the number of children in the household as well as the number of animals born in the last quarter) to identify whether households are net buyers, autarkic, or net sellers. Moreover, although our sample includes 1,394 autarkic households and 565 net seller households, it only includes 78 net buyer households. Thus, both weak identification and multicollinearity likely come into play here. Neither effect will bias our parameter estimates, but the precision of those estimates becomes compromised. We therefore also include the standard errors without the Heckman correction for the net buyer results in the third column of table 4. Selection into the 3% of households who are net buyers proves difficult to explain with the variables in our data set.

The results of the ordered tobit differ from those of the bivariate tobit model under the assumption of simultaneous choice. Many of the more intuitive results only emerge from the more general estimation method we introduce here. For example, fixed costs of marketing and the responsiveness of livestock sales to prices are statistically significant only in the more general, two-stage model. These qualitative differences suggest that the estimator we introduce more accurately reflects livestock marketing behavior among these households.

Having established that the simultaneous and sequential model specifications yield different results and that the ordered tobit results appear intuitively more plausible, we now turn to the question of which model better fits the data statistically. One method is to check whether the IMRs are statistically significant in either of the second-stage linear components of the ordered tobit model. The weakness of that approach is that it depends fundamentally on the instruments used to identify the first-stage choice. As already discussed, the data set offers few good instruments for that purpose. Weak identification causes imprecise estimation of the effect of the IMR on second-stage sales or purchase volumes. As a consequence, the IMR coefficient estimates are not statistically significantly different from zero in either regression reported in table 4.

An alternative and much better method relies on a *J*-test (Davidson and MacKinnon, 1993) to discriminate between our two nonnested models. We first obtained the predicted values for net buyers and net sellers from the ordered tobit model and included them as regressors in their respective bivariate tobit components. We then obtained the predicted values for net buyers and net sellers from the bivariate tobit model and included them as regressors in their respective ordered tobit components. Our null hypotheses are as follows: (i) the estimated coefficients for the predicted values of the ordered tobit model are jointly not statistically significantly different from zero in the bivariate tobit model and (ii) the estimated coefficients for the predicted values of the bivariate tobit model are jointly not statistically significantly different from zero in the ordered tobit model. Thus, our hypotheses, respectively, test that (i) the ordered tobit model has no explanatory power with respect to the bivariate tobit model and (ii) the bivariate tobit model has no explanatory power with respect to the ordered tobit model. Rejection of null hypothesis (i) coupled with failure to reject null hypothesis (ii) favors the ordered tobit model over the bivariate tobit model, that is, favors the hypothesis that households make livestock marketing decisions sequentially and not simultaneously. The test statistics, each distributed χ^2 (2), were 7.20 and 2.64 for hypotheses (i) and (ii), respectively. Thus, we reject the hypothesis that the ordered tobit does not have explanatory power with respect to the bivariate tobit, and the hypothesis that the bivariate tobit does not have explanatory power with respect to the ordered tobit cannot be rejected. This is a strong evidence in favor of the sequential theoretical formulation of herder marketing behavior and the resulting ordered tobit empirical specification.

Conclusion

In this article, we highlighted the important differences in behavior depending on whether households make (discrete) market participation and (continuous) sales or purchase volumes choices sequentially or simultaneously. We then developed—and found strong empirical support for—a two-stage econometric model that permits direct testing between these competing ways of understanding household-level marketing behavior. From a policy perspective, the most important implication of our results is that households that make sequential marketing decisions are more price responsive and less likely to be vulnerable to trader exploitation. This is consistent with recent price analysis in the region that finds little support for the hypothesis that traders are able to vary prices locally to take advantage of herders (Barrett and Luseno, 2004).

Also, our empirical results shed some light on the contemporary puzzle of why pastoralist households in the arid and semiarid lands of East Africa make relatively little use of livestock markets. Households follow strong life cycles of accumulation, steadily building their herds over most of their adult lives. Fixed costs of market participation also impede market participation. Mainly, however, households in this region keep livestock as a sort of walking bank, adjusting sales and purchase volumes to fixed costs and nonlivestock income, as well as to prices, in a manner suggesting that they are used to meet immediate cash needs when cash is not otherwise available but that livestock are the preferred form in which to hold assets when cash is available to meet immediate expenditure needs. It appears that East African pastoralists are less drawn to the commercialization of livestock than to accumulating substantial herds.

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Appendix

Heckman-Corrected Variance Matrix for the Ordered Tobit

In this appendix, we present the Heckman correction used to get the proper standard errors at the second stage of the ordered tobit model. The first step is to consider the ordered probit model estimated in the first stage of the ordered tobit. From that first stage, we derive that

$$\text{(A.1)} \quad y_{1i} = \begin{cases} 0 & \text{if } x_1\beta_1 + \varepsilon_1 \leq \alpha_1 \\ 1 & \text{if } \alpha_1 < x_1\beta_1 + \varepsilon_1 \leq \alpha_2 \\ 2 & \text{if } x_1\beta_1 + \varepsilon_1 > \alpha_2 \end{cases}$$

so that

$$\text{(A.2)} \quad y_{1i} = \begin{cases} 0 & \text{if } \varepsilon_1 \in (-\infty, \alpha_1 - x_1\beta_1] \\ 1 & \text{if } \varepsilon_1 \in [\alpha_1 - x_1\beta_1, \alpha_2 - x_1\beta_1] \\ 2 & \text{if } \varepsilon_1 \in (\alpha_2 - x_1\beta_1, \infty). \end{cases}$$

Thus, by symmetry of $\phi(\cdot)$, the standard normal pdf, we have that $P(y = 0) = \Phi(\alpha_1 - x_1\beta_1)$ and $P(y = 2) = \Phi(x_1\beta_1 - \alpha_2)$. We can then obtain the IMRs for net buyer and net seller households, respectively:

$$\text{(A.3)} \quad \lambda_b = \frac{\phi(\alpha_1 - x_1\beta_1)}{\Phi(\alpha_1 - x_1\beta_1)}$$

$$\text{(A.4)} \quad \lambda_s = \frac{\phi(x_1\beta_1 - \alpha_2)}{\Phi(x_1\beta_1 - \alpha_2)}.$$

Using these, we can fully describe the two-step estimator we use. Our description closely follows that of Heckman's two-step estimator in Greene (2003).

Table A.1. Estimation Results for the Instrumenting Equation

Variable	Coefficient	Std. Err.
Herd size	277.3207***	15.89456
Household head education: one to twelve years of education dummy	7,169.667***	1,616.788
Household head education: 13+ years of education dummy	3,379.176	5,200.209
Household head education: adult literacy class dummy	−103.5908	1,982.516
Land	116.6484	198.7257
Constant	4,890.608***	1,047.275

Note: The symbols *, **, and *** denote the 90, 95, and 99 percent levels of confidence, respectively.

The first step is to estimate the first-stage ordered probit by maximum likelihood in order to obtain estimates for (α', β_1'). Then, for each observation $i \in \{1, \ldots, N\}$, the IMRs $\hat{\lambda}_{bi}$ and $\hat{\lambda}_{si}$ must be computed, but one must also compute

$$\text{(A.5)} \quad \hat{\delta}_{bi} = \hat{\lambda}_{bi}(\hat{\lambda}_{bi} - \hat{\alpha}_1 - x_{1i}\hat{\beta}_1)$$

and

$$\text{(A.6)} \quad \hat{\delta}_{si} = \hat{\lambda}_{si}(\hat{\lambda}_{si} - \hat{\alpha}_2 - x_{1i}\hat{\beta}_1).$$

The second step is to estimate $(\beta_2, \beta_{b\lambda})$ and $(\beta_3, \beta_{s\lambda})$ by a regression of net purchases (net sales) on the set of covariates thought to affect net purchases (net sales) and on $\hat{\lambda}_b(\hat{\lambda}_s)$.

Letting $j \in \{b, s\}$ denote net buyer and net seller households, respectively, the estimated residual variance of each second-stage linear component is such that

$$\text{(A.7)} \quad \hat{\sigma}_{\varepsilon j}^2 = \frac{1}{n}\hat{\varepsilon}_j'\hat{\varepsilon}_j + \hat{\hat{\delta}}_j\hat{\beta}_{j\lambda}^2$$

where

$$\text{(A.8)} \quad \hat{\hat{\delta}}_j = \text{plim}\frac{1}{n}\sum_{i=1}^{n}\hat{\delta}_{ji}$$

where $\hat{\beta}_{j\lambda}^2$ is the square of the estimated coefficient of the jth IMR. Moreover, we have that

$$\text{(A.9)} \quad \hat{\rho}_j^2 = \frac{\hat{\beta}_{j\lambda}^2}{\hat{\sigma}_{\varepsilon j}^2}.$$

Once we have obtained the above values, we can finally compute the Heckman-corrected variance–covariance matrices for our ordered (Type II) tobit model , which are equal to

$$\text{(A.10)} \quad \text{Var}(\hat{\beta}_j, \hat{\beta}_{j\lambda}) = \hat{\sigma}_{\varepsilon j}^2[X'X]^{-1}[X'(I - \hat{\rho}_j^2\hat{\Delta}_j)X + Q_j][X'X]^{-1}$$

where the Q_j matrices are such that

$$\text{(A.11)} \quad Q_j = \hat{\rho}_j^2(X'\hat{\Delta}_jX_1)\text{Var}(\hat{\beta}_1)(X_1'\hat{\Delta}_jX)$$

and X is the data matrix of the second stage, which is identical for net buyer and net seller households, that is, $X \equiv X_b = X_s$, $I - \hat{\rho}_j^2\hat{\Delta}_j$ is a diagonal matrix whose diagonal terms are equal to $1 - \hat{\rho}_j^2\hat{\hat{\delta}}_{ji}$, X_1 is the data matrix of the first-stage ordered probit, and $\text{Var}(\hat{\beta}_1)$ is the variance matrix of the first-stage coefficients. Performing these computations thus yields efficient estimates for the second-stage parameters of our ordered (Type II) tobit and offers an ordered extension to Heckman's (1979) method.