A NEW APPROACH TO CONTINGENT VALUATION FOR ASSESSING THE COSTS OF LIVING WITH WILDLIFE IN DEVELOPING COUNTRIES

by

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Submitted for Presentation as a Selected Paper at the Annual Meeting of American Agricultural Economics Association, July 28-31, 2002, Long Beach, California.

Abstract

This paper describes the first use of a methodology based on a utility-theoretic behavioral model to simultaneously estimate a household's WTP for a non-market good in both money and a non-monetary numeraire good. WTP by subsistence farmers in Namibia for deterrents to wildlife attacks on crops and livestock is estimated.

1 Introduction

African wildlife species, such as the elephant, exhibit substantial, multiple values, including their importance to preservationists and significance to African economic welfare. Wildlife has potential consumptive direct use values, non-consumptive direct use values, indirect use values, and non-use values. In particular, African wildlife generates substantial revenues from tourism. However, terrestrial wildlife species also generate an opportunity cost to society for their existence, in the form of their use of base resources such as land. In addition, there are more direct costs associated with their requirements for management resources like game wardens. Finally, wildlife generates large negative externalities for people living near them (O'Connell, 1995; Wambuguh, 1998; Hoare, 1999), via the damage associated with destruction of crops, property, and human life (Swanson, 1994; Sutton, 1997 and 1998).

Realistic models of wildlife management require accurate measurement of the costs, and in particular the costs incurred by farmers who share their environment with the wildlife. One of the challenges of incorporating the costs of living with wildlife into management models is the difficulty of their measurement. To date, most work done in this area has involved qualitative descriptions of wildlife-human conflict (e.g., Kiiru, 1995; Ngure, 1995). There has been very little progress in quantifying these complex relationships. One might imagine simply going to farmers and asking them what damages they have incurred over the past season in an interview format (Wambuguh, 1998). However, those farmers may not keep accurate records of the damage, and the results might be viewed with suspicion as farmers have an incentive to overestimate the damage costs in an effort to increase the aid that they receive (Kangwana, 1996; Hoare, 1999).

As an alternative, some ecologists have employed the direct, physical measurement of damages. This involves having someone on the ground close to the place and time of the attack in order to estimate the extent of the damage to crops or structures (e.g., O'Connell, 1995a&b; Hoare, 1999). Then, some sort of accounting value is placed on the damaged goods in order to aggregate and compare damages. One advantage of this method is that the researcher does not have to rely on the word of the farmer to acquire the information. However, there are also several disadvantages. First, assuming that the physical extent of the damage can be accurately measured, how does one assign a value to it? Accurately determining the value of crops requires divining what the harvest would have been without the attack, where and when the crops would have been sold, the quality of the produce, and the price that would be received. This information is difficult if not impossible to come by, so ecologists frequently take a more expedient route and inaccurately value damages suffered by farmers by assigning retail market prices to average yields (e.g., O'Connell, 1995a&b).

The second problem with the physical measurement of damages is that the logistics and costs would be prohibitive of stationing agents in areas where attacks may take place and having them interview every victim of attack throughout the year. Third, the direct measurement of damages overlooks all of the indirect costs of living with elephants (Sutton, 2001). It is possible that these costs, such as the opportunity cost of growing less valuable crops because elephants are not as likely to damage them or the cost of psychological stress, may be higher than the direct costs. Finally, the direct measurement of damages, as it is typically applied (e.g. Hoare, 1999), essentially suffers from sample selection bias. The data includes only those households that actually incurred elephant damage. Further, only those victims that suffer considerable damage or have especially negative feelings towards elephants are likely to bother filing a report. Farmers who employ illegal deterrent methods, such as shooting at elephants, would be unlikely to report the incident. Small-scale farmers may also be less likely to contact authorities in general; Wambuguh (1998) found that only 30% of such victims report their incidents. Because random sampling methods are not normally employed for this approach, conclusions from studies employing it cannot be generalized across either human or wildlife populations.

This paper develops a new approach to measuring the costs to farmers of living with wildlife by using the contingent valuation method (CVM). The approach allows for the accurate measurement of both the direct and indirect costs in a relatively quick and cost-effective way. By using a random sample, problems of sample selection bias are avoided, and the results can be aggregated for a region. The information elicited directly measures the households' shadow value for the costs.

The approach is applied to a data set from a willingness to pay survey of farm households in the Caprivi Region of Namibia (Sutton, 2001). That survey was the first to employ CVM to measure the costs to local developing-country communities of living with wildlife. This is also the first use of a methodology based on a utility-theoretic behavioral model to simultaneously estimate a household's WTP for a non-market good in both cash and a non-monetary numeraire good in an internally consistent manner, and estimate the household's shadow value for the non-monetary good. Using a non-monetary numeraire good, or "currency", like maize increases the ease of comprehension of and response to CVM questions by survey respondents in rural developing country economies. It also has econometric advantages, because having two numeraire goods adds more information and more structure to the estimation. This makes possible, for example, the first use of a significance test for differences between market and shadow prices for the numeraire good (though Larson et al., 2001a, use a similar technique to value developed-country environmental amenities in terms of cash and leisure time).

The survey involved asking households their WTP for a deterrent to wildlife attacks—specifically, an electric fence. This is a fence around an individual household's fields and livestock corral. During the survey, it was made explicit that the fence would be owned by the subject household alone, and the recurrent amount that the household would be willing to pay for it every year, in either money or maize, was elicited. Deterrent being valued is therefore characterized by individual property rights and the excludability of other users, so it is a private—not public—good. The level of investment in the fence (though the cost may be subsidized by the government) enters into the choice problem of the concerned household alone. This is in contrast to most contingent valuation studies, which value public goods. There is therefore no possibility of a "warm glow" effect whereby a household can express a WTP for another household's fence.

The Caprivi household survey employed a double-bounded, referendum-style contingent valuation methodology to estimate farm households' WTP for wildlife deterrents. Mitchell and Carson explain at length the advantages of referendum-style CVM surveys (Mitchell and Carson, 1989). They also cite the potential gains in efficiency for estimation from using follow-up questions. Mitchell and Carson assert that WTP, rather than willingness to accept (WTA), is the correct measure of the value of a private or public good that is not currently owned by the respondent, as is the case here.

2 Empirical Model

Cameron and Quiggin (1994) suggested that respondents to double-bounded surveys might form separate WTP values for each of the payment questions, and that these values would likely be correlated but not identical. To accommodate this possibility, they generalized on earlier work (Cameron, 1988) by developing a bivariate model that allows the information elicited by the original and follow-up contingent valuation questions to be the same or different, depending on the data. This model allows for the correlation between the first and second bids proffered to be modeled explicitly. This is accomplished by assuming a joint, bivariate normal distribution for the two unobserved values.

Alberini suggests that, if it is judged that there is likely to be a relatively low correlation between respondents' latent WTP values across questions for the same scenario, a bivariate model would be indicated (Alberini, 1995). In contrast, Poe et al. suggest estimating WTP jointly using a bivariate probit model in cases where there is strong correlation between responses to two scenarios within the same contingent valuation survey (Poe et al., 1997). They also note that this correlation is likely to be high when the goods being valued in the two scenarios are quite similar.

The current study combines aspects of both the Alberini and the Poe et al. work to develop a new approach. Here, the question format was "two-and-a-half bounded," i.e., double-bounded on the positive side and triple-bounded on the negative side for both the money and maize payment options. Thus, there could be as many as six latent WTP values from each respondent for the same good. This follow-up question approach produces more efficient estimates than would an approach employing only one WTP question (Hanemann et al., 1991). However, following the results of Alberini, it was decided not to apply a bivariate (or trivariate) model to data for the same payment option, as was done by Cameron and Quiggin, because the correlation between WTP responses in the same currency was likely to be high since the information content of the question was not altered aside from presenting a follow-up bid. As a result, the estimates from a univariate model would tend to be no more biased than those from a bivariate model, and there would be gains in efficiency.

Instead, it was decided to follow the advice of Poe et al. and employ the bivariate probit approach to what were essentially two contingent valuation scenarios within the same survey—one eliciting WTP for a deterrent in money, and the other in maize. This reduces the bias of estimates of the variance of mean WTP. In essence, it was decided that the larger source of variation and difference in error structure would occur across, rather within, currencies. The technique employed was therefore to assume a univariate error distribution within currencies, and a bivariate distribution across them. By applying the bivariate probit model in this fashion, it was possible to jointly estimate WTP in both the money and maize numeraires. A similar technique was employed by Larson et al. (2001a) to analyze travel-cost data in terms of both money and time commitment for whale watching trips in California, though that study was single-bounded within "currencies" and used a linear WTP function.

The WTP equations for both the cash and maize payment vehicles are based on a farm-household behavioral model developed to describe decision-making by Caprivi households (Singh et al., 1986; de Janvry et al., 1991; Sadoulet and de Janvry, 1995). This allows for the estimation of both WTP values in a manner that is internally consistent and grounded in utility theory. The model is simplified in order to focus on the two constraints related to the two WTP values elicited by the questionnaire—that is, money and maize. In addition, the WTP questions were framed within the temporal context of the households having just completed their prior season's harvest. Thus, their production and total availability of maize would be taken as given.

The farm-household's problem then becomes one of allocating their fixed money budget M and fixed maize stock S to maximize utility. This is achieved by purchasing a vector of m market goods **x** with money prices **p**, and by using maize for n non-market consumption activities **c**, including household consumption, barter, and livestock feed. Consumption of grain also has a "price" or unit cost of consumption **t** that reflects wastage or spillage in converting units of stock to units of consumption of grain. This is not a market price but can be thought of as a technical conversion coefficient, and it could be 1.0 for any specific grain use. The household maximizes its utility given the vector of fixed levels of government-sponsored programs to deter wildlife attacks **g** and socio-economic characteristics of the household **z**. In maximizing its utility, the household faces strictly binding constraints on its money budget M = **px** and on its stock of maize available for consumption $S = \mathbf{tc}$.[1] The household's primal problem then leads to the indirect utility function $V(\mathbf{p},\mathbf{t},\mathbf{g},\mathbf{z},M,S)$, defined as

$$V(\mathbf{p},\mathbf{t},\mathbf{g},\mathbf{z},M,S) \equiv \max_{\mathbf{x},\mathbf{c}} u(\mathbf{x},\mathbf{c};\mathbf{g},\mathbf{z}) + \lambda\{M - \mathbf{px}\} + \mu\{S - \mathbf{tc}\}, \qquad (1)$$

where $u(\mathbf{x},\mathbf{c};\mathbf{g},\mathbf{z})$ is the household's direct utility function. The standard properties of indirect utility functions hold for $V(\cdot)$ in (1). In addition, it is decreasing in $\mathbf{t}$ and increasing in S. The money and grain budgets have been normalized by deflators $\delta^M(\mathbf{p},M)$ and $\delta^S(\mathbf{t},S)$, each homogeneous of degree 1 in its arguments, to maintain homogeneity of degree zero of the indirect utility function in the arguments of each constraint. That is, $V(\cdot)$ is homogeneous of degree zero in $(\mathbf{t},S)$ as well as in $(\mathbf{p},M)$.

The interpretation of the Lagrange multipliers is straightforward. From the Envelope Theorem applied to (1), the marginal utility of money is $V_M \equiv \partial V(\cdot)/\partial M = \lambda$, and the marginal utility of maize stock is $V_S \equiv \partial V(\cdot)/\partial S = \mu$. The ratio of these multipliers, the marginal utility of maize over the marginal utility of money (μ/λ), gives the shadow value of maize in units of dollars per kilo.

The first order conditions for market goods imply

$$u_i/\lambda = p_i, \qquad \text{for } i = 1,\dots,m,$$

where $u_i \equiv \partial u/\partial x_i$. This is the standard result that the household's optimal level of market good purchases is reached by equating the marginal value of consuming a market good (u_i/λ) with its money price p_i. The units are monetary. In addition, the problem generates first order conditions for the consumption of maize for non-market activities, which imply

$$u_j/\mu = t_j, \qquad \text{for } j = 1,\dots,n,$$

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[1] Note that the problem could also involve purchases of maize. However, this possibility will be suppressed for added simplicity, and because households would not typically purchase maize and then turn around and use it for barter, which is the consumptive use to be addressed here.

where $u_j \equiv \partial u/\partial c_j$. This result says that the household's optimal level of market good purchases is reached by equating the marginal value of using maize for consumption (u_j/μ) with the cost of this use. In this case, the units are physical (e.g., kilos of maize).

Defining the function $\upsilon(\cdot)$, where

$$\upsilon(\cdot) \equiv \mu/\lambda = V_S/V_M \tag{2}$$

to represent the shadow value of maize, it is possible to appeal to results derived by Larson and Shaikh (2001) in their work on estimating the shadow value of time in recreation demand models. Here, it will be assumed that the shadow value of maize is a function of household socio-economic conditions **z**, so that it can be written $\upsilon(\mathbf{z})$.

The problem in (1) can then be rearranged as a choice problem subject to full budget with money prices of market goods and grain prices monetized by the (endogenous) shadow value of grain $\upsilon(\mathbf{z})$:

$$V(\mathbf{p},\mathbf{t},\mathbf{g},\mathbf{z},M,S) \equiv \max_{\mathbf{x},\mathbf{c}} u(\mathbf{x},\mathbf{c};\mathbf{g},\mathbf{z}) + \lambda\{(M + \upsilon(\mathbf{z})\cdot S) - \mathbf{px} - \upsilon(\mathbf{z})\cdot \mathbf{tc}\}. \tag{3}$$

From (3), the household can be interpreted to have a full budget $M + \upsilon(\mathbf{z})\cdot S$ consisting of money income plus the monetary value of grain stocks. Problem (3) suggests that the household's indirect utility function has the form

$$V(\mathbf{p},\mathbf{t},\mathbf{g},\mathbf{z},M,S) \equiv \mathit{V}(\mathbf{p},\upsilon(\mathbf{z})\cdot\mathbf{t},\mathbf{g},\mathbf{z},M + \upsilon(\mathbf{z})\cdot S), \tag{4}$$

which is a function of money prices **p**, monetized maize prices $\upsilon(\mathbf{z})\cdot\mathbf{t}$, and full budget $M + \upsilon(\mathbf{z})\cdot S$. This is in fact the case, as Larson and Shaikh have demonstrated for a similar problem within the context of recreation demand. In addition, the form $\mathit{V}(\cdot)$ of the indirect utility function is consistent with the requirement that both constraints are strictly binding, and the requirement from (2) that $\upsilon(\mathbf{z}) = V_S/V_M$, even when the shadow value of maize is an endogenous function. This relationship is used to develop WTP measures based on both money and maize currencies.

3 Willingness to Pay Measures

The indirect utility function $V(\cdot)$ defined in equation (4) can be used as the basis for deriving two measures of the household's WTP—one in money and one in maize—in a manner which is consistent with the household's utility-maximizing behavior. The only additional requirement is that $\upsilon(\mathbf{z})$ be independent of the budgets M and S, which it is here. The two WTP measures are specified in terms of compensating surplus because they are defined as the change in their respective budget constraints that would leave the household indifferent to a parameter change. In this case, the parameter change is an improvement in (or implementation of) the government-sponsored deterrent program, from g^0 to g^1. The WTP for the deterrent program in money (wtp^M) is determined by the change in the money budget necessary to maintain the household at the same level of utility after the deterrent program as before. Since the household will suffer a lower level of damages to its crops and livestock after the implementation of the deterrent program, the WTP money should be positive and the change in the money budget should be negative. This WTP is defined by

$$V(\mathbf{p},\upsilon(\mathbf{z})\cdot\mathbf{t},\mathbf{g^1},\mathbf{z},(M-wtp^M) + \upsilon(\mathbf{z})\cdot S) \equiv V^0, \tag{5}$$

where V^0 is the initial level of utility, before the improvement in the deterrent program. Since indirect utility is monotonically increasing in the full budget argument $M + \upsilon(\mathbf{z})\cdot S$, it can be inverted with respect to this argument (see Larson et al., 2001a) to obtain

$$(M - wtp^M) + \upsilon(\mathbf{z})\cdot S = f(\mathbf{p},\upsilon(\mathbf{z})\cdot\mathbf{t},\mathbf{g^1},\mathbf{z},V^0), \tag{6}$$

which can be solved for money WTP explicitly, resulting in

$$wtp^M = (M + \upsilon(\mathbf{z})\cdot S) - f(\mathbf{p},\upsilon(\mathbf{z})\cdot\mathbf{t},\mathbf{g^1},\mathbf{z},V^0). \tag{7}$$

The WTP for the deterrent program in terms of maize stocks (wtp^S) is derived in a similar manner. It is defined by

$$V(\mathbf{p},\upsilon(\mathbf{z})\cdot\mathbf{t},\mathbf{g^1},\mathbf{z}, M + \upsilon(\mathbf{z})\cdot(S-wtp^S)) \equiv V^0. \tag{8}$$

Since maize stocks are part of the same full budget argument as money budget, (8) can also be inverted with respect to this argument to obtain

$$M + \upsilon(\mathbf{z})\cdot(S - wtp^S) = f(\mathbf{p},\upsilon(\mathbf{z})\cdot\mathbf{t},\mathbf{g^1},\mathbf{z},V^0), \quad (9)$$

which can be solved for maize WTP explicitly as

$$wtp^S = S + (1/\upsilon(\mathbf{z}))\cdot[(M - f(\mathbf{p},\upsilon(\mathbf{z})\cdot\mathbf{t},\mathbf{g^1},\mathbf{z},V^0)]. \quad (10)$$

It should be noted that both (7) and (10) provide measures of households' WTP for discrete—rather than marginal—changes in the level of government-sponsored deterrent programs **g**. This is more realistic because government programs are typically implemented to effect substantial changes, such as a 50 % reduction in animal attacks, which is the context in which the contingent valuation survey questions were posed.

To examine the relationship between the two WTP measures, observe that equations (6) and (9) have the same right-hand side, $f(\mathbf{p},\upsilon(\mathbf{z})\cdot\mathbf{t},\mathbf{g^1},\mathbf{z},V^0)$. As a result, equating the left-hand sides of each,

$$(M - wtp^M) + \upsilon(\mathbf{z})\cdot S = M + \upsilon(\mathbf{z})\cdot(S - wtp^S),$$

and simplifying shows that

$$wtp^M = \upsilon(\mathbf{z})\cdot wtp^S. \quad (11)$$

Thus, a household's WTP money and its WTP maize for the government-sponsored deterrent program (**g**) are related by $\upsilon(\mathbf{z})$, the shadow value of maize. This is intuitive, as $\upsilon(\mathbf{z})$ converts a household's WTP maize into monetary units according to the internal value that the household places on a physical unit of maize, and the household should be willing to pay a quantity of maize for the deterrent program that it values equally to the amount of money it is willing to pay.

Therefore, by beginning with a behavioral model of farm-household choice with two constraints—one on money budget and one on maize stock—and exploiting the structure of the problem, the following three estimates have been derived in a theoretically rigorous and internally consistent manner: 1) WTP money; 2) WTP maize; and 3) the monetary equivalent of maize to the household.

A useful feature of this method is the estimation of the shadow value of maize $\upsilon(\mathbf{z})$, which is the ratio of the two WTP measures, wtp^M/wtp^S. This allows for the testing of whether the shadow value of maize is significantly different from the market price, thereby providing a gauge for the existence of a well-functioning maize market, as well as an indication of the necessity of using a non-monetary numeraire good in the first place.

4 Econometric Model

Following an approach that parallels that of Cameron and Quiggin (1994), though in this case applied across currencies, it is assumed that each household has some unobservable true valuation for the government-sponsored deterrent program that it is offered during the course of the survey. The household's true valuation in money terms is denoted wtp^M. It is composed of a systematic component $h(X\gamma)$, where X is the matrix of explanatory variables that influence the value that the household places on the deterrent program and γ is a conformable parameter vector. Added to this is an unobservable random component ε^m that encompasses the determinants of the household's value for the program that cannot be measured by the researcher. It is assumed that WTP money has a lognormal distribution because the program being evaluated is a good and therefore households should only place a positive value on it. It can therefore be specified as

$$\ln(wtp^M) = \ln[h(X\gamma)] + 1/\sigma^m \cdot (\varepsilon^m), \qquad (12)$$

where σ^m is a scale factor used to transform the error term into a standard normal random variable, and ε^m is therefore marginally distributed N(0,1).

Because of the assumption of a lognormal distribution, the systematic component of WTP money becomes

$$wtp^M = e^{\ln[h(X\gamma)]} = h(X\gamma)$$

Similarly, the household's true valuation for the deterrent program being evaluated in maize terms is denoted wtp^S. It is composed of the same systematic component $h(X\gamma)$, and an unobservable random component ε^s. WTP maize is assumed to have a lognormal distribution, and it can therefore be specified as

$$\ln(wtp^S) = \ln[h(X\gamma)] + 1/\sigma^s \cdot (\varepsilon^s), \quad (13)$$

where σ^s is a scale factor and ε^s is marginally distributed N(0,1).

For the relationship between WTP money and WTP maize to hold as in (11), it must be the case that

$$wtp^S = wtp^M/\upsilon(\mathbf{z})$$

or

$$wtp^S = e^{\ln[h(X\gamma)] - \ln[\upsilon(\mathbf{z})]} = h(X\gamma) - \upsilon(\mathbf{z})$$

In order to empiricize this model, an explicit functional form must be chosen for $h(X\gamma)$. In this case, the Generalized Leontief functional form was selected to represent the systematic component of WTP, resulting in the following expression

$$h(X\gamma) = \sum_{i=1}^{4} \gamma_{ii}(g_i^0 - g_i^1) + 2 \sum_{i,j=1;i\neq j}^{4} \gamma_{ij}\left[(g_i^0)^{.5}(g_j^0)^{.5} - (g_i^1)^{.5}(g_j^1)^{.5}\right] \quad (14)$$

$$+ 2\sum_{i=1}^{4} \gamma_{ik}\left[(g_i^0)^{.5} - (g_i^1)^{.5}\right] \cdot x_k^{.5},$$

where g_i represents the level of effectiveness (or number of animals repelled) of deterrents against one of the four animal threat types i either before (g^0) or after (g^1) the implementation of the government-sponsored program, while g_j represents the level of effectiveness against one of the other animal types. The γ_{ii} are therefore the parameters to be estimated for the own-effects of a deterrent type on WTP, while the γ_{ij} are estimated parameters on the cross effects between animal types deterred. The x_k, meanwhile, represent all of the other explanatory variables that might help to explain a household's WTP for a deterrent program, such as the size of its fields or cattle herd. These are also interacted with each of the four types of deterrent effectiveness g_i, and the resulting parameters represented by γ_{ik}.

Only the change in the effectiveness of the government program in deterring various types of animal attacks also appears as a separate explanatory variable. All other repressors appear only as cross effects with the change in the deterrent program. In addition, the model does not contain an intercept. Both of these features are somewhat unique in WTP models, and are incorporated because the good being valued under fencing Option 1 is a private good. Therefore, the assumption is that WTP would be zero if there were no deterrent program. The functional form specified in (14) also conforms to the requirements of (4). Further, it is fairly flexible, and allows for the possibility of curvature in the relationships between explanatory variables and WTP.

The general form chosen to represent the shadow value of maize $\upsilon(\mathbf{z})$ was a linear function represented by

$$\upsilon(\mathbf{z}) = Y\boldsymbol{\beta}, \qquad (15)$$

where Y is the matrix of household characteristics thought to influence the household's shadow value for maize and $\boldsymbol{\beta}$ is a conformable vector of parameters.

During the survey, the bid amounts offered in money were unrelated to the bid amounts offered in maize. However, one would expect the household's true WTP in the two numeraires to be related, and estimating a model based on the joint distribution of the two amounts allows for more efficient use of all of the available information. Thus, a bivariate probit model was estimated in which ε^m, which represents observations on money responses, and ε^s, which represents observations on maize responses, are jointly distributed N(0,0,1,1,ρ), where ρ is the covariance between the two error terms.

In order to develop the bivariate probit model, binary indicator variables were created to describe each household's response pattern to the WTP questions. For example, the variable $INNYM_i = 1$ if household i responded "no" to the first two offered money amounts and "yes" to the final money amount, and $INNYM_i = 0$ otherwise. Similarly, $IYNS_i = 1$ if household i responded "yes" to the first offered maize amount, and "no" to the second, and $IYNS_i = 0$ otherwise. Any household's response pattern to both the money and maize sets of questions combined could then be described by multiplying one money indicator variable with one maize indicator variable.

The money bids offered to each household can also be represented using a simple notation. As explained earlier, each household was first offered a money bid B1M. If the response was "yes", the household was then offered a second money bid B1bM, such that B1bM > B1M. If, on the other hand, the response was "no" to the first bid, the household was then offered the money bid B2M, such that B2M < B1M. If the household then responded "yes" to B2M, no more bids were offered, so that in these first two cases each household was offered two bids. However, if the household again answered "no" to B2M, a final money bid of B2bM = N$1 was offered to ensure that any household placing some positive value on the offered good would be able to express that value. Only in this case, if the household responded "no" to the first two offered bids, were they offered a total of three bids. To summarize the relationships between the money bids that could potentially be offered to a household: B1bM > B1M > B2M >B2bM. The potential maize bids can be represented using similar notation, such that B1bS > B1S > B2S >B2bS.

Given this notation for the bids, the pattern of receiving "no" responses to all offered money and maize bids can be represented in a similar fashion to that used for the indicator variables, but without the "I", as NNNM and NNNS respectively, and the probability of observing this pattern derived as

$$\begin{aligned}
\text{Prob}\{\text{NNNM, NNNS}\} &= \text{Prob}\{wtp^m < \text{B2bM}, wtp^s < \text{B2bS}\} \\
&= \text{Prob}\{\ln(wtp^m) < \ln(\text{B2bM}), \ln(wtp^s) < \ln(\text{B2bS})\} \\
&= \text{Prob}\{\varepsilon^m < [\ln(\text{B2bM}) - \ln[h(X\gamma)]]/\sigma^m, \varepsilon^s < [\ln(\text{B2bS}) - \ln[h(X\gamma)] + \ln[\upsilon(\mathbf{z})]]/\sigma^s\} \\
&= \Phi\{[\ln(\text{B2bM}) - \ln[h(X\gamma)]]/\sigma^m, [\ln(\text{B2bS}) - \ln[h(X\gamma)] + \ln[\upsilon(\mathbf{z})]]/\sigma^s, \rho\},
\end{aligned}$$

where $\Phi\{\cdot,\cdot,\rho\}$ is the bivariate normal cdf.

The probabilities of observing the other response patterns can be derived in similar fashion. These probability statements encompass all of the possible response patterns from the Caprivi households that participated in the survey. Each household can then be grouped together with those that gave the same responses (though the offered bids and levels of deterrent programs will differ) into subsets denoted by multiplying together their associated indicator variables (e.g., INNNM·INNNS for households that answered "no" to all money and all maize questions). The likelihood of observing the pattern of responses for all of the households in the sample is then given by

$$
\begin{aligned}
L = \Sigma\, [&\text{INNNM}\cdot\text{INNNS}\cdot\text{Prob}\{\text{NNNM}\cdot\text{NNNS}\} \qquad (16)\\
&+ \text{INNNM}\cdot\text{INNYS}\cdot\text{Prob}\{\text{NNNM}\cdot\text{NNYS}\}\\
&+ \text{INNNM}\cdot\text{INYS}\cdot\text{Prob}\{\text{NNNM}\cdot\text{NYS}\}+ \text{INNNM}\cdot\text{IYNS}\cdot\text{Prob}\{\text{NNNM}\cdot\text{YNS}\}\\
&+ \text{INNNM}\cdot\text{IYNS}\cdot\text{Prob}\{\text{NNNM}\cdot\text{YYS}\}\\
&+ \text{INNYM}\cdot\text{INNNS}\cdot\text{Prob}\{\text{NNYM}\cdot\text{NNNS}\} + \text{INNYM}\cdot\text{INNYS}\cdot\text{Prob}\{\text{NNYM}\cdot\text{NNYS}\}\\
&+ \text{INNYM}\cdot\text{INYS}\cdot\text{Prob}\{\text{NNYM}\cdot\text{NYS}\}+ \text{INNYM}\cdot\text{IYNS}\cdot\text{Prob}\{\text{NNYM}\cdot\text{YNS}\}\\
&+ \text{INNYM}\cdot\text{IYNS}\cdot\text{Prob}\{\text{NNYM}\cdot\text{YYS}\}\\
&+ \text{INNYM}\cdot\text{INNNS}\cdot\text{Prob}\{\text{NNYM}\cdot\text{NNNS}\} + \text{INNYM}\cdot\text{INNYS}\cdot\text{Prob}\{\text{NNYM}\cdot\text{NNYS}\}\\
&+ \text{INNYM}\cdot\text{INYS}\cdot\text{Prob}\{\text{NNYM}\cdot\text{NYS}\}+ \text{INNYM}\cdot\text{IYNS}\cdot\text{Prob}\{\text{NNYM}\cdot\text{YNS}\}\\
&+ \text{INNYM}\cdot\text{IYNS}\cdot\text{Prob}\{\text{NNYM}\cdot\text{YYS}\}\\
&+ \text{INYM}\cdot\text{INNNS}\cdot\text{Prob}\{\text{NYM}\cdot\text{NNNS}\} + \text{INYM}\cdot\text{INNYS}\cdot\text{Prob}\{\text{NYM}\cdot\text{NNYS}\}\\
&+ \text{INYM}\cdot\text{INYS}\cdot\text{Prob}\{\text{NYM}\cdot\text{NYS}\}+ \text{INYM}\cdot\text{IYNS}\cdot\text{Prob}\{\text{NYM}\cdot\text{YNS}\}\\
&+ \text{INYM}\cdot\text{IYNS}\cdot\text{Prob}\{\text{NYM}\cdot\text{YYS}\}\\
&+ \text{IYNM}\cdot\text{INNNS}\cdot\text{Prob}\{\text{YNM}\cdot\text{NNNS}\} + \text{IYNM}\cdot\text{INNYS}\cdot\text{Prob}\{\text{YNM}\cdot\text{NNYS}\}\\
&+ \text{IYNM}\cdot\text{INYS}\cdot\text{Prob}\{\text{YNM}\cdot\text{NYS}\}+ \text{IYNM}\cdot\text{IYNS}\cdot\text{Prob}\{\text{YNM}\cdot\text{YNS}\}\\
&+ \text{IYNM}\cdot\text{IYNS}\cdot\text{Prob}\{\text{YNM}\cdot\text{YYS}\}\\
&+ \text{IYYM}\cdot\text{INNNS}\cdot\text{Prob}\{\text{YYM}\cdot\text{NNNS}\} + \text{IYYM}\cdot\text{INNYS}\cdot\text{Prob}\{\text{YYM}\cdot\text{NNYS}\}\\
&+ \text{IYYM}\cdot\text{INYS}\cdot\text{Prob}\{\text{YYM}\cdot\text{NYS}\}+ \text{IYYM}\cdot\text{IYNS}\cdot\text{Prob}\{\text{YYM}\cdot\text{YNS}\}\\
&+ \text{IYYM}\cdot\text{IYNS}\cdot\text{Prob}\{\text{YYM}\cdot\text{YYS}\}].
\end{aligned}
$$

6.5 Estimation

To jointly estimate the parameters in equations (12), (13), and (15), representing WTP money and maize as well as the shadow value of maize, the log of the likelihood function in (16) was taken. Maximum likelihood estimation was then carried out using the Maximum Likelihood Module Version 4.0.26 of Gauss Version 3.2.32. There was an effort to remove those households from the sample that were identified as “protesters”. In addition, being a private good, a household should only be in the “market” for the fence if it had experienced some animal attacks. Therefore, households that did not report any animal attacks of any kind were removed from the sample.

In Table 1 a summary is given of the basic variables that provide the foundation for creating the regressors of the final model. The Deterrent Effectiveness variables in Table 1 represent the different deterrent qualities of the electric fence that was offered to households. The effectiveness was specified for each of the four animal types as a 25, 50, 75, or 100 percent reduction in the number of animal attacks over the previous year. The various models estimated also contained variables to represent the number of animal attacks experienced per household during the past year. These variables measured the number of individuals of each animal type that were reported to have attacked, ranging from an average of only 0.88 predators per household to 67.72 livestock. The interaction between the animal attacks variables and deterrent effectiveness variables results in variables representing net reductions in the numbers of animals attacking.

Descriptive statistics are provided for additional variables that played a pivotal role in the estimation. One is a dummy variable for the village of Muyako. Muyako is structurally very different from all of the other villages. Its differences include the fact that the average household owns more cattle, has larger fields, produces more maize, has a higher cash income, and is generally better off than households in the other survey villages. As a result, it was important to allow the model to reflect these differences. Table 6.1 also describes variables that were included to measure the impact on WTP of the surface area of a household's cropland, the number of head of cattle it owns, and the number of cattle in the entire village.

Table 1: Select Descriptive Statistics for the Sample (N = 148)[2]

Variable	Units	Mean	Std. Dev.	Min.	Max.
Elephant Deterrent Effectiveness	Percent Reduction	0.62	0.29	0.25	1.0
Herbivore Deterrent Effectiveness	Percent Reduction	0.61	0.28	0.25	1.0
Predator Deterrent Effectiveness	Percent Reduction	0.65	0.28	0.25	1.0
Livestock Deterrent Effectiveness	Percent Reduction	0.64	0.28	0.25	1.0
Elephant Attacks	Animals/HH/Year	13.84	29.80	0.0	170.0
Herbivore Attacks	Animals/HH/Year	20.66	72.56	0.0	540.0
Predator Attacks	Animals/HH/Year	0.88	1.80	0.0	16.0
Livestock Attacks	Animals/HH/Year	67.72	95.63	0.0	800.0
Muyako Dummy	(0 = no, 1 = yes)	0.19	0.39	0.0	1.0
Field Size	Hectares/HH	10.16	10.07	1.0	100.0
Household Cattle	Head/HH	18.59	27.87	0.0	210.0
Village Cattle	Head/Village	493.68	317.62	188.0	1041.0

5.1 Estimation Results

Table 2 provides the results of a bivariate probit model that jointly estimates the parameters for WTP cash and maize, including the shadow value of maize. Numerous forms of the WTP and shadow value functions were estimated in an effort to take full advantage of the rich survey data collected on farm households in Caprivi and to explain the sources of variation in WTP as much as possible. For example, cross effects between the numbers of different animal types deterred

[2] Because the survey was "two-and-a-half bounded", the sample size is effectively larger.

as indicated in (14) were created and estimated. Measures of the importance of different agricultural activities to the household-such as the value of their livestock, the total numbers of their livestock, the total value of their annual harvest, and the size of their fields-were examined. Agricultural practices such as the start date of cultivation were included.

Various components of full money and maize budgets were also estimated, including money income and the value of maize harvests. However, these did not prove to be very good predictors of WTP, possibly because incomes and harvests are not well measured or recorded in this rural and largely non-literate society. Further, households do not always feel at ease in reporting their wealth, creating an additional measurement bias.

A number of variables were also created from Geographic Information System (GIS) data on the Caprivi Region (see Mendelsohn and Roberts, 1997). These included measures of the local elephant population, farming potential, conservation potential, distance from the nearest conservation area and percentage of cultivated area. These variables were interacted with the animals deterred variables as indicated by (14). However, they would become insignificant as other, more powerful determinants of WTP were added. This is probably because the GIS variables were at the village level and rather imprecise to begin with, unlike the data collected during the survey which was at the household level.

Different forms of the shadow value of maize function were also examined. In addition to a constant, dummy variables for other characteristics that were hypothesized to affect the value households placed on maize were also included in the shadow value function. Among these were variables indicating whether or not the household sold any maize during the past year, whether the household was determined to be in a grain production deficit status in relation to its needs during the previous year, and whether the household was located in Muyako. Several combinations of these status indicators were also employed (e.g., located in Muyako and a grain seller). The binary variable created to identify households located in Muyako was also interacted with other variables such as the number of each animal type deterred by the program and used in the WTP expressions.

In the end it was found that the model presented in Table 2 was the most effective in explaining WTP money and maize jointly, as well as estimating the shadow value of maize. The model is also highly significant, and makes a great improvement over a naive model with only the dispersion and correlation parameters, as measured by the total log-likelihood, resulting in a likelihood ratio test statistic of 174.77 and a pseudo-R^2 of 0.305. The number of elephants deterred is significant at the 3% level, with a Student's t of 1.883. All of the other explanatory variables—the number of predators deterred, the cross effects between the number of predators and livestock deterred, the cross effects between the number of herbivores deterred and the household's field size, the cross effects between the number of predators deterred and the size of the household's cattle herd, the cross effects between the number of livestock deterred and the size of the village cattle herd, and the interaction between the Muyako dummy variable and the number of livestock deterred—are all highly significant at the 1% level. Their Student's t-statistics are all 2.365 or greater (in absolute values), and are reported in Table 2. The shadow value of maize and the dispersion and correlation parameters are also highly significant. The shadow value has a Student's t of 4.849, the standard errors of money and maize have Student's t-statistics of 10.621 and 9.842, respectively, and the correlation has a Student's t of 9.580 (all resulting in P-values of zero).

The signs of all the estimated coefficients are positive except for that of predator/livestock deterrent cross effects. However, it is difficult to interpret the meaning of the negative sign at this point because both predators and livestock deterred appear several times in the final WTP expression, and they enter in a non-linear fashion. In addition, the covariates used in the model and presented in Table 1 have been scaled in order to make estimation possible, which affects the scale of the estimated coefficients. Due to the Generalized Leontief functional form, this negative coefficient could be viewed as adding curvature to the effects of predators and livestock deterred on WTP. It may imply that households will focus on the largest source of attacks. That is, if a household suffers many predator attacks, it will be less concerned about livestock attacks, and vice versa. The net effects of all the variables are determined in Section 5.2 below.

Table 2: Joint Bivariate Probit Estimates of WTP and the Shadow Value of Maize

Variable	Coefficient	Asymptotic Student's t
Willingness to Pay:		
Elephants Deterred	2.6228	1.883
Herbivores Deterred	.	.
Predators Deterred	3.4321	3.602
Livestock Deterred	.	.
Predator/Livestock Deter. Cross Effects	-5.6814	-4.942
Herbivore Deter./Field Size Cross Effects	4.9754	4.202
Predator Deter./HH Cattle Cross Effects	7.9763	2.875
Livestock Deter./Vill. Cattle Cross Effects	2.6007	3.627
Muyako/Livestock Deter. Interaction	3.1588	2.365
Shadow Value of Maize:		
Constant	0.3070	4.849
Dispersion and Correlation:		
σ^m	1.5796	10.621
σ^s	1.3359	9.842
ρ	0.7426	9.580
Pseudo-R^2	0.305	
Total log-L	-198.68748	
Total log-L (γ=β=0)	-286.07098	
χ^2 (d.f.)	174.77 (8)	
N	148	

Among the animal types, only the numbers of elephants and predators deterred were significant on their own. Both have a positive influence on WTP. The herbivores deterred/field size cross effects variable indicates that households with larger surface areas under cultivation would be willing to pay more to deter herbivores from attacking. The predators deterred/household cattle cross effects variable suggests that a household with a larger cattle herd would be willing to pay more to deter predators from attacking. The livestock deterred/village cattle cross effects variable indicates that in villages with larger cattle populations, households are willing to pay more for a deterrent to livestock attacks. All of these results seem quite reasonable and intuitive. In addition, the Muyako/livestock deterred interaction variable implies that households in Muyako are willing to pay more to deter livestock attacks. This may be because there is a much greater number of cattle in Muyako than in other villages, and also because on average Muyako households have larger fields and generate more revenue from their field crops.

Regarding the dispersion parameters for money and maize WTP, the estimate of 1.3359 for σ^s is significantly lower than the estimate of 1.5796 for σ^m at the 5% confidence level, providing evidence that the respondents were better able to express their valuations in maize than in money.

The estimated correlation parameter ρ is 0.7426, which represents a high degree of correlation between the error terms. Hypothesis testing reveals that ρ is highly significantly different not only from zero, but also from one. This supports the argument for using a bivariate model to estimate WTP across the two payment vehicles, instead of the univariate "double-bounded" models, which implicitly assume that $\rho = 1$. The correlations is lower than the ρ of 0.95 that Cameron and Quiggin found in their 1994 study, making it more likely, according to Alberini, that parameter estimates would be biased if a bivariate model had not been used.

In the end, the shadow value of maize $\upsilon(\cdot)$ was estimated as a constant. The other variables that were tried in this expression became insignificant as the variation in WTP became better explained. The estimated shadow value of N$0.3070/kg of maize is significantly lower (99% confidence level) than the 1998 mill-door price for maize in the regional capital, which was N$0.86/kg (Jurgen Hoffmann, Namibian Agronomic Board, pers. comm.). This makes intuitive sense because there are transportation and other transactions costs involved in getting the maize to the mill. However, the magnitude of the difference implies that there are important imperfections in the Caprivi maize market. It illustrates why it would be inappropriate to simply multiply households' WTP in maize by the market price in order to determine their WTP in money. The difference also demonstrates that these households are not fully integrated into the market economy, strengthening the case for using a non-monetary measure of WTP.

5.2 Willingness to Pay Estimates

Table 3 provides estimates of WTP money and maize for the fence for the entire sample, with the quality characteristics as they were presented to respondents in the survey questionnaire. Throughout this section, three measures of WTP are presented in the tables for each scenario. Both the median and the mean are calculated as measures of central tendency. The tables also present figures for the mean WTP as a percentage of the mean total annual household income of N$7,080 (Sutton, 2001). The median WTP figures are N$31.49 in cash or 102.59 kg in maize (at the time of the survey, US$1 = N$5.80). The estimated mean WTP figures are N$733.76 and 1,675.48 kg of maize. Table 3 also reports that the annual mean WTP for the fence as described to respondents was predicted to be 10.4% of mean annual income.

Table 3: Willingness to Pay Money and Maize for Deterrent Programs as Offered to Households (whole sample), and Mean Income Share

	Measure of Central Tendency		
Numeraire	**Median**	**Mean**	**Income Share**
Money (N$)	31.49	733.76	10.4%
Maize (kg)	102.59	1,675.48	10.4%

Table 4 presents the "marginal effects" of an individual of each animal type deterred on WTP both cash and maize. The marginal effects are calculated by taking the derivative of the WTP expression with respect to one animal type deterred (i.e., $\partial wtp/\partial g_i$) for each household, and then applying the appropriate measure of central tendency-the median or the mean. Note that each calculation is based only on those households that incurred at least one attack from the relevant animal type. Table 4 indicates that the mean household in the sample would be willing to pay N$150.60 to deter one predator from attacking one time, while they would only be willing to pay N$0.91 to deter an elephant. Livestock and other wild herbivores fall in-between, at N$77.59 and N$17.59 respectively. Since these measures reflect the cost of only one animal attacking one time, the shares of mean income are generally low. However, the figure of 2.13% for predators is prominent.

Thus at the margin, given the level of attacks experienced from each animal type during the previous year, the median and mean households would be most concerned about deterring the attack of an additional predator. This makes sense, since there are relatively few predators and they tend to attack as individuals or in small groups, yet they are capable of destroying a Caprivi farm household's most valuable asset—its cattle. Meanwhile, it appears that the average household places substantially less value on deterring the attack of an additional elephant. Even a cow would seem to be of greater concern to these households than an elephant.

Table 4: Marginal Effects on Household WTP Money and Maize of One Animal Deterred, by Type and Mean Income Share

	Measure of Central Tendency		
Animal Type	**Median**	**Mean**	**Income Share**
Willingness to Pay Money (N$):			
Elephant	0.26	0.91	0.01%
Other Herbivore	3.61	17.59	0.24%
Predator	31.38	150.60	2.13%
Livestock	0.79	77.59	1.10%
Willingness to Pay Maize (kg):			
Elephant	0.85	2.09	0.01%
Other Herbivore	11.76	40.17	0.24%
Predator	102.21	343.89	2.13%
Livestock	2.57	177.18	1.10%

While Table 4 provides information on households' WTP for a marginal reduction in attacks by each type of animal, the more relevant information for policy-making is the effect on WTP of discrete changes in animal attacks. That is because potential interventions for reducing animal attacks—such as the construction of fences, the reduction of animal populations, or the decrease of cultivated area—would likely entail large shifts in the incidence of attacks, and not simply tinkering at the margins. Thus, Table 5 provides measures of the discrete effects on annual household WTP money and maize of a 100% reduction in each type of animal attack, while holding the levels of the other three types of animal attacks constant. Again, each calculation is based only on those households that incurred at least one attack from the relevant animal type.

It is interesting to note the differences between Tables 4 and 5. Naturally, the figures in Table 5 are substantially higher than those in Table 4 because they measure larger changes, which are of greater benefit to households. However, the WTP money by the mean household for a 100% reduction in livestock attacks, at N$1,289.44 per year, is now much higher than for any of the other animal types, replacing predators which were highest in Table 4. Other wild herbivores now have the second highest mean at N$194.04, while predators are close behind at N$185.86, although predators have a higher median WTP than herbivores. The mean WTP for a 100% reduction in elephant attacks is again lowest, at N$32.81. The cost from animal attack damage reflected in these WTP amounts now represents a higher percentage of total income than that for the marginal effects, with livestock attacks alone accounting for a hefty 18.2%.

Table 5: Discrete Effects on Annual Household WTP Money and Maize of a 100% Reduction in One Type of Animal Attack and Mean Income Share

	Measure of Central Tendency		
Animal Type	**Median**	**Mean**	**Income Share**
Willingness to Pay Money (N$):			
Elephants	5.25	32.81	0.5%
Other Herbivores	37.23	194.04	2.7%
Predators	37.80	185.86	2.6%
Livestock	56.62	1,289.44	18.2%
Willingness to Pay Maize (kg):			
Elephants	17.09	74.92	0.5%
Other Herbivores	121.28	443.07	2.7%
Predators	123.11	424.39	2.6%
Livestock	184.44	2,944.36	18.2%

6 Conclusions

This is the first study to use contingent valuation methods to measure the costs to local developing-country communities of living with wildlife. Further, it is the first use of a methodology consistent with utility theory to simultaneously estimate a household's WTP for a non-market good in both cash and a non-monetary numeraire good, and estimate the household's shadow value for the non-monetary good. This allowed for the first application of a significance test on differences between market and shadow prices for the numeraire good. It also provided an objective indicator of the degree of market imperfection for the non-monetary numeraire good, and the importance of valuing non-monetary WTP using a household's shadow value, rather than market prices. Evidence was also found of the increased comprehension of respondents with the use of a non-monetary currency that is very familiar to them—maize. The WTP measures developed here could just as easily have been used to value any other non-market good in this context. They are direct, Hicksian compensating surplus measures of farmers' welfare. They encompass all the types of costs to farmers of living with wildlife except the psychological costs. The measures include the opportunity costs to farmers of changes in production practices caused by the threat of animal attacks, which no one has measured using the "physical" techniques of ecologists.

The estimation results demonstrate that rural Caprivi farmers do incur significant costs from living with elephants and other types of wildlife. However, the measures of the marginal and discrete effects on WTP of changes in the levels of animal attacks reveal that at the margin households are most concerned about preventing attacks by predators on their livestock. In contrast, they are most concerned about deterring livestock as a group. This is in stark contrast to the information gathered from focus groups and key informants prior to survey implementation, where elephants were often reported to be the biggest problem. Perhaps this is because livestock also generate important benefits for Caprivi households, and so they do not naturally think of them as pests. It is also possible that the cost of living with elephants derives as much from their attacks on people and the fear that they create as it does from the damage to crops and property that they cause. These psychological costs were not measured here.

Several policy implications can be drawn from this analysis. Caprivi farm households incur significant costs from wildlife attacks, while research has shown that they receive few benefits (Sutton, 2001). Therefore, for reasons of equity, income distribution and conservation incentives, the tourism industry and government should compensate eastern Caprivi farmers. However, if the goal is to increase the welfare of rural Caprivians, efforts should focus more on reducing livestock attacks than on reducing wildlife attacks. This could include developing well-defined property rights determining where livestock can graze and who is responsible for the damages (Jarvis, 1984). It could also include promoting the use of barbed-wire fencing of crops (see Sutton, 2001). Given the WTP estimates generated here, it is unlikely that most Caprivi households would be able to afford an electric fence, which would cost about N$8.60/m (Pricewaterhouse, 1998), unless it were heavily subsidized. To reduce the costs of wildlife attacks at the margin, priority should be given to developing methods to deter predator attacks. Future analysis will begin with the estimation of the psychological costs of wildlife attacks.

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