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

Marc F. Bellemare†
Christopher B. Barrett‡

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Abstract

We estimate a two-stage model of livestock market participation by households in northern Kenya and southern Ethiopia. In the first stage, we partition the real line into net buyer, autarkic and net seller households and estimate an ordered probit model of household discrete choice with respect to market participation. In the second stage, we study the determinants of how much each net buyer or net seller household transacts in the market. The end result, which we call an ordered tobit, could be applied to many other settings. Our results indicate that prices matter to the extent of participation and that fixed transactions costs matter both in the participation and in the extent of participation decisions, thus offering additional evidence in favor a well-known behavioral anomaly.

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†Corresponding Author and Ph.D. Candidate, Department of Applied Economics and Management, Cornell University, Ithaca, NY, 14853-7801, mfb24@cornell.edu. We thank J.S. Butler and Christian Vossler for their useful comments, Sharon Osterloh and Amare Yirbecho for data assistance, and the Pastoral Risk Management (PARIMA) project of the USAID Global Livestock Collaborative Research Support Program (GL CRSP) for financial support of the data collection and analysis. Any remaining errors are solely the authors' responsibility.

‡Professor, Department of Applied Economics and Management, Cornell University, Ithaca, NY, 14853-7801, cbb2@cornell.edu.

1 Introduction

Increased reliance over the past decade or so on markets as the foundation for development strategies puts a premium on understanding household market participation. If many households do not participate actively in markets or do not respond to market signals, market-based development strategies may fail to facilitate wealth creation and poverty reduction. Although in simple textbook models households almost surely participate in all markets, in rural areas of the developing world, significant market frictions commonly impede market participation, dampening households' capacity to take advantage of market opportunities and governments' capacity to influence microeconomic behavior through changing market incentives. Development agencies and policymakers worldwide have therefore made increasing market participation a priority.

Yet there has been scant research on market participation, especially in developing country settings where significant frictions make this question most salient. Goetz (1992) studied the participation of Senegalese agricultural households in the coarse grains market, using a probit model of households' decision to participate in the market (whether as buyers or sellers, without distinction) followed by a second-stage switching regression model of the extent of market participation. Key et al. (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 usefully differentiates between the effects of fixed transactions costs (FTCs) and of proportional transactions costs (PTCs). Holloway et al. (2001) used a Bayesian double-hurdle model to study participation of Ethiopian dairy farmers in the milk market when non-negligible fixed costs lead to non-zero censoring, as in Key et al. These papers begin, however, from fundamentally different assumptions on the nature of households' market participation choices. Goetz and Holloway et al. 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 et al., by contrast, implicitly model the household as making the discrete market participation choice simultaneously with the continuous decision as to volumes purchased or sold.

Our contribution in this paper is 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 approach the data most support. The estimation method we introduce has the added virtue of being simpler to implement than the more elaborate structural model developed by Key et al. It 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 durable assets — livestock — missing in the extant studies on grain and milk. Finally, our data also permit us to address some interesting empirical questions related to possible behavioral anomalies in household marketing behavior.

The rest of the paper is structured as follows. In section 2, we lay out a simple theoretical model of household marketing behavior, highlighting the implications of different assumptions about whether households make (discrete) participation and (continuous) volume decisions. Then, in section 3, we 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 in section 4, section 5 then reports the estimation results from applying this novel method to study livestock marketing behavior among a population of poor herders in east Africa. The concluding section focuses on both the practical policy implications of our empirical findings and prospective other uses of the ordered tobit model.

2 A Theoretical Model of Market Participation

Pastoralist households in the drylands of East Africa routinely make decisions as to whether to buy or sell livestock, the principal form of wealth in the region. Under the maintained hypothesis that market behavior is driven by a household's objective of maximizing the discounted stream of consumption it enjoys, one can usefully focus attention on the choice problem that relates optimal (non-negative) quantities bought and sold, Q^{b*} and Q^{s*}, respectively, to household attributes and the environmental factors that condition consumption and market behaviors. For a representative household, let C_t represent discretionary consumption over period t. The household posesses a vector of assets at the beginning of period t. Let W_t be liquid but non-productive household wealth, H_t reflect the size of a household's herd, and A_t equal the amount of cultivable land it operates. The productive assets — herd and land size — generate income over period t according to the mapping $Y_t = y(H_t, A_t)$.[1] The household may also incur obligatory, norms-driven ceremonial expenses, X_t, associated with births and deaths, which we treat as exogenously determined.

Under the assumption that the household makes its market participation and marketed amount[2] decisions simultaneously, household livestock marketing behavior can thus be described by

$$\max_{C_t, Q_t^j} E \sum_{t=0}^{\infty} \delta^t U(C_t) \; \forall j \in \{b, s\} \tag{1}$$

$$\text{s.t.} \;\; C_t \leq y(H_t, A_t) + W_t - X_t \tag{2}$$

$$H_{t+1} = H_t + g(H_t, e_t) + Q_t^b - Q_t^s \geq 0 \tag{3}$$

$$W_{t+1} = W_t - X_t - C_t + y(H_t, A_t) + p_t^{*s} Q_t^s - p_t^{*b} Q_t^b \geq 0 \tag{4}$$

where E is the expectation operator, δ is the household's discount rate and $g(H_t, e_t)$ represents the biological recruitment (growth) rate of the herd as

[1]We use uppercase letters to reflect household attributes and lowercase letters to represent community-level conditions or functional relationships.

[2]We use the terms "amount", "extent" and "volume" interchangeably to represent the nonnegative continuous variable reflecting net sales or net purchases. We also abstract from the possibility that households could be both buyers and sellers in the same period. In the data set we use, there were no such observations. Further, in places where transactions costs drive a significant wedge between buyer and seller shadow prices, there should not be observations of both purchases and sales within the same (sufficiently disaggregated) period.

a function of beginning period herd size and current local environmental conditions, e_t. This model is essentially the dynamic generalization of the structural model presented in Key et al. (2000). The p^{*j} are the shadow prices for purchases ($j = b$) and sales ($j = s$). The shadow prices reflect the boundaries of the "price band" that defines household endogenous valuation of a resource that may or may not be traded (de Janvry et al., 1991). At the upper boundary of the price band, households buy, paying a shadow price that adds the fixed and variable transactions costs of market participation to the underlying market price, p_t^m. At the lower boundary, households sell, receiving net unit value equal to p_t^m less the fixed and variable transactions costs of market participation. Thus,

$$\begin{aligned} p_t^{*b} &= (1 + vc_t)p_t^m + fc_t \\ p_t^{*s} &= (1 - vc_t)p_t^m - fc_t \end{aligned}$$

where vc represents the (proportional) variable costs, $vc_t \in [0, \infty)$, such as market taxes and transport fees per unit sold, and fc summarizes non-negative fixed costs, including the cost of the person's transport to and from market, search, screening and negotiation costs, etc. Controlling for seasonal variation — described by the function $z^k(\zeta_t)$ for $k \in \{p, fc, vc\}$ — future market prices, fixed costs and variable costs follow a random walk:

$$\begin{aligned} p_{t+1}^m &= p_t^m + \; z^p(\zeta_t) \\ fc_{t+1} &= fc_t + \; z^{fc}(\zeta_t) \\ vc_{t+1} &= vc_t + \; z^{vc}(\zeta_t) \end{aligned}$$

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

$$Q_t^{b*} = q^b(A_t, H_t, W_t, X_t, e_t, fc_t, p_t^m, vc_t, \delta, \zeta_t), \text{ and} \tag{5}$$

$$Q_t^{s*} = q^s(A_t, H_t, W_t, X_t, e_t, fc_t, p_t^m, vc_t, \delta, \zeta_t). \tag{6}$$

The theoretical predictions of this model are several. We would expect that Q_t^{b*} (Q_t^{s*}) is decreasing (increasing) in A_t because 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. Sales (purchases) should be decreasing (increasing) in income and wealth as households use livestock sales (purchases) to smooth consumption. Sales should be increasing in household demographic shocks that necessitate ceremonial expenditures, X. Both sales and purchases should be decreasing in fixed and variable costs, while sales (purchases) should be increasing (decreasing) in the market price. This system of reduced form equations is estimable as a bivariate censored regression model.

However, the preceding specification relies on the earlier assumption that the discrete household choice to participate in the market is made simultaneously with the continuous choice as to the number of animals to buy or sell conditional on having chosen to go to market. If, however, participation and volume choices are made sequentially, as other papers in this literature assume (e.g. Goetz, 1992; Holloway et al., 2001), then the preceding model will be misspecified. If households make decisions sequentially, we need to break each period down into sub-periods.

In the interests of parsimony, we break each period t into only two sub-periods: $r = 0$ when the household makes the discrete participation decision, and $r = 1$ when those households that have chosen to participate in the market as either net buyers or net sellers make their continuous decision as to net sales or purchase volume. This changes the household's optimization problem to

$$\max_{C_{rt}, I^j_{rt}, Q^j_{rt}} E \sum_{r=0}^{1} \sum_{t=0}^{\infty} U(C_{rt}) \; \forall j \in \{b, s\} \tag{7}$$

$$\text{s.t. } \; C_{rt} \leq y(H_{rt}, A_{rt}) + W_{rt} - X_{rt} \tag{8}$$

$$H_{1t} = H_{0t} + g(H_{0t}, e_{1t}) \geq 0 \tag{9}$$

$$H_{0t+1} = H_{1t} + g(H_{1t}, e_{0t}) + I^b_{1t} Q^b_{1t} - I^s_{1t} Q^s_{1t} \geq 0 \tag{10}$$

$$W_{1t} = W_{0t} + X_{0t} - C_{0t} + y(H_{0t}, A_{0t}) + \widetilde{p}^s_t I^s_{1t} Q^s_t - \widetilde{p}^{*b}_t I^b_{1t} Q^b_t \geq 0 \tag{11}$$

$$W_{0t+1} = W_{1t} - X_{1t} - C_{1t} + y(H_{1t}, A_{1t}) - (I^{s\,s}_{1tt} + I^b_{1t}) fc_t \geq 0 \tag{12}$$

where the indicator variable $I^b_{rt} = 1$ if the household chooses to be a net buyer ($I^b_{rt} = 0$ otherwise) and $I^s_{rt} = 1$ if it chooses to be a net seller ($I^s_{rt} =$

0 otherwise), with a complementary slackness condition that $I^b_{rt} \cdot I^s_{rt} = 0$. This implies that $I^b_{0t} = I^b_{1t}$ and $I^s_{0t} = I^s_{1t}$, with $Q^b_{0t} = Q^s_{0t} = 0$. In this formulation, the boundary shadow prices no longer include the fixed costs of market participation, since those are paid in subperiod 0 when the household makes the discrete market participation choice. So the relevant marginal cost or revenue per animal bought or sold, respectively, is

$$\widetilde{p}^b_t = (1 + vc_t)p^m_t$$
$$\widetilde{p}^s_t = (1 - vc_t)p^m_t$$

The household's optimum continuous marketing decisions under the assumption of sequential decision making therefore does not include the fixed costs already incurred:

$$I^{b*}_{rt} = i^b(A_t, H_t, W_t, X_t, e_t, p^m_t, fc_t, vc_t, \zeta_t) \quad (13)$$

$$I^{s*}_{rt} = i^s(A_t, H_t, W_t, X_t, e_t, p^m_t, fc_t, vc_t, \zeta_t) \quad (14)$$

$$Q^{b*}_{rt} = q^b(A_t, H_t, I^b_{rt}, W_t, X_t, e_t, p^m_t, vc_t, \zeta_t) \quad (15)$$

$$Q^{s*}_{rt} = q^s(A_t, H_t, I^s_{rt}, W_t, X_t, e_t, p^m_t, vc_t, \zeta_t) \quad (16)$$

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 ($S_t \equiv Q^{s*}_t - Q^{b*}_t$) positions, we can treat the $\{I^{b*}_{rt}, I^{s*}_{rt}\}$pair as an ordinal variable: $\{I^{b*}_{rt} = 1, I^{b*}_{rt} = 0; I^{b*}_{rt} = 0, I^{s*}_{rt} = 0;$ and $I^{b*}_{rt} = 0, I^{s*}_{rt} = 1\}$, a point we exploit in developing the estimator in the next section. In the next section we also introduce a more formal test for whether household choice appears sequential or simultaneous, based on the correlation between the sub-period 0 choice over $\{I^{b*}_{rt}, I^{s*}_{rt}\}$and the sub-period 1 choices of Q^{b*}_{rt} and Q^{s*}_{rt}.

In the sequential choice model, several things change. Most importantly, note that fixed costs should no longer have any effect on sales quantity decisions, only on the market participation choices, I^{b*}_{rt} and I^{s*}_{rt}. 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 they really should not. Moreover, because fixed costs are incurred before sales revenues are generated — sometimes by quite a gap in time if there are payments delays, as commonly takes place in rural markets in the developing world — the earlier negative relationship between income or liquid wealth and sales that one expects to find when choice is simultaneous breaks down. There need not be any relationship between sales and wealth, although there should still be a positive relationship between wealth and purchases, due to the budget constraint. The rest of the predicted relations between sales or purchase quantities and the explanatory variables are as in the simultaneous choice case. But the subtle distinction between whether a household makes its market participation and purchase or sales volume decisions sequentially or simultaneously thus has significant implications for several relationships of interest in market participation studies. We now present an estimator that permits estimation of the discrete choice over I_{rt}^j as well as the continuous choice over Q_{rt}^j and allows one to test whether the sequential or simultaneous choice model fits the data better.

3 An Econometric Model of Market Participation

This section develops the ordered tobit model we implement in the next section. The idea behind the model comes from the assumed sequence and joint estimation 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[3], one can partition the continuous market participation outcome into three distinct categories: net buyer (households whose net sales are strictly negative), autarkic (households whose net sales are equal to zero) and net seller (households whose net sales are strictly positive) households. Because these categories are logically ordered, and since it is informative to distinguish between net buyers and net sellers rather than just lump them

[3] In the presence of non-zero censoring points, regions between zero and the censoring point(s) may have zero density.

together as "market participants", we can first estimate an ordered probit participation decision, then estimate a censored model of net sales or net purchase volume. By testing the correlation between the first and second stage regression residuals, we can then establish whether the participation and extent (or volume) decisions are made sequentially or simultaneously.

3.1 The Participation Decision

In the first stage, households decide whether they will be net buyers of livestock, autarkic, or net sellers of livestock. As described previously, if we consider a household's net sales $S_t \in \mathbb{R}$, i.e., its total sales of livestock minus its total purchases of livestock, S_t, we can partition $\mathbb{R}$ into three distinct parts, which correspond respectively to net buyer ($S_t < 0$), autarkic ($S_t = 0$) and net seller ($S_t > 0$) households. We can then let y_1 represent the category to which the household belongs, since the net buyer, autarkic, and net seller partition leaves us with an ordered response. Let the ordered response y_1 be such that

$$\begin{aligned} y_{1i} &= 0 \text{ if } S_{ti} < 0 \\ y_{1i} &= 1 \text{ if } S_{ti} = 0 \\ y_{1i} &= 2 \text{ if } S_{ti} > 0 \end{aligned} \tag{17}$$

Recall that in an ordered probit, $y_{1i} \in 0, 1, 2, ..., J$ and that we assume

$$y_1^* = \mathbf{x_1}\beta_\mathbf{1} + \epsilon_1 \tag{18}$$

where y_1^* is a latent variable, i.e., the utility the household gets from participating in the market in this case, $\mathbf{x_1}$ is an $(N \times K)$ vector of covariates which does not contain a unit N-vector, $\beta_\mathbf{1}$ is a $(K \times 1)$ vector of parameters to be estimated, and $\epsilon_1|\mathbf{x_1}$ is distributed standard normal. In what follows, let $J = 2$, first because it does not entail any loss of generality, and second because the categorical ordered response can only take three values in the application of sections 5

Let $\alpha_1 < \alpha_2$ be unknown threshold parameters, and define

$$y_{1i} = \begin{cases} 0 & \text{if } y_{1i}^* \leq \alpha_1 \\ 1 & \text{if } \alpha_1 < y_{1i}^* \leq \alpha_2 \\ 2 & \text{if } y_{1i}^* > \alpha_2 \end{cases} \tag{19}$$

This is the set-up of a regular ordered probit (Wooldridge, 2002). The probability of observing each of the ordered responses is such that:

$$
\begin{aligned}
P(y_1 = 0|\mathbf{x_1}) &= P(y_1^* \leq \alpha_1|\mathbf{x_1}) = \Phi(\alpha_1 - \mathbf{x_1}\beta_\mathbf{1}) \\
P(y_1 = 1|\mathbf{x_1}) &= P(\alpha_1 \leq y_1^* \leq \alpha_2|\mathbf{x_1}) = \Phi(\alpha_2 - \mathbf{x_1}\beta_\mathbf{1}) - \Phi(\alpha_1 - \mathbf{x_1}\beta_\mathbf{1}) \\
P(y_1 = 2|\mathbf{x_1}) &= P(y_1^* > \alpha_2|\mathbf{x_1}) = 1 - \Phi(\alpha_2 - \mathbf{x_1}\beta_\mathbf{1})
\end{aligned}
$$

Clearly, these sum up to unity. Defining $\mathbb{I}(y_{1i} = 0)$, $\mathbb{I}(y_{1i} = 1)$ and $\mathbb{I}(y_{1i} = 2)$ as indicator variables, the log-likelihood function of the ordered probit is thus:

$$
\begin{gathered}
\ell_i(\alpha, \beta) = \mathbb{I}(y_{1i} = 0) \ln[\Phi(\alpha_1 - \mathbf{x_{1i}}\beta_\mathbf{1})]\cdot \\
\mathbb{I}(y_{1i} = 1) \ln[\Phi(\alpha_2 - \mathbf{x_{1i}}\beta_\mathbf{1}) - \Phi(\alpha_1 - \mathbf{x_{1i}}\beta_\mathbf{1})]\cdot \\
\mathbb{I}(y_{1i} = 2) \ln[1 - \Phi(\alpha_2 - \mathbf{x_{1i}}\beta_\mathbf{1})],
\end{gathered} \tag{20}
$$

where $\Phi(\cdot)$ denotes the standard normal cumulative density function (cdf).

3.2 The Amount-of-Participation Decision

Let us now turn to the second stage decision of how much net buyer households buy and how much net seller households sell. Each decision could be studied using a tobit model. Let the subscripts 2 and 3 denote net buyer and net seller households, respectively. Recall that in a tobit with left-censoring at zero, $y_{2i} = \max\{0, y_{2i}^*\}$ and that we assume that

$$
y_2^* = \mathbf{x_2}\beta_\mathbf{2} + \epsilon_2 \tag{21}
$$

where y_2^* is a latent variable, i.e., the utility the household derives from buying animals, in this case, $\mathbf{x_2}$ is an $(N \times L)$ vector of covariates thought to affect net purchases (or an $(N \times M)$ vector of covariates thought to affect net sales for net seller households), $\beta_\mathbf{2}$ is an $(L \times 1)$ (or an $(M \times 1)$) vector of parameters to be estimated, and $\epsilon_2|\mathbf{x_2}$ is distributed normal with mean zero and variance σ_2^2.

Defining $\mathbb{I}(y_{2i} = 0)$ and $\mathbb{I}(y_{2i} > 0)$ as indicator variables, the log-likelihood function of the censored tobit is thus:

$$\ell_i(\beta_{\mathbf{2}}, \sigma_{\mathbf{2}}) = \mathbb{I}(y_{2i} = 0) \ln[1 - \Phi((\mathbf{x_{2i}}\beta_{\mathbf{2}}/\sigma_2)]$$

$$+\mathbb{I}(y_{2i} > 0) \left\{ \ln \phi[(y_{2i} - \mathbf{x_{2i}}\beta_{\mathbf{2}})/\sigma_2] - \ln(\sigma_2^2/2) \right\}, \tag{22}$$

where $\phi(\cdot)$ denotes the standard normal probability density function (pdf).

If, however, households take these two decisions — whether to participate on the marker as net buyer, autarkic, or net seller households and how much to buy or sell when they are at the tails of the distribution — sequentially, we then need to jointly estimate these two decisions, for which we propose the following framework.

3.3 The Ordered Tobit Model

Our "ordered tobit"[4] specification allows to study fixed and variable transactions costs separately, as do Key et al. (2000), but using an estimator that we find converges more readily than does their somewhat more cumbersome likelihood function. This approach also allows for non-zero censoring points, as in Key et al. and Holloway et al. (2001).

The specification of the ordered tobit model is as follows. Let y_{1i} denote the category — net buyer, autarkic, or net seller — household i belongs to, as defined in equation (1) above. The specification of the first-stage decision remains exactly the same as in section (3.1), so the first-stage decision is just a regular ordered probit. The innovation comes at the second stage. Let $y_{2i} \geq 0$ 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 and collectively exhaustive subsets of the dataset: a household cannot simultaneously be a net buyer and a net seller.

We could treat the full problem separately by estimating two type II tobits (or heckits, following Heckman, 1979), one for net buyer households, and one for net seller households or even estimating them jointly as a bivariate tobit. A better way to study the determinants of pastoralists' market participation

[4]Klein and Sherman (1997) also combine the ordered probit and tobit estimators into what they term an "orbit" estimator, but in the 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.

in northern Kenya and southern Ethiopia might be 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 supported by the data. Note that in the following analysis, $\mathbf{x_1} \neq \mathbf{x_2}$ and $\mathbf{x_1} \neq \mathbf{x_3}$ (but note that $\mathbf{x_2}$ could be equal to $\mathbf{x_3}$). Thus, the end result is an ordered probit combined with two of what Amemiya (1985) refers to as Type II tobit models, i.e. tobit models in which the "if" binary decision is regressed on a set of covariates different from the set of covariates on which the "how much" decision is regressed.[5]

Dropping boldface notation for vectors, the log-likelihood function of the ordered tobit is such that

$$\ell_i(\alpha', \beta', \sigma') = \mathbb{I}(y_{1i} = 0) \left\{ \ln \Phi(\alpha_1 - x_{1i}\beta_1) + \ln \phi \left[\tfrac{(y_{2i} - x_{2i}\beta)}{\sigma_2} \right] - \ln \left(\tfrac{\sigma_2^2}{2} \right) \right\}$$

$$+\mathbb{I}(y_{1i} = 1) \left\{ \ln[\Phi(\alpha_2 - x_{1i}\beta_1) - \Phi(\alpha_1 - x_{1i}\beta_1)] \right\}$$

$$\mathbb{I}(y_{1i} = 2) \left\{ \ln[1 - \Phi(\alpha_2 - x_{1i}\beta_1)] + \ln \phi \left[\frac{(y_{3i} - x_{3i}\beta)}{\sigma_3} \right] - \ln \left(\frac{\sigma_3^2}{2} \right) \right\}, \quad (23)$$

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, and σ is (2×1) vector of variance parameters, one for each linear component, i.e., net purchases and net sales. Thus, the model will estimate $K + L + M + 4$ parameters by maximum likelihood.

Thus, the three error terms in the model, ϵ_1, ϵ_2 and ϵ_3 follow a trivariate normal distribution, i.e., $\epsilon \sim N(\mathbf{0}, \Sigma)$, where $\mathbf{0}$ is a (3×1) vector of zeros and Σ is the (3×3) variance-covariance matrix between the equations of the ordered tobit model:

$$\Sigma = \begin{pmatrix} 1 & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_2^2 & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_3^2 \end{pmatrix}.$$

[5]Groot and van den Brink (1999) use a similar estimator, but incorporating a Type I rather than a Type II tobit.

Also note that we can rewrite this matrix in terms of correlation coefficients between the error terms,

$$\mathbf{R} = \begin{pmatrix} 1 & \rho_{12} & \rho_{13} \\ \rho_{12} & 1 & \rho_{23} \\ \rho_{13} & \rho_{23} & 1 \end{pmatrix},$$

where ρ_{ij} is the correlation coefficient between the error terms of equations i and j, respectively. Thus, much like in a bivariate probit model (Maddala, 1983; Gouriéroux, 2000), a non-zero correlation coefficient between two equations will be evidence in favor of the joint, sequential model. That is, rejecting the joint hypothesis that $H_0 : (\rho_{12}, \rho_{13})' = \mathbf{0}$ is, in effect, a rejection of separately estimating an ordered probit, then two linear regressions in favor of estimating the ordered tobit model.[6] The advantage of this model is that it sequentially estimates the participation and the amount-of-participation decisions while correcting for selection bias at the second stage.

The ordered tobit model has been the object of very little published work. Groot and Maassen van den Brink (1999) study overpayment and earnings satisfaction, developing a computationally similar but atheoretical model. Ranasinghe and Hartog's (1997) unpublished working paper explores investment in post-compulsory education in Sri Lanka. Yet, the prospective applications of this model are many — as we discuss in the concluding section — and it is rather easy to estimate with any statistical package that accommodates maximum likelihood.[7]

4 Data and Descriptive Statistics

We apply the ordered tobit estimator to 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

[6]Note that we do not test any hypothesis on ρ_{23}. Since every non-autarkic observation is either a net buyer or a net seller, ρ_{23} is not identified.

[7]For this paper, estimation was conducted using STATA's `ml` set of commands and generally converged in under ten iterations using the Newton-Raphson algorithm.

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 scarce wealth. 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 (Osterloh et al. 2003, Lybbert et al. 2004, McPeak 2004).

The data come from an ongoing study of risk management among east African pastoralists. The data consists of a panel of 337 pastoralist households from eleven sites in the arid and semi-arid lands of northern Kenya and southern Ethiopia. Each household was observed quarterly between June 2000 and June 2002. We pool all nine time periods together and treat the dataset as a cross-section, first due to the inherent complexity that an extension of the ordered tobit model to a panel setting would involve, and second because of the highly unbalanced nature of our panel.[8] The descriptive statistics presented here thus treat household i in period t and household i in period s as two distinct observations for $s \neq t$. Further details on the surveys, sites and instruments are available in Barrett et al. (2004).

Table 1 summarizes the descriptive statistics for the variables used in section 5. Almost 70 percent of the households are male-headed, with an average size of 7.4 people and a dependency ratio of nearly 0.5.[9] Most households own livestock, with an average herd size of more than 20 tropical livestock units (TLU), a standard measure for aggregating across ruminant species such as camels, cattle, goats and sheep.[10] Herds reproduce, on average, at a rate of about 6.1 percent 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, with implications for livestock marketing patterns. Households often give or

[8] The number of observations per time period ranged from 233 to 255, and not necessarily when ordered from last to first period.

[9] 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. Thus, a dependency ratio of zero indicates a household whose resources are not strained at all, whereas a dependency ratio of one indicates a household whose resources are extremely strained.

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

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 of the clan or village. These encumbered or restricted property rights affect less than ten percent of a household's herd, on average, yet may matter to marketing decisions, especially with respect to purchasing cows (for which restricted gifts may be a substitute) or selling bulls. Less than one-third of households own poultry and mean land holdings are small, at about 1.4 hectares, 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, non-local breed animals, vehicles and urban property, all valued in Kenyan shillings (Ksh).[11] The value of these assets amounts to a bit more than US$35 per capita, while household income (the sum of milk and crop production, sales of firewood, charcoal, crafts and hides and skins, and wage and salary earnings) over the preceding quarter averaged well under one dollar per day. Fixed and variable cost expenditures on market participation represent a perhaps surprisingly modest share of price.[12] Variable costs related to per animal transport costs and market fees add (for buyers, subtract for sellers) only about 10 percent to the small stock (goat or sheep) price and less than 2 percent to the large stock (camel and cattle) price. Fixed costs associated with transport and lodging expenditures of the individual who sells or buys animals and any market fees unrelated to volumes sold or purchased are about 60 percent larger than variable costs per TLU. We omit descriptive statistics for location and time dummies, both because these aren't very interesting and due to space limitations.

5 Results and Analysis

This section first presents estimation results for two tobit models — one for net buyer households, one for net seller households — consistent with the model outlined earlier when household market participation and volume

[11]For Ethiopian households, we use 1 Ethiopian birr = 8.75 KSh. Note that US$1.00 ≅ KSh75.

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

choices are made simultaneously. Then we present estimation results from the ordered tobit model that corresponds to the model of sequential household choice. Finally, we test the hypothesis that we can effectively model household livestock marketing behavior using the simultaneous choice model.

5.1 Two Tobit Models

As a first step in understanding how the households in our dataset behave, we estimate two tobit models — one for net buyer households, one for net seller households — using the classic type I tobit model. The estimated coefficients are reported in Table 2 for both the net buyer and net seller tobit models. In reporting the estimated coefficients, we will omit reporting the results for the time and location dummies, and in our estimation results, the superscripts *, ** and *** indicate a coefficient significant at the 99, 95 and 90% levels of confidence, respectively.

Female-headed households buy and sell fewer animals than their male-headed counterparts. As regards household size and composition, the number of individuals a household decreases the number of TLUs sold on one hand, but on the other hand, a household's dependency ratio decreases the number of TLUs bought. This indicates that more individuals means more wage labor and that households with strained resources spend less on buying animals than others.

For their part, births increase the number of animals sold, and that is likely because of the ceremonial expenses associated with the birth of a child within the household. Household land and other assets increase the number of animals sold, thus indicating a certain complementarity between various forms of wealth. Land also decreases the number of animals bought, likely due to the fact that households who possess more land cultivate more, which in turns restricts their mobility and their ability to herd animals. Household income[13] increases the number of animals bought, which points to the fact

[13]Household income being likely endogenous in both these models and in the model of subsection 5.2, we instrumented it using the household head's education. Our dataset included dummy variables for whether or not the head of the household had no education, between 1 and 12 years of education, 13 or more years of education or had completed an adult literacy class. We also included time and location dummies as well as time and location interaction terms in our instrumenting regression.

that livestock is a normal good.

Finally, we turn to the effect of the variables of interest. The fact that variable costs increase the number of animals cost is certainly puzzling — one would expect the volume of trade to be strictly decreasing in variable costs. Finally, although the average price of large stock has the expected sign in the tobit for net buyers, i.e. the demand for large stock is downward sloping, the average price of small stock increases the number of animals bought. We discuss such an unexpected result in greater detail in the next subsection.

5.2 The Ordered Tobit

We now explore whether our estimation results change if we instead model household marketing as a sequence of choices and employ the ordered tobit model. In essence, our model consists in estimating an ordered probit at the first stage and then estimating two linear regressions — one for the amount of participation conditional on being a net buyer, and one for the amount of participation conditional on being a net seller — at the second stage. Since both linear components include a selection term, the usual inverse Mills ratio (IMR), our model is actually an ordered type II tobit. Following Heckman (1979), we corrected 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.

The ordered probit model of discrete market participation yields intuitive results (Table 3). The non-zero censoring points are of opposite signs, with the lower censoring threshold at -1.43 TLU net sales and the upper threshold at 1.11, each statistically significantly different from zero. These estimates suggest that purchases or sales of less than one 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 small stock (goats or sheep) are commonly means by which households meet immediate cash needs related to payment of school fees, food purchases and ceremonial or emergency health expenses.

The number of human births in the household positively affects market participation, i.e., it makes net buyer households more likely to be autarkic and autarkic households more likely to be net sellers. This surely reflects greater demand for cash as new member is added to the household. Herd size and animal births likewise exert a positive effect on the ordered market participation variable. The bigger a household's herd size or the more animal births it 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. 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 high fixed costs are extremely high — beyond about KSh376 — this encourages households to move from net seller positions to autarky.

The net purchase and net sales volume choices conditional on expected market participation per the ordered probit first-stage estimates likewise make sense (Table 4). Female-headed households buy and sell fewer animals when they participate in the market. There are pronounced and intuitive life cycle effects, 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. Household size has a negative effect on both purchases and sales as larger families are both less able to buy animals and can less afford to liquidate the primary source of food (blood and milk) in a pastoralist household (McPeak, 2004). As one would expect, non-productive household assets and household income are both positively associated with purchase and sales volumes. Wealthier people transact in larger volumes. Household land holdings are negatively and significantly related to purchases and 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 and composition matter to livestock marketing patterns. Households with larger herds buy more and sell fewer animals, although these effects, while statistically significant, are rather small in magnitude. This is consistent with other findings from the region that there exist multiple dynamic herd size equilibria, with small herds collapsing toward a single TLU (Lybbert 2004). The larger the share of the herd that is female, the smaller a household's net sales, as pastoralists try to hold onto (more valuable) cows than bulls. Cows with encumbered property rights are associated with lower net purchases, signalling that interhousehold loans and gifts (associated with encumbered property rights) provide an alternative to market purchases for providing a household with a regular source of milk. Similarly, bulls with encumbered property rights are less likely to be sold, although that effect is quite small.

The multifunctional nature of livestock holding in pastoralist regions 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 increase significantly with price while net purchases decrease. Pastoralists appear reasonably responsive to large stock prices, with estimated price elasticities of supply and demand of and , respectively at the sample means. Small stock (goats and sheep), however, appear characterized by backward-bending supply curves and forward-sloping demand. The former is consistent with the use of small ruminants as a sort of walking bank. Herders tend to liquidate goats and sheep, as needed, to meet immediate cash needs (Osterloh et al. 2004), thus the number they sell falls as price increases.

The anomalous results in these models relate to transactions costs. Variable costs appear to exert a very small, signficant positive effect on both purchase and sales volumes, contradicting the predictions of the theoretical model. Meanwhile, fixed costs appear to significantly affect purchase volumes negatively and sales volumes positively when the theoretical model based on sequential choice predicts fixed costs should have no effect on the continuous volume decision, only on the discrete participation decision. This could indicate that fixed costs reduce the cash available to liquidity-constrained buyers, thereby limiting the number of head they can purchase and that sellers wish to "recover" their sunk costs once they choose to participate as net sellers. Or it could simply reflect the well-known behavioral anomaly that people take sunk costs into consideration when they really should not were they trying to maximize profits. We must defer more in depth investigation of these alternative explanations to future research.

The results of the ordered tobit differ substantially from those of the two type I tobit models 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, life cycle effects and those of encumbered property rights appear only in the ordered tobit specification. Prices and herd size only have a significant effect in the more general, two-stage model. And without the first stage ordered probit selection control, assets (income) have negative and statistically insignificant effects on net purchases (net sales). All of these qualitative differences suggest that the estimator we introduce indeed adds real value.

5.3 Hypothesis Tests

We have established that the simultaneous and sequential model specifications yield different results and that the ordered tobit results appear more sensible. But which model better fits the data statistically? One method is to check whether the IMR variables are statistically significant in either of the second-stage linear components of the ordered tobit model. Indeed, the IMR is highly significant in the net seller equation, suggesting a selection effect that would be missed if one specified household marketing behavior as a simultaneous choice of participation and volume. This indication is reinforced by the estimated matrix of correlation coefficients between the residuals of all three components of the ordered tobit:

$$\widehat{\mathbf{R}} = \begin{pmatrix} 1 & 0.1594^* & 0.2949^* \\ 0.1594^* & 1 & 0.2462^* \\ 0.2949^* & 0.2462^* & 1 \end{pmatrix}.$$

Recall that ρ_{12} and ρ_{13} are the degrees of correlation between the decision to participate respectively as a net buyer or a net seller and the extent of participation conditional on having decided to participate in the market. Thus, if the residual vectors $\hat{\epsilon}_2$ and $\hat{\epsilon}_3$ are both correlated with $\hat{\epsilon}_1$, i.e., if both $\hat{\rho}_{12}$ and $\hat{\rho}_{13}$ are statistically significantlly different from zero, then the sequential choice ordered tobit model is preferred to the simultaneous choice model estimating two separate tobit models (or a bivariate tobit). Given that $\hat{\rho}_{12}$ and $\hat{\rho}_{13}$ are both significant, we infer that our data supports the ordered tobit model.[14]

[14] In a future version of this paper, we will present a more formal test of the ordered

Finally, we have also computed price elasticities. Recall that

$$\eta_{pb} = \frac{\partial Q^b}{\partial p^m} \cdot \frac{p^m}{Q^b}$$

is the price elasticity of demand for net buyer households and that

$$\eta_{ps} = \frac{\partial Q^s}{\partial p^m} \cdot \frac{p^m}{Q^s}$$

is the price elasticity of supply for net seller households. Plugging in our second-stage ordered probit estimates for the effect of average price of large stock and the mean values for prices and quantities in Table 1, we obtain the following estimates for η_{pb} and η_{ps}:

$$\hat{\eta}_{pb} = -33.81 \tag{24}$$

$$\hat{\eta}_{ps} = 0.17 \tag{25}$$

In words, at the means of our variables, when the average price of large stock increases by 1%, the demand for animals decreases by almost 34%, but the supply of animals increases by less than two tenths of one percent.

6 Conclusion

In this paper, we developed an econometric model of dynamic household choice with respect to livestock market participation that nests within it the structural alternatives extant in the literature. We demonstrated the subtle but 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 a two-stage econometric model that permits direct testing between these competing ways of understanding household level marketing behavior. This method should be applicable to a range of other economic problems similarly characterized by an ordered first-stage process and a continuous second stage process. Examples include financial investments — e.g., ranking risk tolerance and share of alternative instruments in a portfolio — and market integration in domestic

tobit model versus the two tobit models or the bivariate tobit.

and international trade — establishing whether markets are segmented, competitively integrated or non-competitively integrated and identifying trade volumes. For now, we leave such topics to future research. One could likewise adapt this basic approach to cover multinomial or count data, instead of ordinal data, in the first stage estimation.

In the application we explore, our empirical results shed some light on the contemporary puzzle of why pastoralist households in the arid and semi-arid 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 and the complex property rights in animals that accompany cultural livestock gifting and lending institutions impede market participation. Small stock marketing responds as if households use goat and sheep sales to meet immediate cash needs while camel and cattle marketing appears highly responsive to large stock prices. While increasing local cattle prices through, for example, enhanced promotion of east African breeds in international markets may elicit a supply increase, it is by no means clear that this is the most effective means for increasing pastoralist welfare.

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Table 1 – Descriptive Statistics.

Variable	**Mean**	**Std. Dev.**
Household Head Sex (1=female)	.3112314	.4631017
Household Head Age (years)	49.19578	14.6925
Children (under 15)	3.360288	2.359304
Household Size (persons)	7.386343	3.873955
Land Assets (hectares owned)	1.414645	2.535116
Poultry (1=yes, 0=none)	.3063792	.4610927
Assets (KSh)	19816.18	189207.2
Births (persons)	.0633139	.2435813
Deaths (persons)	.0166143	.1313166
Income (Ksh)	3760.479	25477
Herd Size (TLU)	20.38237	30.06591
Percentage of Female TLU	.6800255	.2422851
Encumbered Male TLU	.4728469	2.823439
Encumbered Female TLU	1.011073	4.466281
Average Price of Large Stock (Ksh)	5529.666	2655.46
Average Price of Small Stock (Ksh)	787.6219	425.2299
Animal Births (TLU)	1.236916	3.348557
Net Buyer (1=yes)	.0377189	.1905584
Autarkic (1=yes)	.6834306	.4652423
Net Seller (1=yes)	.2788505	.4485345
Dependency Ratio	.4799896	.1987313
Net Sales (TLU)	.2346206	1.59179
Fixed Fees (Ksh)	127.4858	183.2684
Variable Fees (KSh/TLU)	80.13303	95.88441
Sales (Net Sellers)	1.038969	2.157152
Purchases (Net Buyers)	1.460714	4.943286

Table 2 – Estimation Results for the Two Tobits.

	Quantity Bought		Quantity Sold	
Variable	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**
Household Head Sex	-3.74753^{*}	1.05778	$-.431021^{*}$	.1391402
Household Head Age	.0578461	.1492907	.0074086	.0239585
Household Head Age Squared	$-.0007221$	.0013777	$-.0001174$	.0002202
Individuals in Household	.0574184	.1343994	$.0487775^{**}$	.0201658
Dependency Ratio	-4.839133^{*}	1.881833	.2088737	.3152383
Births	$-.1119378$	1.350317	$.5971826^{*}$	.2132551
Deaths	-1.637814	2.802439	.5647842	.3799012
Household Assets	$-8.24e-07$	$2.75e-06$	$3.27e-06^{*}$	2.41e-07
Land	$-.3807264^{***}$	.1996328	$.055198^{**}$	.0264067
Poultry	1.131214	.8028521	$-.1103579$	.1412932
Income	$.0001121^{**}$	.0000499	$-8.12e-06$	9.63e-06
Herd Size	$-.007349$	.0217358	$.0070014^{*}$	.002394
% Female TLUs	$-.2965489$	1.517288	.2044945	.2687875
Encumbered Males	$-.1722929$	.3321668	.0319443	.0224009
Encumbered Females	.1629258	.1677863	$-.0101656$	.0140812
Fixed Fees	.0020475	.0031768	.000292	.000431
Variable Fees	.0034954	.0067061	$.003946^{*}$	.0010312
Avg. Price Large Stock	$-.0003286^{***}$	.0001723	.0000138	.0000248
Avg. Price Small Stock	$.0023427^{***}$	.001299	$-.0001887$	.0001886
Constant	-5.922154	3.99007	-1.221007^{***}	.6601108
$\rho(\hat{\epsilon}_b, \hat{\epsilon}_s)$	0.1021^{**}			

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

Variable	**Coefficient**	**Standard Error**
Household Head Sex	−.064822	.0662964
Household Head Age	.0133551	.0118169
Household Head Age Squared	−.0001469	.0001101
Individuals in Household	.0145552	.0215116
Children	.0070373	.040078
Dependency Ratio	.1241913	.266967
Births	.2633899**	.1149377
Deaths	.143118	.2079003
Household Assets	$7.96e-08$	$2.01e-07$
Land	.0192183	.014291
Poultry	−.0738758	.0726459
Income	$-7.78e-06$	$4.75e-06$
Total TLUs	.0035911*	.001397
% Female TLUs	.1252709	.1319699
Encumbered Males	.0141939	.0146533
Encumbered Females	−.0057105	.0083725
Fixed Fees	.0023034*	.0004892
Fixed Fees Squared	$-3.06e-06$*	$7.21e-07$
Animal Births	.0226398***	.0122662
$\widehat{\alpha}_1$	−1.431258*	.3418696
$\widehat{\alpha}_2$	1.112707*	.3416785

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

	Quantity Bought		Quantity Sold	
Variable	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**
Household Head Sex	−.0963713***	8.8361276	−.0031754***	.04705614
Household Head Age	.5317809	.27439155	−.0602495**	.00183423
Household Head Age Squared	−.0051779**	.00002361	.0005692**	$1.497e-07$
Individuals in Household	−.4437889	.22490578	−.0144865**	.00139733
Dependency Ratio	−14.68171***	48.759707	.0241061	.27335316
Births	−1.168027*	29.163599	−.1666941*	.19520473
Deaths	4.95485*	92.966823	.6896717*	.65480799
Household Assets	.0000321**	$8.432e-11$	$3.41e-06$**	$6.767e-13$
Land	−.3968368***	.44153552	.0618913**	.00300519
Poultry	2.093993	10.660143	−.117332	.06160394
Income	.0000851**	$4.541e-08$	$5.83e-06$**	$2.278e-10$
Herd Size	.0914124**	.00385022	−.0016528**	.00003042
% Female TLUs	5.266053	34.669319	−.0944944***	.18541052
Encumbered Males	.3569368	.47962856	−.0123225**	.00406392
Encumbered Females	−.3668492**	.15448461	.0005697	.00120172
Fixed Fees	−.0123314**	.00007009	.0001888**	$3.655e-07$
Variable Fees	.0437107**	.00005423	.0003068**	$4.356e-07$
Avg. Price Large Stock	−.008932**	$7.874e-09$	.0000324**	$2.537e-10$
Avg. Price Small Stock	.0021236**	$5.526e-07$	−.0000489**	$2.017e-08$
Inverted Mills Ratio	78.89231	92.556822	−5.742575*	.67935644
Constant	-65.05073	–	6.240187	–