Journal of Agricultural and Resource Economics 30(3):431–448

Asymmetric Willingness-to-Pay Distributions for Livestock Manure

F. Bailey Norwood, Ryan L. Luter, and Raymond E. Massey

The Environmental Protection Agency's new Concentrated Animal Feeding Operations (CAFO) regulations are forcing some farms to export livestock manure to off-farm acres. The regulation compliance cost depends on the willingness of neighboring crop producers to accept or pay for the manure. This study estimates a manure willingness-to-pay distribution for crop producers using a contingent valuation mail survey. A flexible parametric distribution is borrowed from the crop yield literature, which shows that manure willingness to pay is left-skewed. Most crop producers in our sample will pay a positive price close to the savings in commercial fertilizer, but approximately 25% require a payment before accepting manure.

Key words: animal waste, asymmetric distribution, contingent valuation, manure, nonmarket valuation, pollution, willingness to pay

Introduction

Studies employing the contingent valuation method increasingly rely on the interval-censored model, initially developed by Cameron (1998). For example, two articles employing this model appear in the November 2003 edition of the *American Journal of Agricultural Economics* (Lusk; Qaim and De Janvry). This model assumes that willingness to pay (WTP) has a deterministic and a stochastic component, where the stochastic component goes by a symmetric probability distribution.

The assumption of a symmetrically distributed WTP may not be valid for all cases. This study presents one such case: WTP for livestock manure by crop producers. Based on existing prior evidence, the WTP for livestock manure is skewed to the left. Thus, the assumption of a normally distributed WTP may lead to inefficient parameter estimates, and misleading inferences. In these cases, a more flexible WTP distribution is warranted. One could employ nonparametric estimation techniques, but such methods make it difficult to identify the marginal effects of explanatory variables on WTP. Ideally, a flexible parametric distribution would be employed that contains a structure and coefficient interpretation similar to the conventional interval-censored model, but allows WTP to be skewed in either direction.

Fortunately, much earlier work has focused on developing such a distribution for crop yields, which can easily be extended to the contingent valuation setting. Most notable

F. Bailey Norwood is assistant professor and Ryan L. Luter is graduate student, both in the Department of Agricultural Economics, Oklahoma State University; Raymond E. Massey is assistant professor, Department of Agricultural Economics, University of Missouri-Columbia. The authors thank Francis Epplin, Jayson Lusk, Arthur Stoeker, Paul Jakus, and two anonymous referees for helpful comments and support. A special thanks goes to Damona Doye for access to her survey database. This research was supported in part by the Six-State Consortium on Animal Waste.

Review coordinated by Paul M. Jakus.

is the research by Ramirez (1997) and Ramirez, Misra, and Nelson (2003) on the Johnson S_U distribution. This study demonstrates how the Johnson S_U can be used to develop flexible WTP distributions, using the demand for livestock manure as a case study. The remainder of the paper is organized as follows. First, the environmental problems associated with manure and environmental regulations seeking to mitigate these problems are discussed in order to motivate the importance of estimating the WTP for livestock manure. Next, data generated from a contingent valuation survey are described, followed by sections detailing the estimation methodology and the estimation results. The final section provides summary remarks and discussion.

The Manure Problem

The last two decades have ushered in new regulations for controlling how animal feeding operations handle manure. Virtually all livestock manure is applied to crops after some period of storage and treatment. Manure is costly to transport, and if unregulated, many livestock operations would choose to overapply manure close to the farm. Continuous overapplications of manure lead to nutrient runoff, polluting surface and ground waters. In response, new regulations have been passed to minimize nutrient runoff by requiring manure applications to be consistent with crop uptake.

While many states have passed their own regulations, the Environmental Protection Agency's Concentrated Animal Feeding Operations rule (hereafter, CAFO rule) has received the most attention. The new CAFO rule regulates more livestock operations, and is more specific in how those farms must apply manure. For example, the CAFO rule states:

> Today's rule requires large CAFOs to determine and implement site-specific nutrient application rates that are consistent with technical standards.... The permitting authority may use the USDA Natural Resources Conservation Service (NRCS) Nutrient Management Conservation Practice Standard, Code 590 (U.S. Congress, *Federal Register*, 2003, p. 7209).

NRCS Code 590 provides three options for applying manure to land, each of which can be described generally as follows. First, the nitrogen application must not exceed the nitrogen needs of the crop.[1] Second, since the phosphorus-to-nitrogen ratio in manure is generally higher than the ratio consumed by crops, supplying all the crop's nitrogen needs with manure results in a buildup of phosphorus in the soil. If the soil phosphorus buildup becomes too large, producers must either reduce their per acre application rate or temporarily cease manure applications (USDA/Natural Resources Conservation Service, 2004).

As regulations force the per acre application rate of manure to fall, more acres are needed to dispose of the same amount of manure. For farms that are limited in land, manure must be exported to off-farm acres. This typically involves a livestock producer transporting manure to another livestock or crop producer's land for application. To avoid confusion with the terms "livestock producer" and "crop producer," we refer to the

[1] The nitrogen needs of a crop are always greater than the nitrogen removed at harvest. Thus, there is always some nitrogen that was applied but not harvested. Nitrogen needs are defined here as the nitrogen *application* required to achieve a targeted yield.

exporter of the manure as the *deliverer* and the importer of manure as the *receiver*. It should be noted that in some cases the deliverer may pay the receiver to accept the manure, in which case the price is negative. In the southeastern United States, surveys have found that 40% of swine farms may be land constrained (Carter-Young et al., 2003) under new CAFO regulations. Similar results have been found for Oklahoma (Oklahoma State University, 2004). Since the transportation costs of manure are large, these land-constrained farms will face the highest compliance costs.

The new regulations have received much debate, mainly regarding their benefits and costs, both of which are difficult to estimate. Many studies have focused on estimating the costs of new manure management standards to livestock farms (Feinerman, Bosch, and Pease, 2004; Fleming and Long, 2002; USDA/Economic Research Service, 2003; U.S. Environmental Protection Agency, 2001). Estimating compliance costs requires assumptions about farm types, transportation costs, nutrients generated in manure, cropland surrounding the farm, and the willingness of neighboring crop producers (receivers) to pay for or accept manure. This last item—willingness of receivers to pay for manure—is the dynamic about which the least is known. As no study has measured receivers' willingness to pay for manure, researchers must employ best guesses about whether deliverers must pay to export manure or whether they will receive a positive price for the manure. For example, the Environmental Protection Agency assumed all receivers would accept manure but would neither require a payment nor pay for the manure. Transportation costs of manure were then estimated based on the surrounding cropland area (U.S. Environmental Protection Agency, 2001).

In a similar study, the USDA's Economic Research Service (ERS) also assumed receivers would not require a payment nor would they pay for manure, but allowed the percentage of receivers accepting manure to vary. The ERS report states, "Crop producer willingness to accept manure has a profound impact on net costs" (USDA/ERS, 2003, p. 20). When less than 10% of receivers were willing to accept manure, costs for hog farms were as high as $20 per animal unit, but when this percentage approached 100%, costs turned negative (positive profits were made from complying with the regulations). In a study of dairy and poultry farms, Feinerman, Bosch, and Pease (2004) calculated costs assuming 50%, 75%, and 100% of receivers would accept manure, where the price paid by receivers depends on the nutrient content of the manure and the price of commercial fertilizer.

Clearly, research is needed on the willingness of receivers to pay for livestock manure and the factors that enhance the marketability of manure. Two items are of particular interest. First is the percentage of receivers who would accept manure at a price of zero. The second relates to the substitutability of manure for commercial fertilizer. Often, as in Feinerman, Bosch, and Pease (2004), studies assume that if a receiver will accept manure, she will pay the full "nutrient value," which is essentially the savings in commercial fertilizer. Yet, there are many reasons why receivers may not view manure as a perfect substitute for commercial fertilizer. Manure may contain undesirable foreign material, be associated with an offensive odor, alter the soil pH, and may release nutrients at a different rate, leading receivers to discount manure relative to commercial fertilizer. Receivers may also associate manure with greater regulation and environmental problems.

Conversely, manure contains organic material—providing more than just nitrogen, phosphorus, and potassium—inducing a premium over commercial fertilizers. What portion of the commercial fertilizer savings will receivers pay for manure, and how does this portion vary across the population of receivers? What portion of receivers must receive a payment (pay a negative price) before accepting manure? This study seeks to answer these questions using a contingent valuation analysis of Oklahoma receivers.

The estimation methodology must differ from conventional methods for two reasons. First, the contingent valuation method must allow both positive and negative values for manure. This is achieved by asking some crop producers if they would pay a positive amount for manure, while asking others if they would accept manure if compensated by a certain amount (a negative price). This approach is akin to the methodology employed by Clinch and Murphy (2001), where some individuals were asked if they would pay to encourage forests in Ireland, while others were asked if they would pay to discourage forests. Second, as discussed earlier, most surveys eliciting WTP assume that WTP is symmetrically distributed. In the case of manure, assuming symmetry in the WTP distribution may not be valid. Conversations with swine producers in North Carolina and Oklahoma reveal that they believe most receivers will pay a small price for manure or accept it for free, but a significant proportion will require a payment before accepting manure. Indeed, in a survey of 36 Oklahoma swine farmers, 64% said manure buyers would not require a payment nor would they pay for manure (i.e., WTP = 0), 28% said buyers would require a payment to accept manure, and 8% of buyers would pay a positive price for manure. These findings suggest that WTP for manure is left-skewed, with the mass of the WTP distribution at a low price but with a left tail extending over negative WTP values (Oklahoma State University, 2004).

For these reasons, assuming a normal or extreme-value distribution for WTP may not be valid, yet we do not wish to impose a left-skew distribution either. Swine producers' perceptions may be wrong, and WTP could instead be symmetric or right-skewed. Thus, the WTP distribution used should be flexible, allowing skewness to be estimated directly from the data. In a review of the literature, little work has been conducted on parametric WTP distributions that allow asymmetry of either direction. Occasionally a lognormal or exponential distribution is used (Lusk, 2003), but this is usually to avoid negative WTP values (whereas we must allow negative WTP) and would impose a specific type of skewness. However, a large volume of research has been conducted on asymmetric distributions in the crop yield literature, and can easily be extended to the stated preference area.

In particular, the Johnson S_U (JS_U) distribution, initially developed by Ramirez (1997) and later refined by Ramirez, Misra, and Nelson (2003), is appealing. The JS_U form allows for left-skewed, right-skewed, or normal distributions, the decision of which is data-driven. The usefulness of the JS_U model is further enhanced by the fact that, even when the distribution is nonnormal, the mean and variance of WTP follow simple deterministic equations, allowing for easier interpretation of parameters. The next section describes a contingent valuation survey used to elicit WTP for livestock manure by crop producers. The Johnson S_U distribution will later be applied to these data to develop a flexible WTP distribution.

Survey Data

In August of 2003, a stated preference survey was mailed to 513 crop producers in Oklahoma, with no follow-up mailings. The database of producers had been maintained

In the next question, we would like you to tell us how you feel about substituting livestock manure for commercial fertilizer. Studies have found that people tend to overestimate their willingness to accept or pay money in hypothetical situations. When answering the question, please consider how you would react if you actually had to pay or accept real money that could be used for other goods and services.

7) Suppose your crop has traditionally received commercial fertilizer but no livestock manure. You now have the opportunity to let a nearby producer apply swine manure to your crop. With the swine manure application, you would not need to apply commercial fertilizer and would save $20 per acre in commercial fertilizer costs. The manure is of the liquid form and is incorporated into the soil.

   If the livestock producer offered to pay you $6 per acre to apply manure to your crop, would you accept the offer?

   ❑ Yes ❑ No ❑ No Answer

8) **If you checked "No Answer" to the previous question, was this because:**

   ❑ Rough indifference between a "yes" or "no" answer
   ❑ Inability to make a decision without more information
   ❑ Preference for some other mechanism for making this decision
   ❑ Other (please explain)

9) **If you checked "Yes" to Question 7,** on a scale of 1 to 10, where 1 means "very uncertain" and 10 means "very certain," how certain are you that you would accept $6 per acre for the manure application, if actually given the opportunity? (CIRCLE ONE NUMBER)

1	2	3	4	5	6	7	8	9	10
very uncertain									very certain

Figure 1. Sample contingent valuation question

by Oklahoma State University for many years and was used to conduct surveys on rental rates of agricultural services. Because producers on this list originally agreed to be placed on a mailing list, they represent producers who are more willing to respond to surveys than the general population. This introduces a sample selection bias, where the direction of this bias is unknown. Most crop producers also managed a cow-calf and/or stocker operation. Very few raised swine, sheep, poultry, or dairy cattle, and most of those who did probably used them for youth livestock shows.

The purpose of the survey was to measure crop producers' (receivers') willingness to pay for manure from other livestock farms. Eliciting the demand for manure through simple survey questions is a difficult task, as the good "manure" is not well defined. Manure varies substantially in its moisture and nutrient content, odor, organic material, and temporal availability across and even within a livestock species. Also, the nutrients contained in manure may be released more slowly than those in commercial fertilizers, which may positively or negatively influence crop yields. Many of the complexities of manure demand were eliminated by using a contingent valuation question (as presented in figure 1).

Table 1. Contingent Valuation Variables Defined

Variable	Definition	Range of Values
Manure Price (1)	Producers given a situation with savings of $10 per acre could receive a price between -$10 and $15	-10, -9, -8, ..., 0, ..., 13, 14, 15
Manure Price (2)	Producers given a situation with savings of $20 per acre could receive a price between -$10 and $25	-10, -9, -8, ..., 0, ..., 23, 24, 25
SAVINGS	Fertilizer savings dummy variable = 1 if fertilizer savings are $20 per acre, and 0 otherwise	$20 or $10
LIQUIDSWINE	Liquid swine manure dummy variable = 1 to represent the qualitative characteristics of liquid swine manure, and 0 otherwise (dry poultry manure is the omitted manure dummy variable)	1 or 0
DRYSWINE	Solid swine manure dummy variable = 1 to represent the qualitative characteristics of dry (solid) swine manure, and 0 otherwise (dry poultry manure is the omitted manure dummy variable)	1 or 0
INCORPORATE	Manure incorporation dummy variable = 1 if the producer was told manure was incorporated (sub-surface) into the soil, and 0 if it was spread across the top of the ground	1 or 0
PREVMANURE	Previous manure experience dummy variable = 1 if the crop producer had spread manure on his/her land in the last 10 years, and 0 otherwise	1 or 0

Receivers were told the manure would be applied to their crop by the livestock producer (deliverer). This eliminates the need to discuss transportation costs. The value of manure relates directly to its ability to substitute for chemical fertilizer. As chemical fertilizer savings rise and fall, we would expect the value of manure to rise and fall accordingly. To gauge receivers' willingness to pay for manure, it is imperative that they be given information on chemical fertilizer savings. Receivers were told that with the manure application, they would save a certain amount on commercial fertilizer costs. This eliminates the need to discuss the crop type or nutrient content of the manure. The amount of fertilizer savings varied randomly across each survey as $10 per acre and $20 per acre. This range was chosen because commercial fertilizer costs for wheat, the major Oklahoma crop, are estimated to be around $16 per acre (Oklahoma State University, 2003). Receivers were then asked one of two questions: (*a*) if they would accept the manure if given a certain payment, or (*b*) if they would pay a certain amount for the manure. Each survey had an equal chance of containing each question.

The "price" of the manure on each survey could then take a negative value if the receiver was told she would receive a payment, and a positive value if the respondent was told she must make a payment to receive the manure (see table 1). This allows us to model the distribution of willingness to pay (WTP) as taking on both positive and negative values. The amount a receiver could be paid for accepting manure was chosen from a uniform distribution between $10 and $1 per acre, while the price a receiver would have to pay varied from $0 to $15 per acre if the fertilizer savings were $10 per acre, and $0 to $25 per acre if the per acre fertilizer savings were $20. For each survey mailed, there was a 50% chance that savings would be $10 or $20, and a 50% chance the price would be negative or positive.

The manure was described as either (*a*) dry swine manure, (*b*) liquid swine manure, or (*c*) dry poultry manure. The manure may or may not be tilled into the soil. Each manure and tillage option had an equal chance of appearing on any given survey. Table 1 describes the explanatory variables used in the survey. When asked if they would accept the manure, receivers could respond "yes" they would accept the manure at the price listed in the survey, "no" they would not accept the manure, or "no answer." The "no answer" option was administered as suggested by the National Oceanic and Atmospheric Administration (NOAA) panel guidelines for value elicitation, which is described in Haab and McConnell (2002) and shown here in figure 1. Since the receiver simply responds "yes," "no," or "no answer" to one hypothetical opportunity, this is a dichotomous choice question, which is the preferred tool for contingent valuation (Haab and McConnell).

The value receivers place on manure is revealed through their answers to the dichotomous choice questions. Suppose a receiver is told the manure application would save her $20 per acre in chemical fertilizer costs, and she can purchase the manure for $10 per acre. If she indicates "no" she would not purchase the manure, this implies she values the manure at less than $10 per acre, and places a discount on manure of more than $10 per acre, relative to chemical fertilizer. Similarly, if she indicates "yes" she would purchase the manure at $20 per acre, this response implies she assigns manure no discount relative to chemical fertilizers.

There are many reasons why a receiver would give a discount to manure. While interpretation of the dichotomous choice question will vary across surveys, pretests suggested receivers would interpret the fertilizer savings as the additional per acre monetary expenditures that would have been made for the current crop year without manure.[2] It was not interpreted to include any discounted savings from future years. Pretests also revealed some respondents thought yield may differ with livestock manure, even if the same nutrient application was made, but that the yield difference would not be "too large." Some receivers may feel that yields will be lower when the same amount of nutrients is applied through manure instead of chemical fertilizer, and the price of manure must be less than fertilizer savings before they would accept it.

Receivers may also be concerned with odor; compaction of soil from the manure application equipment; pathogens, plant diseases, weeds, and pests transported with the manure; and concerns about regulatory oversight may also cause WTP to be less than fertilizer savings. On the other hand, manure may release nutrients more slowly than chemical fertilizers, and may contain organic materials and trace elements that enhance the soil fertilizer, making manure more desirable than chemical fertilizer.

The price a receiver will pay for manure may depend on her experience with manure applications. Manure may receive a high discount for receivers who have used only commercial fertilizer, due to the uncertainty of manure performance as a fertilizer. But over time, if the manure nutrients prove effective, these receivers would pay a higher price. The survey contained a question that allowed us to identify which respondents have applied manure to their crop in the past. The variance of willingness to pay may be lower for those with manure experience as well.

Stated preference surveys are always subject to hypothetical bias. Receivers may find it easy to say they will pay for manure, but when real money is involved, their

---

[2] Participants in the pretests included approximately 20 students who had some managerial oversight on a crop farm.

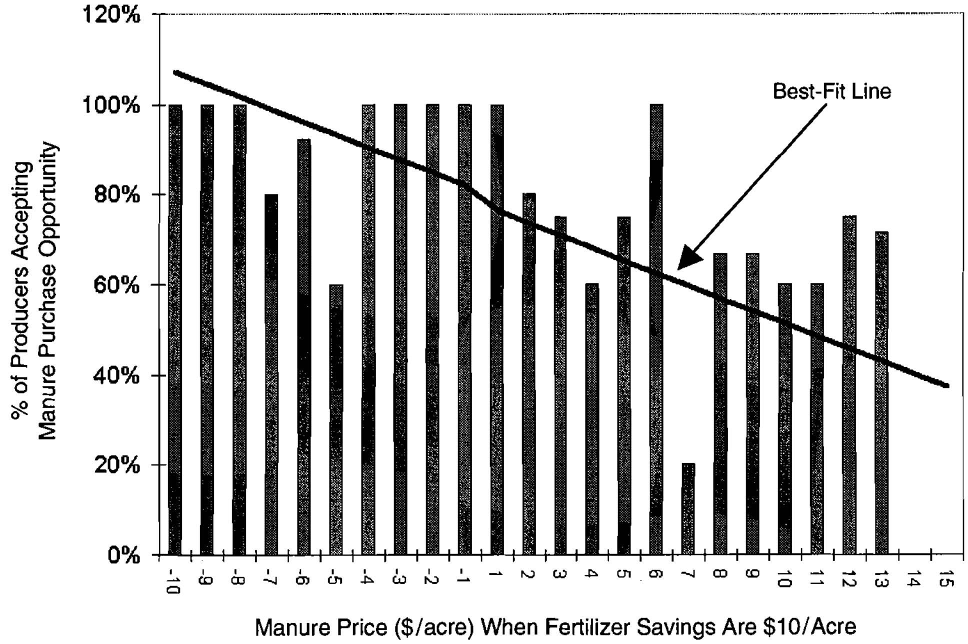
enthusiasm wanes. Two safeguards against hypothetical bias were included. First, a short cheap talk script was administered where hypothetical bias was described to the receiver (as shown in figure 1). The receiver was then asked to try to avoid the hypothetical bias. The cheap talk script has been shown to eliminate hypothetical bias in some situations, and almost always reduces stated values (Aadland and Caplan, 2003; Cummings, Taylor, and Taylor, 1999; Little and Berrens, 2004; Lusk, 2003).

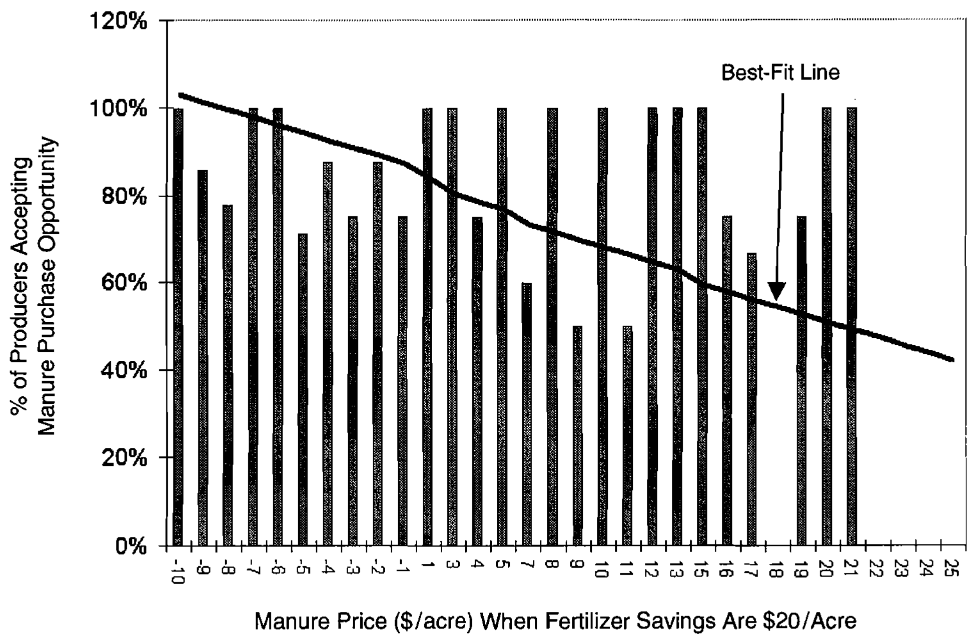
Second, the discrete choice question was followed with a certainty question (figure 1). If the receiver stated "yes" she would accept the manure at the listed price, she was asked to indicate on a scale of 1 to 10 how certain she was that she would accept the manure at the listed price if actually given the opportunity. An answer of 1 refers to "very uncertain," while an answer of 10 indicates "very certain." A lower certainty rating has been shown to induce greater hypothetical bias (Johannesson et al., 1999). Moreover, Champ and Bishop (2001) eliminated hypothetical bias by changing "yes" answers to "no" if the subject responded "yes" to the hypothetical question but indicated a certainty level of less than 8. In this study, some models are calibrated using the Champ and Bishop method. While further studies are needed to fully validate these two methods, we believe they are the best available methods for addressing hypothetical bias.

A total of 513 surveys were administered. Of these, 294 surveys were returned, yielding a very high response rate of 57%. This high response rate is likely attributable to the brevity of the survey and the fact that the database contained receivers who had earlier indicated they were willing to participate in Oklahoma State University surveys. Those who indicated "no answer" to the discrete choice question were recoded as a "no" (Haab and McConnell, 2002). After eliminating surveys that did not provide answers to the discrete choice question, 288 surveys remained. Changing "no answer" responses to "no" will have an impact on the corresponding WTP estimate. Of the 288 responses, 54 respondents answered "no" and 52 responded "no answer." Consequently, this recoding scheme almost doubles the number of "no" responses, which will lead to lower WTP estimates than if the "no answer" responses were removed from the sample.

Before estimating a parametric distribution for WTP, it is useful to discuss the survey responses. The two panels of figure 2 show the percentage of producers who accept the hypothetical manure purchase opportunity at various prices and savings in chemical fertilizer. The "best-fit line" in the two graphs represents an OLS regression of this percentage as a function of an intercept and the manure price. In both cases, the coefficient on price was significantly negative, indicating producers are less inclined to accept manure as its price rises. Figure 2 illustrates the heterogeneity of WTP across crop producers. Some decline a payment of $9 dollars per acre, and some will pay a price of $21 per acre, even though chemical fertilizer savings are $20 per acre.

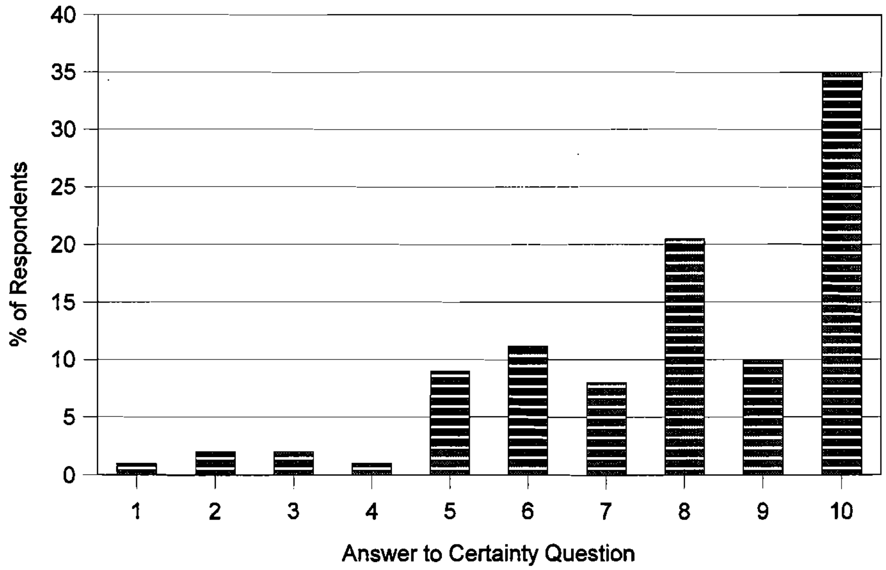
Figure 3 provides a histogram of responses to the certainty question. The most frequent answer was "10," with only a few producers indicating a response of "1." Since only those who say they would purchase manure answer the certainty question, it is interesting that more than 5% said they would purchase manure but indicated a certainty level of less than 5. Of those who said they would purchase manure, the mean certainty response was 7.9 and the median was 8. Next, these survey responses are used in conjunction with a flexible probability distribution from the crop yield literature to estimate a WTP distribution.





Notes: Those who indicated "no answer" to the purchase opportunity are excluded here. A total of 128 (107) producers indicated "yes" or "no" to a purchase opportunity that saves $10 ($20) per acre in chemical fertilizer costs. Manure prices not appearing on any returned surveys (e.g., a price of $0 in both graphs, a price of $2 in lower graph) are omitted from the figure, which is why the linear function often appears nonlinear. The "best-fit line" represents the results of an OLS regression, and the slope is significantly different from zero in both cases. A total of 156 (131) producers received a survey with savings of $10 ($20) per acre, and 49% of all producers received a survey with a negative price.

Figure 2. Distribution of "yes" responses to manure purchase opportunity



Note: A total of 182 producers answered the certainty question.

Figure 3. Histogram of certainty question answers (1 = very uncertain, 10 = very certain)

Estimation Methodology

Data from the survey described in the previous section are used to estimate a manure willingness-to-pay function. An interval-censored model is employed, which was originally developed by Cameron (1998) and also used by Lusk (2003) and Qaim and De Janvry (2003). This interval-censored model allows us to estimate willingness to pay (WTP) directly, rather than infer it from a utility function. The WTP for manure for respondent i is assumed to follow the form:

$$(1) \quad WTP_i = X_i\beta + \varepsilon_i = \beta_0 + \beta_1 SAVINGS_i + \beta_2 DRYSWINE_i + \beta_3 LIQUIDSWINE_i + \beta_4 INCORPORATE_i + \beta_5 PREVMANURE_i + \varepsilon_i,$$

where *SAVINGS* is a dummy variable equal to one if fertilizer savings are $20 per acre and zero otherwise. The intercept β_0 then refers to WTP when saving are $10 per acre, and $\beta_0 + \beta_1$ is the WTP when savings are $20 per acre, assuming all other variable values are zero. *DRYSWINE* and *LIQUIDSWINE* are dummy variables for dry swine manure and liquid swine manure, with dry poultry manure constituting the baseline; *INCORPORATE* is a dummy variable for when the respondent is told the manure is incorporated into the soil by the livestock producer (deliverer); and *PREVMANURE* is a dummy variable for receivers who have applied livestock manure to their crop(s) within the last 10 years.

The random error ε_i is expected to be heteroskedastic and skewed. Receivers who have applied manure in the past may display more homogeneous preferences, so the variance of the error term is stated as:

$$\text{(2)} \qquad E(\varepsilon_i^2) = (\alpha_0 + \alpha_1 PREVMANURE)^2.$$

Typically, the distribution of ε_i is assumed to take the extreme-value or the normal distribution. This study uses a nonnormal distribution for ε_i, where the skewness is determined by the data, the function in (1) still denotes the expected WTP, and the function in (2) still denotes the variance of WTP. The Johnson S_U distribution described by Ramirez, Misra, and Nelson (2003) meets these requirements well. This distribution assumes the ε_i is a transformation of normality, with the specific transformation denoted by:

$$\text{(3)} \qquad \begin{aligned} \varepsilon_i &= WTP_i - X_i\beta = \frac{\sigma\{\sinh(\Theta V) - F(\Theta,\mu)\}}{\Theta G(\Theta,\mu)}, \\ V &\sim N(\mu, 1), \\ F(\Theta,\mu) &= \exp(\Theta^2/2)\sinh(\Theta\mu), \\ G(\Theta,\mu) &= \left[\frac{\{\exp(\Theta^2) - 1\}\{\exp(\Theta^2)\cosh(-2\Theta) + 1\}}{2\Theta^2}\right]^{1/2}, \\ \sigma &= \alpha_0 + \alpha_1 PREVMANURE, \end{aligned}$$

where sinh(·) and cosh(·) are the sine and cosine function, respectively. This model is exactly as described in Ramiriz, Misra, and Nelson (refer to that work for further details). As Ramirez, Misra, and Nelson show, the beauty of this error distribution is that WTP_i can be skewed to the right or the left and it can exhibit kurtosis, both of which are determined by the parameters Θ and μ. Kurtosis is increasing in the absolute value of Θ (the sign of Θ is irrelevant), and a positive (negative) μ implies a right-skew (left-skew) distribution. The expected value of ε_i is zero and its variance is still given by equation (2).

The estimation method must be modified from Ramirez, Misra, and Nelson (2003) to accommodate discrete dependent variables. Let P_i be the price of manure on the *i*th survey, which can be negative if the receiver is offered a payment to accept the manure. A person answers "yes" she will accept manure whenever $WTP_i > P_i$ or $\varepsilon_i > P_i - X_i\beta$.[3] The probability of a "yes" response then equals

$$\text{(4)} \qquad \Pr(WTP_i > P_i) = 1 - \int_{-\infty}^{P_i - X_i\beta} \varphi\left(\frac{V-\mu}{1}\right)\left(\frac{dV}{d\varepsilon}\right) d\varepsilon,$$

where φ is the standard normal probability distribution function. The term $(dV/d\varepsilon)$ can be solved for by first letting

$$\sinh(\Theta V) = \varepsilon\frac{\Theta G(\Theta,\mu)}{\sigma} + F(\Theta,\mu) = A.$$

[3] Often, a purchase decision is modeled using a utility function of the form $U_i = X_i\beta + \varepsilon_i - \alpha P$, where $X_i\beta$ is the observable utility of manure, ε_i is the unobservable utility of manure, and $-\alpha P_i$ is the disutility from having to pay a price of P_i for the manure. The manure is then purchased whenever utility is greater than zero, or $X_i\beta + \varepsilon_i > \alpha P_i$. To estimate such a utility function, at least one parameter must be set to some fixed value, usually zero. Often, the variance of ε_i is set to one. In the present study, we set $\alpha = 1$ and estimate the variance of ε_i, as discussed in Cameron (1998). This yields a parameter vector β that expresses utility (net of disutility from giving up money) in money-metric form, as manure will be purchased only when $X_i\beta + \varepsilon_i > P_i$.

Using the formula for the inverse hyperbolic sine function, V can then be expressed as $V = \ln(A + \sqrt{A^2 + 1})/\Theta$. Taking the derivative of V with respect to ε allows us to rewrite (4) as:

$$\text{(5)} \quad \Pr(WTP_i > P_i) = 1 - \int_{-\infty}^{P_i - X_i\beta} \varphi\left(\frac{V-\mu}{1}\right)\left(A + \sqrt{A^2+1}\right)^{-1} \times \left(1 + 0.5(A^2+1)^{-1/2}2A\right)G(\Theta, \mu)\sigma^{-1}d\varepsilon.$$

While (5) contains a highly nonlinear integral, the "*quadl*" numerical integration tool in MATLAB is able to integrate it well. The log-likelihood function can then be constructed as:

$$\text{(6)} \quad \text{LLF} = \sum_{i=1}^{N} Y_i \ln\left(\Pr(WTP_i > P_i)\right) + \sum_{i=1}^{N}(1 - Y_i)\ln\left(1 - \Pr(WTP_i > P_i)\right),$$

where Y_i equals one if the respondent indicates she would accept the manure application, and zero otherwise. The log-likelihood function was maximized using the unconstrained optimization algorithm "*fminunc*" in MATLAB. Due to the nonlinearity of the objective function, extra care must be taken to ensure the solution is optimal. Parameter estimates were sensitive to starting values, especially those of Θ and μ, so 50 randomly generated starting values were used to identify the optimal parameters.

Estimation Results

Table 2 reports the maximum-likelihood estimates of four models. The first model (column 2) constrains Θ and μ to equal zero, which amounts to assuming normality in WTP. This model is uncalibrated, which means the survey responses were not modified based on the subject's answer to the certainty question. The nonnormal-uncalibrated model (column 3) is the same except that the values of Θ and μ are unrestricted, allowing a normal, left-skewed, or right-skewed WTP distribution. Column 4 contains estimates for the nonnormal-calibrated model, where all "yes" answers are changed to "no" if the respondent indicated a certainty level of less than 8.[4] Finally, column 5 is referred to as a nonnormal-composite model and, as will be discussed, provides a weaker calibration that is akin to a composite model.

The regression results from table 2 for mean willingness to pay (WTP) are interpreted as follows. The intercept indicates receivers' per acre WTP for dry poultry manure when commercial fertilizer savings are \$10 per acre. The dummy variables *DRYSWINE* and *LIQUIDSWINE* show how WTP changes for dry swine and liquid swine manure, respectively. The increase in WTP when commercial fertilizer savings increase from \$10 to \$20 per acre is given by the coefficient on *SAVINGS*. *INCORPORATE* shows the effect on WTP when manure is incorporated into the soil (without charge), and *PREVMANURE* illustrates the difference in WTP for receivers who have previously applied manure from other livestock farms.

First, compare the parameter estimates from the uncalibrated normal and nonnormal models (table 2, columns 2 and 3). The asymptotic t-statistics for Θ and μ in the non-

---

[4] Specifically, if a subject said "yes" she would purchase the manure at the listed price, but gave an answer of less than 8 to the certainty question shown in figure 1, this answer was changed to "no."

Table 2. Manure Willingness-to-Pay Parameter Estimates

[1] Variable / Description	[2] Normal-Uncalibrated Model	[3] Nonnormal Uncalibrated Model	[4] Nonnormal Calibrated Model	[5] Nonnormal Composite Model
Mean Equation:				
Intercept	7.8374***	-3.5917***	-21.5799***	-17.1003***
	(6.17)	(-2.74)	(-6.00)	(-10.60)
SAVINGS	2.2207**	5.8230***	1.1093	3.7668***
	(2.27)	(2.95)	(0.35)	(3.08)
DRYSWINE	3.0924***	2.5356**	-0.5927	1.3940
	(2.68)	(2.05)	(-0.36)	(1.16)
LIQUIDSWINE	-1.8434	-4.5469***	-4.9533***	-4.0473***
	(-1.42)	(-2.74)	(-4.56)	(-3.77)
INCORPORATE	1.3543	-0.8054	-1.7895	-0.0751
	(1.38)	(-0.69)	(-1.61)	(-0.11)
PREVMANURE	3.1619***	2.4091**	6.7174***	7.6883***
	(2.25)	(2.06)	(3.74)	(7.19)
Variance Equation:				
Intercept	19.6416***	44.4976***	59.2469***	61.2823***
	(9.78)	(43.41)	(48.17)	(52.85)
PREVMANURE	2.7876***	0.6534	-3.9313***	-3.5721***
	(2.42)	(0.63)	(-4.02)	(-3.53)
Nonnormality Parameters:				
Θ (leptokurtic	—	1.2860***	-0.9861***	-1.0949***
		(12.35)	(-13.36)	(-9.65)
μ (leptokurtic and skewness)	—	-3.2878***	-4.0612***	-4.1731***
		(-3.00)	(-3.22)	(-4.20)
Log-Likelihood Function Value	-172.3516	-167.9530	-175.1672	-180.82
Sample Size	288	288	288	288

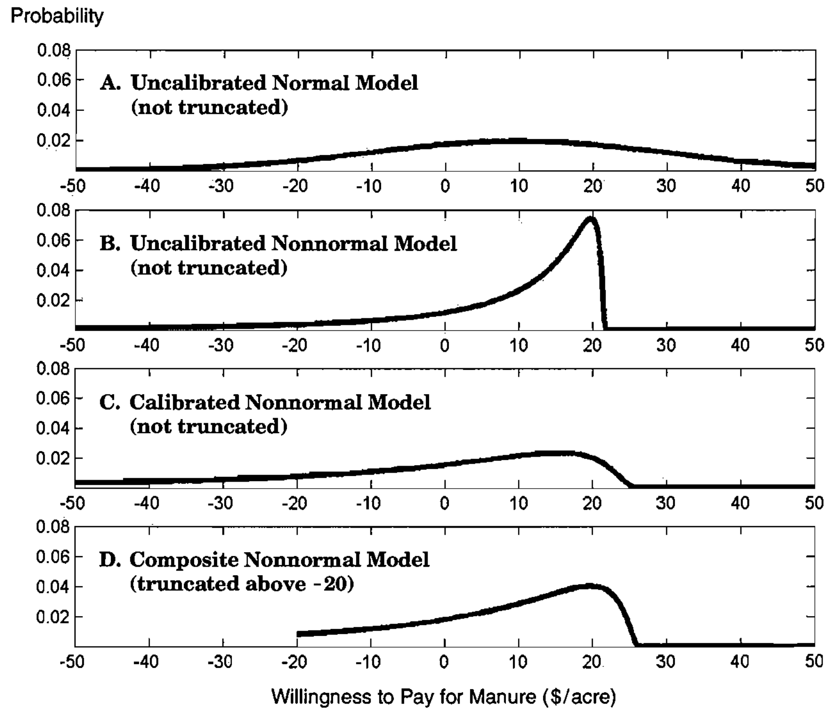
Notes: Single, double, and triple asterisks (*) denote statistical significance at the 1%, 5%, and 10% levels, respectively. Values in parentheses are *t*-statistics.

normal model indicate they are indeed different from zero, leading us to reject normality in favor of a left-skewed distribution.[5] The difference between the two distributions is stark, as demonstrated by figure 4. At a savings of $15 per acre, figure 4 shows that under the normal model some receivers will pay more than $40 per acre, while the non-normal model has a maximum WTP close to $20. Buyers would be very unlikely to assign a large premium to manure over commercial fertilizer, so clearly the nonnormal model's predictions are better in this respect.

The intercept in the normal model is much larger than in the nonnormal model, implying its mean WTP estimate is larger.[6] Since Wald tests favor the nonnormal model,

[5] As Ramirez, Misra, and Nelson (2003) explain, likelihood-ratio tests cannot be used for the joint hypothesis $\Theta = \mu = 0$ because the model under the null hypothesis contains a nuisance parameter. While Wald tests are sometimes discouraged due to their sensitivity to scaling, note that all of the explanatory variables are dummy variables, making the scaling issue moot.

[6] If the uncalibrated normal model is estimated removing the "no answer" respondents, the intercept estimate becomes $18.62, indicating a higher willingness to pay.



Notes: The value of *SAVINGS* and *PREVMANURE* in table 1 is set to 0.5 and 0.25, respectively. All other explanatory variables are set to zero. This assumes dry poultry manure, not incorporated in the soil, which saves the producer $15 in chemical fertilizer costs. It also assumes the producer has a 25% chance of having previous experience with manure.

Figure 4. Manure willingness-to-pay probability distribution functions

we conclude that the assumption of normality in this case would lead to an overestimation of true WTP. This naturally leads to an underestimation of manure regulation compliance costs. The nonnormal model only requires estimation of two additional parameters, and even though estimation entails numerical integration at each observation, today's computers provide fast convergence (less than five minutes). Thus, in instances when normality is questionable, one should consider using the more flexible JS_U distribution.

The remainder of this section focuses on the results of nonnormal models only, with particular attention to developing accurate WTP estimates. The uncalibrated (nonnormal) model suggests dry swine manure is the most marketable manure, while the calibrated model has no clear preference for dry swine or dry poultry manure. In both models, liquid swine manure is discounted by approximately $4.50–$5.00 for each acre the manure is applied. The fact that manure is incorporated has no significant impact on WTP, while previous experience with manure significantly increases WTP. The calibrated model—less subject to hypothetical bias—will have a lower mean WTP by construction. In this case, mean WTP is reduced by approximately $18 per acre—a substantial reduction.

Notice that the calibrated model produces some results more consistent with a priori expectations. There is little reason to suggest dry swine manure is better than poultry manure, holding the nutrient content constant, and the calibrated model reflects this.

Also, it was expected that receivers with previous manure experience would display less WTP variance—the calibrated model reflects this as well. However, the calibrated model does not reflect the expectation that WTP should increase with fertilizer savings.

Both the calibrated and uncalibrated models place an upper bound on WTP at $18–$25 per acre when fertilizer savings are $15 per acre (see figure 4). Some receivers do indeed place a premium on manure relative to commercial fertilizers. Of the 288 subjects, 13 reported they would pay a price higher than the fertilizer savings, and seven of those indicated a certainty level of 8 or higher. While some receivers place a premium on manure, other receivers place a discount. The distribution of WTP across receivers contains many individuals who require a payment before accepting manure.

However, due to imperfect survey design, all the models discussed thus far likely overestimate both the number of receivers who assign this discount and the size of the discount. Prior to administering the survey, almost all subjects were expected to accept manure if paid $10 per acre, and pretests supported this expectation. Although all seven subjects who were offered a hypothetical payment of $10 per acre accepted it, three subjects rejected a hypothetical payment of $9, and four rejected a payment of $8. This forces the left tail of the distribution to the left of −$10. A larger survey with a wider range of payments is needed to better identify the lower bound for WTP. Until this larger survey is conducted, the only remedy is to truncate the WTP distributions from below.

Two adjustments are made to the uncalibrated and calibrated models to provide a final WTP distribution. First, a composite model is constructed from the two models by providing a weaker calibration. In the calibrated model, "yes" answers accompanied by a certainty level of less than 8 were recoded as "no." This essentially assumes researchers believe that people who answer "yes," when asked in a non-hypothetical setting will answer "no," and their value of Y_i is changed from $Y_i = 1$ to $Y_i = 0$. In the composite model, instead of changing $Y_i = 1$ to $Y_i = 0$, we recode the data as $Y_i = 0.5$. This is akin to assuming there is a 50% chance that those who say "yes" but have a certainty level of less than 8 will actually say "no." This composite is constructed under the perception that the calibrated model underpredicts WTP (given its extended left tail shown in figure 4). In fact, other studies have demonstrated situations where this calibration provides downward-biased estimates of true WTP (Blumenschein et al., 1998; Norwood, 2005). Since uncalibrated models are upward-biased, this composite model should better describe true WTP.[7]

The parameter estimates for the composite model are shown in the last column of table 2. Next, this composite model is truncated from below, under the pretense that no receiver would require a payment in excess of $20 per acre to accept manure.[8] This composite-truncated distribution is illustrated in the bottom panel of figure 4. Next, the composite-truncated model is used to provide a simple framework for incorporating WTP estimates in manure management cost models. The composite-truncated model is used

---

[7] This composite model can be alternatively derived as follows. Consider the log-likelihood function value for an individual observation, $LLF_i = Y_i \ln(\Pr(WTP_i > P_i)) + (1 - Y_i)\ln(1 - \Pr(WTP_i > P_i))$. Suppose this observation is such that $Y_i = 1$ but the subjects' certainty level is less than 8. In the uncalibrated model this formula is $(1)\ln(\Pr(WTP_i > P_i)) + (0)\ln(1 - \Pr(WTP_i > P_i))$, and for the calibrated model is $(0)\ln(\Pr(WTP_i > P_i)) + (1)\ln(1 - \Pr(WTP_i > P_i))$. If one constructs a composite likelihood function that equals $LLF_{Composite} = (0.5)LLF_{Calibrated} + (0.5)LLF_{Uncalibrated}$, this is exactly the same as changing $Y_i = 1$ to $Y_i = 0.5$ when the certainty level is less than 8.

[8] Let $F(WTP)$ be the cumulative distribution function for WTP. The new truncated cumulative distribution is calculated as $F(WTP)/[1 - F(-20)]$.

Table 3. Willingness-to-Pay Distribution Using the Truncated-Composite Model for Dry Manure

Per Acre Maximum WTP Is Between:	% of Producers When Savings = $15/Acre	% of Producers When Savings = $25/Acre
-$20 and -$10	10%	8%
-$10 and -$0	15%	12%
$0 and $10	23%	19%
$10 and $20	35%	30%
$20 and $30	17%	31%
Mean WTP (90% Confidence Interval of Mean WTP)	$8.37 ($6.21, $10.58)	$11.28 ($8.72, $14.07)

Notes: It is assumed 25% of producers have previous experience with manure. This distribution is estimated using the composite model estimates from table 2, where WTP is truncated from below at -$20. For a savings of $15 ($25) per acre, the value of *SAVINGS* is set to 0.5 (1.5). The confidence interval for the mean WTP is calculated by simulating the truncated-composite model parameters from their estimated joint distribution (given in column 5 of table 2) 500 times, calculating the mean WTP at each simulation, and removing the 5% lowest and highest simulated mean WTPs. The lowest and highest remaining values then constitute the 90% confidence interval.

because it accounts for hypothetical bias, contains bounds on WTP (which to us appear reasonable), and has coefficients which display desirable properties in an engineering-cost model.

In table 3, the WTP distribution is divided into intervals of WTP, using the truncated composite model for dry manure. The mean WTP is also provided. The WTP distributions are listed for two values of fertilizer savings: $15 and $25 per acre. A savings of $15 per acre is midway between $10 and $20, the two values of savings used in the survey, while a savings of $25 entails extrapolating outside the range of data. Assuming that fertilizer savings are $15 per acre, 25% of receivers require a payment before accepting manure, and 23% have a positive WTP, but will not pay the full fertilizer savings. Approximately 35% of receivers are in the $10–$20 interval which contains fertilizer savings, suggesting most receivers would not assign a large discount or premium to manure. Finally, 17% of receivers are willing to pay a premium for manure.

Next, the distribution of WTP is shown for the case where fertilizer savings equal $25 per acre. This is extrapolating outside the data, as the largest savings were $20 per acre. Under this scenario, the WTP distribution does shift toward the right, but the shift is not very large, as the percentage of receivers requiring a payment before they accept manure decreases from 25% to only 20%. Manure will usually be applied such that the manure nutrients supply the crop's nutrient needs for at least one year. For most crops, this will save the receiver between $10 and $25 per acre. For example, crop budgets suggest the yearly per acre fertilizer costs for wheat, corn, alfalfa, and grain sorghum are $16.68, $19.03, $20.50, and $9.50, respectively (Oklahoma State University, 2003). Thus, table 3 can be used to provide simple WTP estimates for manure for most crop enterprises.

Summary and Discussion

While many studies have focused on measuring the cost of complying with new manure management regulations, no study has yet estimated the crop producers' willingness to pay (WTP) for other farms' livestock manure. This study conducted a contingent valuation analysis of manure WTP across a group of Oklahoma crop producers (receivers). Typically, studies assume symmetric distributions for WTP, whether it be an extreme-value or normal distribution. In this case, the prior expectation is that WTP is asymmetric, with the bulk of evidence pointing toward a left-skewed distribution. To permit skewness to be determined by the data, a flexible distribution developed by Ramirez (1997) and Ramirez, Misra, and Nelson (2003) in the crop yield literature was modified for use in WTP estimation.

Receivers were presented with a hypothetical situation where they could allow a manure application to their crop, and where this manure application would save them $10 or $20 per acre in chemical fertilizer costs. Receivers were then asked if they would purchase the manure at a given price, or accept it if paid a given amount. A certainty question and cheap talk script were used to correct for hypothetical bias.

Hypothesis tests reject normality in favor of a left-skewed WTP distribution. The distribution of WTP was centered around fertilizer savings for most receivers, but a significant proportion of receivers reported a negative WTP. Assuming that the non-normal model is indeed superior, the assumption of normality would overestimate true WTP. Liquid manure was discounted relative to dry manure. If the manure is applied at agronomic rates, liquid manure decreases mean WTP by about $4 to $5 per acre. Results suggest livestock producers (deliverers) wishing to export manure should attempt to identify receivers who have previously accepted manure, as these individuals demonstrated a greater WTP for manure.

Much research has focused on how compliance costs for new manure management regulations may vary across farms. Land availability and the willingness of receivers in the surrounding area to accept manure are two key variables explaining variations in compliance costs. Until now, no study has measured the variability in WTP for livestock manure. This study provides a complete WTP distribution researchers can use to capture the lower and upper bounds on compliance costs across regions. Results show that preferences for manure are heterogeneous. Many receivers are not only willing to accept livestock manure, but some stated they will pay a premium over commercial fertilizers. However, a significant proportion of receivers are very wary about accepting manure, and may require a large payment before they are willing to accept it.

The good news for livestock farms is that once receivers have experience with manure, their willingness to pay for manure rises. This finding introduces a dynamic element into manure management. If a receiver finds little initial demand for her manure, she can pay to have the manure accepted on off-farm acres. Then, once the manure receiver gains experience with manure as a fertilizer, she may be able to negotiate a higher price in the future.

Finally, results suggest researchers should pay more attention to nonnormality in nonmarket valuation. It would be desirable for popular software packages to incorporate the Johnson S_U distribution as a standard program, so that nonnormality can be easily tested before WTP estimates are published.

[*Received October 2004; final revision received September 2005.*]

References

Aadland, D., and A. J. Caplan. "Willingness to Pay for Curbside Recycling with Detection and Mitigation of Hypothetical Bias." *Amer. J. Agr. Econ.* 85,2(May 2003):492–502.

Blumenschein, K., M. Johannesson, G. C. Bloomquist, B. Liljas, and R. M. O'Connor. "Experimental Results on Expressed Certainty and Hypothetical Bias in Contingent Valuation." *S. Econ. J.* 65,1(July 1998):169–177.

Cameron, T. A. "A New Paradigm for Valuing Non-market Goods Using Referendum Data: Maximum Likelihood Estimation by Censored Logistic Regression." *J. Environ. Econ. and Mgmt.* 15(1998): 355–379.

Carter-Young, H., S. Cates, J. Chvosta, Y. Ji, A. Wossink, and K. Zering. "Evaluation of Swine Producers' Perceptions of Alternative Waste Management Systems: The Smithfield Foods-Premium Standard Farms Agreement with the North Carolina Attorney General." Special report prepared for the Animal and Poultry Waste Management Center, North Carolina State University, May 2003.

Champ, P., and R. C. Bishop. "Donation Payment Mechanisms and Contingent Valuation: An Empirical Study of Hypothetical Bias." *Environ. and Resour. Econ.* 19(2001):383–402.

Clinch, J. P., and A. Murphy. "Modeling Winners and Losers in Contingent Valuation of Public Goods: Appropriate Welfare Measures and Econometric Analysis." *Economic J.* 111(April 2001):420–443.

Cummings, R. G., G. Taylor, and L. O. Taylor. "Unbiased Value Estimates for Environmental Goods: A Cheap Talk Design for the Contingent Valuation Method." *Amer. Econ. Rev.* 89(1999):649–665.

Feinerman, E., D. J. Bosch, and J. W. Pease. "Manure Applications and Nutrient Standards." *Amer. J. Agr. Econ.* 86,1(February 2004):14–25.

Fleming, R. A., and J. D. Long. "Animal Waste Management." *Agronomy J.* (January/February 2002): 57–64.

Haab, T. C., and K. E. McConnell. *Valuing Environmental and Natural Resources.* Northampton, MA: Edward Elgar Publishing, Ltd., 2002.

Johannesson, M., G. C. Blomquist, K. Blumenschein, P. Johannesson, and B. Liljas. "Calibrating Hypothetical Willingness-to-Pay Responses." *J. Risk and Uncertainty* 8(1999):21–32.

Little, J., and R. Berrens. "Explaining Disparities Between Actual and Hypothetical Stated Values: Further Investigation Using Meta-Analysis." *Economics Bulletin* 3,6(March 2004):1–13.

Lusk, J. L. "Effects of Cheap Talk on Consumer Willingness to Pay for Golden Rice." *Amer. J. Agr. Econ.* 85,4(November 2003):840–856.

Norwood, F. B. "Can Calibration Reconcile Stated and Observed Behavior?" *J. Agr. and Appl. Econ.* 37,1(April 2005):237–248.

Oklahoma State University, Department of Agricultural Economics. "Survey of Oklahoma Swine Farms." Unpub. preliminary results made available through personal communication with F. Bailey Norwood, June 2004.

Oklahoma State University, Oklahoma Cooperative Extension Service. "Crop Budgets." OSU, 7 April 2003. Online. Available at http://www.agecon.okstate.edu/budgets/sample_pdf_files.asp.

Qaim, M., and A. De Janvry. "Genetically Modified Crops, Corporate Pricing Strategies, and Farmers' Adoption: The Case of Bt Cotton in Argentina." *Amer. J. Agr. Econ.* 85,4(November 2003):814–828.

Ramirez, O. A. "Estimation and Use of a Multivariate Parametric Model for Simulating Heteroskedastic, Correlated, Nonnormal Random Variables: The Case of Corn Belt Corn, Soybean, and Wheat Yields." *Amer. J. Agr. Econ.* 79(1997):191–205.

Ramirez, O. A., S. K. Misra, and J. Nelson. "Efficient Estimation of Agricultural Time-Series Models with Nonnormal Dependent Variables." *Amer. J. Agr. Econ.* 85,4(November 2003):1029–1040.

U.S. Congress. "Rules and Regulations: CAFO." *Federal Register* 69, no. 29 (12 February 2003):7209.

U.S. Department of Agriculture, Economic Research Service. "Manure Management for Water Quality: Costs to Animal Feeding Operations of Applying Manure Nutrients to Land." Agr. Econ. Rep. No. 824, USDA/ERS, Washington, DC, June 2003.

U.S. Department of Agriculture, Natural Resources Conservation Service. "Nutrient Management Standards 590." Technical Resources, November 2004. Online. Available at http://www.nrcs.usda.gov/technical/ECS/nutrient/590.html.

U.S. Environmental Protection Agency. "Cost Methodology Report for Swine and Poultry Sectors." Pub. No. EPA-821-R-01-018, USEPA, Washington, DC, January 2001.