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* Manuscript

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

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Abstract

The costs of living with wildlife are assessed using Namibian subsistence farmers' willingness to pay (WTP) for deterrents to attacks on crops and livestock as a measure of damage costs. A utility-theoretic approach jointly estimates household WTP for deterrent programs in two "currencies," maize and cash. This has a double payoff. Use of a non-cash staple increases respondent comprehension and provides more information about preferences, improving the accuracy of results. The household shadow value of maize is also identified. Significant costs from living with elephants and other types of wildlife are demonstrated. Compensation for farmers may be warranted on equity and efficiency grounds. Uncontrolled domestic cattle generate even higher costs to farmers than wildlife, highlighting the need to clarify property rights among these farmers.

JEL classification: O13; Q2; Q12; C35; C81; D13
Keywords: Wildlife-human conflict; Elephants; Non-market valuation; Damage cost; Shadow value

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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 (e.g., Barbier *et al.*, 1990; Barnes 1998, 2001). In particular, African wildlife generates substantial revenues from tourism. However, terrestrial wildlife species also generate a social opportunity cost through their use of resources such as land. Additional direct costs are associated with their requirements for management resources like game wardens. Finally, wildlife generates negative externalities for people living near them (Bell, 1984; Wambuguh, 1998; Hoare, 1999), via the damage associated with destruction of crops, property, and human life (Swanson, 1994; Sutton, 1998).

Realistic economic models of wildlife management require accurate measurement of both the magnitude and distribution of costs, particularly those incurred by farmers who share their environment with the wildlife. However, a challenge to the incorporation of these costs into management models is the difficulty of their measurement. Most work to date has involved qualitative descriptions of wildlife-human conflict (e.g., Kiiru, 1995; Ngure, 1995). In some cases, farmers have been interviewed systematically regarding the damages incurred (e.g., Wambuguh, 1998; Bandara & Tisdell, 2002). However, farmers may not keep accurate damage records, recall may be imperfect, and farmers have an incentive to overestimate damage costs to increase the aid received (Kangwana, 1996; Hoare, 1999; Bandara & Tisdell, 2002).

Some ecologists have attempted direct, physical measurement of damages by placing someone proximate to the place and time of the attack to estimate the damage to crops or structures (e.g., O'Connell, 1995a&b; Hoare, 1999). A financial value is then placed on the damaged goods. With this method, the researcher does not have to rely on the farmer's word. However, this approach is expensive and significant subjectivity is involved. Accurately determining the value of crops destroyed requires divining what the harvest output 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 have been received. As this information is difficult to come by, damages are frequently assessed by assigning retail market prices to average yields (e.g., O'Connell, 1995a&b), a very crude approach.

The direct measurement of damages also overlooks the indirect costs of living with wildlife (Sutton, 2001), which may be higher than the direct costs. The indirect costs include the opportunity cost of growing less valuable crops because they are less attractive to wildlife and planting smaller areas that are easier to guard, and the psychological cost of threats to humans from fearsome species.

Finally, the direct measurement of damages, as typically applied (e.g., Hoare, 1999), suffers from sample selection bias. The data include only those households that actually report wildlife damage. Farmers who employ illegal deterrent methods, such as shooting at wildlife, are less likely to report damage incidents. Small-scale farmers may also be generally less likely to contact authorities; Wambuguh (1998) found that only 30% of such victims report their incidents. Because random sampling methods are not typically employed for the direct physical measurement 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 assessing farmers' willingness to pay (WTP) for technologies that prevent wildlife damage. This WTP to avoid damage from an externality is, by definition, the damage cost from the externality (Freeman, 1993). By focusing on the WTP to avoid damage, we can utilize the contingent valuation method (CVM) to obtain a damage measure that does not suffer from the problems that plague the direct physical measurement approach. CVM has been used in numerous studies to elicit the viewing value of wildlife from western tourists (e.g., Brown and Henry, 1993; Stoltz, 1997; Krug, 1998). We believe this is the first application of CVM to measure externality costs to local people who live with wildlife in developing countries. The information elicited directly measures the shadow costs of the wildlife problem households seek to avoid. 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. By focusing on farmers' payments for a private good to reduce their externality costs, the incentive problems that plague the physical measurement approach are reduced.

We also ask WTP questions in two "currencies," money and bags of maize, that are analyzed jointly in a utility-theoretic framework. The use of two currencies has important advantages over standard applications of CVM, particularly in developing countries. Since many rural households are cash-constrained, the concept of exchanging a household staple such as maize to acquire goods should offer them a more realistic choice. Asking WTP in multiple currencies also provides more information about household preferences. Use of the dual CVM responses to estimate WTP also provides a third payoff, which is an estimate of the monetary value of the non-monetary currency—in our case, the household shadow value of maize. Because the shadow values are random variables whose standard errors are estimated, this allows us to test whether shadow values differ significantly from market prices. Household shadow values of staple goods may differ substantially from their market prices due to imperfect or missing markets[1] and our approach provides a new way of assessing household shadow values.

2. The Study Setting

The damage assessment approach is conducted for farm households in the eastern Caprivi Region of Namibia (Sutton, 2001). The Caprivi Region (see map) is blessed with an abundance and diversity of wildlife and is one of the few places in Namibia where significant numbers of large mammals roam freely outside the confines of parks or game ranches (Rodwell *et al*., 1995). It is also home to a rapidly growing human population that exploits natural resources for subsistence and economic development (Mendelsohn and Roberts, 1997). The combination of these factors has resulted in considerable conflict between Caprivi farmers and the local wildlife (O'Connell, 1995a&b).

The household survey conducted for this assessment used a random sample stratified by agro-ecological zones and villages (Directorate of Planning, 1999). Two villages were randomly selected in each of three zones and 30 households were randomly selected in each village (except for one village where all 20 households were interviewed). The six villages represent the diversity of agricultural practices, ethnicities, market conditions and

[1] This is one of the significant criticisms of the direct physical measurement approach to assessing wildlife damage, as noted above.

environmental characteristics found in Caprivi, and also demonstrate a continuum of severity of conflict with wildlife. A total of 165 households completed the survey.

The survey asked households their WTP for a deterrent to wildlife attacks—specifically, an electric fence. This is a familiar technology, since electric fences have been used on an experimental basis in the Caprivi Region to protect villages and crops from wildlife (O'Connell, 1995a). Visual aids were also used to illustrate the concept. Though the study began with a focus on elephants, it was soon realized that an electric fence would also be effective against other wildlife types and domestic livestock. By including those species as well as the elephant in the CVM survey, the study controls for their effects on WTP and also generates estimates of their individual shadow costs to farmers. Animal species were divided into four groups: elephants, other wild herbivores, wild predators and livestock. Elephants pose unique management problems and were identified in other studies (e.g., von Rohr, 1997) and our own prior interviews with farmers and wildlife management specialists as the species causing the most problems.

As described in the survey, the hypothetical electric fencing surrounds both the household's fields and its livestock corral. Thus, it protects crops from being eaten or trampled and protects livestock from being killed in the corral. It was made explicit to respondents their household alone would own the fence and that the household would be required to pay for it every year, in either money or maize. The fence is therefore a private good, characterized by individual property rights and the excludability of other users. The level of investment in the fence enters into the choice problem of the concerned household alone (though the government may subsidize the cost).[2]

The characteristics of the fence deterrent, e.g., cost and the proportion of wildlife attacks deterred for each wildlife type, were varied randomly across households. It is realistic to assume that different types of fences protect differentially against different types of wildlife and that success is related to cost. By varying these characteristics randomly across the sample, we can identify the WTP to reduce attacks by each wildlife type.

After the fence deterrent had been described in detail, including the proportion of attacks prevented and its cost, the respondent (typically the head of household) was asked whether he or she would be willing to pay a specified amount (the "bid") every year for a permanent reduction in attacks. Two sets of questions were asked: one for WTP money, with no payment of maize, and a second set for WTP in bags of maize, with no money payment. For each, a "two-and-a-half" bounded format was used (e.g., Cooper *et al.*, 2002). This is an extension of the standard double-bounded, referendum-style format to include an additional question for those who answer "no" to both the initial and follow-up WTP questions. The advantages of the referendum format are well known and include ease of use and minimal information demands on respondents (Mitchell and Carson,

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[2] There is therefore no possibility of a "warm glow" effect whereby a household can express a WTP for another household's fence.

1989).[3] The use of a follow-up question can improve estimation efficiency (Hanemann *et al*., 1991). It is generally accepted 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 (Mitchell and Carson, 1989; Freeman, 1993).

3. The Village Household Model

The WTP equations for both cash and maize payment 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 approach allows for the definition of both WTP measures in a manner that is internally consistent and grounded in utility theory. The model is simplified to focus on the two constraints related to the two WTP values elicited by the questionnaire: money and maize. The questions were framed in the temporal context of the households having just completed their prior season's harvest. Thus, their production and total maize availability is predetermined.

The farm-household's problem 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 activities **c**, including household consumption, barter, and livestock feed. Use 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

[3] A survey question posed to both respondents and enumerators rated the comprehension of respondents. The results were that over 85% of respondents understood the CVM section "very well", and even better than the non-CVM parts of the survey. This was apparently due in large part to the use of visual aids (see Sutton, 2001).

of as a technical conversion coefficient. It would be 1.0 if no wastage occurs and higher if some does occur. The household maximizes its utility given socio-economic characteristics of the household **z** and the vector of fixed levels of government-sponsored programs to deter wildlife attacks **g**. The household faces strictly binding constraints on its money budget M = **px** and on its stock of maize S = **tc**.[4] The household's primal problem then leads to the indirect utility function V(**p**,**t**,**g**,**z**,M,S), defined as

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

where u(**x**,**c**;**g**,**z**) is the household's direct utility function. The standard properties of indirect utility functions hold for V(·) in (1). In addition, it is decreasing in **t** and increasing in S. The money and grain budgets have been normalized by deflators δ^M(**p**,M) and δ^S(**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 (i.e., (**t**,S) and (**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 (μ/λ) gives the shadow value of maize in units of dollars per kilo.

The first order conditions for market goods imply

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[4] 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 addressed here.

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

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. The problem also generates first order conditions for the consumption of maize for non-market activities, which imply

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

where $u_j \equiv \partial u/\partial c_j$. This result says that the household's optimal level of non-market good consumption 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

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

represents the shadow value of maize, the results of Larson and Shaikh (2001) and Larson (2002) can be used to identify arguments of $\upsilon(\cdot)$. They show that the normalized shadow value is homogeneous of degree zero in ($\mathbf{p}$,M), ($\mathbf{t}$,S), and ($\mathbf{p}$,$\mathbf{t}$,S,M), a specification that is satisfied if $\upsilon(\cdot)$ is a function of household characteristics $\mathbf{z}$ and independent of the budget arguments. Specifying the maize shadow value this way, as $\upsilon(\mathbf{z})$, one can rewrite the problem in (1) as

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

This equivalent representation of the two-constraint household choice problem can be interpreted as a single-constraint problem where the resource constraint is "full" budget $M + \upsilon(\mathbf{z})\cdot S$, against which money expenditures $\mathbf{px}$ and grain expenditures monetized by the shadow value of maize, $\upsilon(\mathbf{z})\cdot\mathbf{tc}$, are made. 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 $\mathbf{p}$, monetized maize prices $\upsilon(\mathbf{z})\cdot\mathbf{t}$, and full budget $M + \upsilon(\mathbf{z})\cdot S$ (as well as the deterrent program $\mathbf{g}$ and household characteristics $\mathbf{z}$). Larson and Shaikh showed that the full budget, monetized prices formulation in (4) is consistent with the hypothesis that both constraints bind. Also, it is straightforward to see that in (4), $V_S/V_M=\upsilon(\mathbf{z})$; that is, the functional form in (4) is consistent with the definition of the maize shadow value in (2). This relationship is used to develop WTP measures based on both money and maize currencies.

4. Willingness to Pay Measures

The indirect utility function $\mathit{V}(\cdot)$ defined in equation (4) can be used to derive two compensating variation measures of the household's WTP, in money and in maize, in a manner consistent with the household's utility-maximizing behavior. The parameter change represents the implementation of the government-sponsored deterrent program, from g^0 to g^1. The WTP 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, with the household free to choose the levels of other activities:

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

where V^{0} is the initial level of utility. 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*., 2004) to obtain

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

which can be solved for money WTP explicitly, resulting in

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

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

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

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

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

which can be solved for maize WTP explicitly as

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

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 in money and its WTP in 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.

To summarize, 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. Econometric estimates of the shadow values of maize are produced as part of the likelihood maximization corresponding to the household's choice of fence deterrent. These estimates allow for the testing of whether the shadow value of maize is significantly different from the prevailing market price. This provides a gauge for the existence of a well-functioning maize market, as well as an indication of the bias that would be incurred from using market prices to approximate the shadow price values, as is commonly done (e.g., Shyamsundar and Kramer, 1996).

5. Econometric Model

To develop an econometric model, functional forms for the WTP functions, the shadow value of maize, and the error distribution must be chosen. The household's true valuation in money terms is denoted wtp^M. It is composed of a systematic component $h(X\boldsymbol{\gamma})$, where X is the matrix of explanatory variables that influence the value the household places on the deterrent program and $\boldsymbol{\gamma}$ 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 in 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

$$\ln(wtp^M) = \ln[h(X\boldsymbol{\gamma})] + \sigma^m \cdot \varepsilon^m, \tag{12}$$

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).

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 $h(X\boldsymbol{\gamma})$, and an unobservable random component ε^s. For the relationship between WTP money and WTP maize in (11) to hold, it must be the case that

$$\ln(wtp^S) = \ln(wtp^M) - \ln[\upsilon(\mathbf{z})],$$

so that from (12), it is apparent that

$$\ln(wtp^S) = \ln[h(X\boldsymbol{\gamma})] - \ln[\upsilon(\mathbf{z})] + \sigma^s \cdot \varepsilon^s, \tag{13}$$

where σ^s is a scale factor and ε^s is marginally distributed N(0,1). The separate error ε^s is used to reflect the fact that there may be some sources of error specific to the maize question. In any event, as it includes ε^m, it is likely to be correlated with ε^m.

The Generalized Leontief functional form was selected to represent the systematic component h(X$\boldsymbol{\gamma}$) of WTP, resulting in the expression

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

where g_i represents the effectiveness of (number of animals repelled by) 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 represent all other explanatory variables that might 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 each of the four types of animal attack also appears as a separate explanatory variable. All other regressors appear only as cross effects with the change in the deterrent program. In addition, the model does not contain an intercept. Each of these features is somewhat unique in WTP models. They are incorporated because the good being valued is private. We assume that WTP would be zero if the respondent household did not expect to benefit from the deterrent program. The functional form specified in (14) also conforms to the requirements of (4), is fairly flexible, and allows for curvature in the relationships between explanatory variables and WTP.

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

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

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.

Although money and maize bids were each varied randomly across the sample, one would expect the household's true WTP in the two numeraires to be related. Estimating a model based on the joint distribution of the two amounts allows for more efficient use of the available information. A bivariate probit model was estimated in which ε^m and ε^s are jointly distributed N(0,0,1,1,ρ), where ρ is the covariance between the two error terms.

Because the response format was two-and-a-half bounded, a total of five intervals of WTP are defined for both money and maize: yes to both the first money bid M_1 and to the higher follow-up M_H; yes and no to the initial and follow-up; no to M_1 and no to the (in this case, lower) follow-up question M_L; no to both the initial and follow-up lower bids, and yes to the minimal WTP question M_3; and no to all 3 questions. Using, for a moment, the marginal (normal) distribution for money WTP to illustrate, the probability of a person saying "yes" to the first bid, M_1, and "no" to the second bid, M_H, is

$$\text{Prob}\{M_1 < wtp^M < M_H\} = \text{Prob}\{M_1 < \ln[h(X\boldsymbol{\gamma})] + \sigma^m \cdot \varepsilon^m < M_H\}$$

$$= \text{Prob}\{[M_1 - \ln[h(X\boldsymbol{\gamma})]]/\ \sigma^m < \varepsilon^m < [M_H - \ln[h(X\boldsymbol{\gamma})]]/\ \sigma^m\}$$

$$= \Phi([M_H - \ln[h(X\boldsymbol{\gamma})]]/\ \sigma^m) - \Phi([M_1 - \ln[h(X\boldsymbol{\gamma})]]/\ \sigma^m),$$

where $\Phi(\cdot)$ is the cumulative distribution function (cdf) of the standard normal variate. Extending this to the case of correlated responses for both money and maize WTP, where maize bids are represented by "S", the probability of a person saying "yes-no" to the money question and "no-no-yes" to the maize question is

$$\text{Prob}\{M_1 < wtp^M < M_H,\ \ S_3 < wtp^S < S_L\} \tag{16}$$

$$= \text{Prob}\{[M_1 - \ln[h(X\boldsymbol{\gamma})]]/\sigma^m < \varepsilon^m < [M_H - \ln[h(X\boldsymbol{\gamma})]]/\sigma^m,$$

$$[S_3 - \ln[h(X\boldsymbol{\gamma})] - \ln[\upsilon(\mathbf{z})]]/\sigma^s < \varepsilon^s < [S_H - \ln[h(X\boldsymbol{\gamma})] - \ln[\upsilon(\mathbf{z})]]/\sigma^s\}$$

$$= \Phi_2(M_H, S_L, \rho) - \Phi_2(M_1, S_L, \rho) - \Phi_2(M_H, S_3, \rho) + \Phi_2(M_1, S_3, \rho)$$

where $\Phi_2(\cdot,\cdot,\rho)$ is the bivariate probit cdf, and the arguments M_j and S_k in (16) refer to the bids offered to the individual. Indexing the set of all 25 possible response patterns (5 intervals each for the two WTP amounts) by r, and defining an indicator variable $I_r = 1$ if response pattern r occurs, $I_r = 0$ otherwise, the likelihood function for the observed patterns of responses across the sample can be written succinctly as

$$L = \Sigma_r\ I_r \cdot \text{Prob}_r. \tag{17}$$

6. Estimation

To jointly estimate the parameters in equations (12), (13), and (15), the log of the likelihood function in (17) was maximized using the Maximum Likelihood Module

Version 4.0.26 of Gauss Version 3.2.32. We removed 17 households from the sample that were identified as "protesters," resulting in a final sample of 148.

Table 1 summarizes the variables that provide the foundation for creating the regressors of the model. The Deterrent Effectiveness variables represent the deterrent qualities of the electric fence that varied across 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 experienced by the household relative to the previous year. Other variables represented the number of attacks of each animal type experienced per household during the past year. The number of attacks ranged widely, e.g., an average of only 0.88 predator incidents per household to 67.72 livestock incidents. The interactions between the animal attack variables and the deterrent effectiveness variables yield estimates of the reductions achieved in the numbers of animals attacking.

Table 1 describes additional potential determinants of WTP, including the area of a household's cropland, which averages over 10 hectares; the number of cattle it owns, which averages 18.59 head; and the number of cattle in an entire village, which is nearly 500 head. A dummy variable was introduced for the village of Muyako, as it is structurally different from the other villages in the sample. The average household in Muyako owns significantly more cattle, has larger fields, produces more maize, has a higher cash income, and is generally better off (Sutton, 2001).

7. Results

Table 2 provides the bivariate probit results for a model that jointly estimates the parameters for WTP in cash and/or maize and 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. Cross effects between the numbers of different animal types deterred as indicated in (14) were 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. The Muyako dummy was also interacted with variables such as the number of each animal type deterred by the program. Various estimates of the full money and maize budgets were included, including money income and the value of maize harvests. These did not prove to be very good predictors of WTP, possibly because incomes and harvests are not well measured or accurately reported.

A number of variables were also created from Geographic Information System (GIS) data, including measures of the local elephant population, farming potential, conservation potential, distance from the nearest conservation area and percentage of cultivated area (see Mendelsohn and Roberts, 1997). These variables were interacted with the animals-deterred variables as indicated by (14). They became insignificant as other, more powerful determinants of WTP were added, probably because the GIS variables were village-level aggregates, unlike the household-level data we collected.

In addition to a constant, dummy variables for other characteristics hypothesized to affect the value households placed on maize were included in the shadow value function. Among these were indicators of whether the household sold any maize during the past year, whether the household was estimated to be in a grain production deficit, 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 model presented in Table 2 was the most effective in explaining jointly the WTP money and maize and the shadow value of maize. The model is highly significant 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 statistic of 1.88. 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 significant at the 1% level, with t-statistics of 2.37 or greater in absolute values, as reported in Table 2. The shadow value of maize and the dispersion and correlation parameters are also highly significant. The shadow value has a t-statistic of 4.85, the standard errors of money and maize have t-statistics of 10.62 and 9.84, respectively, and the correlation ρ has a t-statistic of 9.58 (all resulting in P-values of zero). The estimated model offers a great improvement over a naïve model using only the dispersion and correlation parameters.

The herbivores deterred/field size cross effects variable indicates that households with larger areas under cultivation are willing to pay more to deter herbivores. The predators deterred/household cattle cross effects variable suggests that households with larger cattle herds are 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. The Muyako/livestock deterred interaction variable implies that Muyako households are willing to pay more to deter livestock attacks. All of these results seem reasonable and intuitive. The elephants deterred variable is significant and has a positive influence on WTP. It was not significant when interacted with other variables.

The estimated correlation parameter ρ is 0.74, representing a high degree of correlation between the error terms. Hypothesis testing reveals that ρ is highly significantly different from zero and from one. This result supports the use of a bivariate model to estimate WTP across the two currencies instead of the univariate "double-bounded" model, which implicitly assumes that $\rho = 1$. The correlation is lower than the ρ of 0.95 that Cameron and Quiggin found in their 1994 study, making it more likely, according to Alberini (1995), that parameter estimates would be biased if a bivariate model were not used.

Ultimately, the shadow value of maize $\upsilon(\cdot)$ was estimated as a constant; the other variables used in this expression became insignificant as the variation in WTP became better explained. The estimated shadow value of N$0.31/kg of maize was highly significant and significantly different from the reported 1998 mill-door purchase price for maize in the regional capital (N$0.86/kg, Jurgen Hoffmann, Namibian Agronomic Board, pers. comm.). Farmers' shadow values should be lower than the mill-door price because of transportation and other transaction costs involved in getting the maize to the mill, though the magnitude of the difference (2.8 times) is unusually high. It suggests the presence of important imperfections in the rural Caprivi maize market.

The remoteness of communities in the Caprivi reduces their level of information about changing end-use prices, and increases the cost of getting crops to market. It also reduces their bargaining power with the few traders commercializing low volumes. Storage costs are high, and there are also losses of stock during storage and transport. Each of these helps explain the significant difference between household shadow values and market prices for maize.

This difference demonstrates the potential for error in the conventional approach to CVM in developing countries, which is to simply multiply households' WTP in the non-market currency (maize in this application) by the market price in order to determine their WTP money. It reinforces impressions obtained during field research that Caprivi households are not fully integrated into the market economy and underscores the importance of identifying the shadow values of non-monetary goods when they are used to measure WTP because they are more familiar to respondents.[5]

8. Willingness to Pay Estimates

Table 3 presents the marginal effects of a reduction of one attack by each animal type deterred on WTP in cash and in maize. These values are the derivative of the WTP with respect to an animal type deterred, evaluated at each household's actual level of attacks and averaged across the sample. The mean household WTP to deter one predator from attacking one time is N$150.60 in cash or 343.89 kg in maize (at the time of the survey, US$1 = N$5.80). Surprisingly, the mean WTP to deter one elephant attack is only N$0.91 or 2.09 kg of maize. The WTP to deter attacks by one livestock or one wild herbivore falls in-between, at N$77.59 and N$17.59 respectively. At the margin, given the level of attacks experienced from each animal type during the previous year, households were most concerned about deterring an attack from an additional predator. This makes sense, since there are relatively few predators and they tend to attack as individuals or in small groups, yet are capable of destroying a Caprivi farm household's most valuable non-human asset—its cattle. The average household appears to place substantially less value on deterring the attack of an additional elephant. Table 3 also shows the WTP to deter an attack as a share of the household's total income. Since these measures reflect the cost of only one animal attacking one time, the shares of mean income are generally low. However, the WTP to deter a single predator attack equals over 2% of mean annual income.

Table 4 provides estimates of the annual household WTP in money and in maize for a 100% reduction in each type of animal attack, holding constant the levels of the other three types of animal attacks. These estimates show the total annual cost of damage incurred from each of the four animal types. That is, while Table 3 provides information

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[5] The cause of the low shadow value could also be that farmers want the fence, but cannot afford to pay much in money because they cannot readily convert maize into cash and then pay the government. It could be that they fear accumulating large amounts of cash, which could be stolen, or that others might pressure them to use that cash for purposes other than the purchase of the fence.

on households' WTP for a marginal reduction in attacks, Table 4 shows the more relevant information for policy-making, which is the effect on WTP of eliminating animal attacks.

The relative importance of each type of animal changes when its total, rather than its marginal effect, is considered. Strikingly, the mean WTP money for a 100% reduction in livestock attacks, at N$1,289.44 or 2,944.36 kg of maize per year, is much higher than for any of the other animal types, largely because of their high frequency of occurrence. Other wild herbivores have the second highest mean total effect at N$194.04, while predators are third at N$185.86. The mean WTP for a 100% reduction in elephant attacks is again lowest, at N$32.81. The WTP for complete elimination of all animal attacks is 24% of annual household income, with wildlife accounting for 6% and livestock attacks for 18%. The 6% figure is an estimate of the cost borne by villagers from living with wildlife and thus provides a quantitative dimension to the anecdotal evidence supplied by villagers in discussions and interviews.

9. Conclusions

This paper presents estimates of the costs of living with wildlife suffered by villagers in a rural pastoral economy, developed through a novel extension to the village setting of the widely-used contingent valuation stated preference methodology. Compared to past approaches to measuring wildlife damage costs, this one is relatively simple and fast to implement, requiring only single visits to a sample of households. Its conceptual underpinnings and application represent several "firsts" in the literatures on assessing damage costs and on household shadow pricing in development economics. It is the first study to use contingent valuation methods to measure the costs to local communities of living with wildlife. It presents the first use of a utility-theoretic approach to joint estimation of a household's WTP for a non-market good or government program in both cash and a non-monetary numeraire good, along with the shadow value for the non-monetary numeraire. The strategy pays a double bonus because the shadow value of the non-monetary numeraire—in this case, maize—is interesting in its own right. Household shadow pricing is an important issue in settings where markets are imperfect and prevent the use of market prices to assess household welfare impacts.

The WTP measures are Hicksian compensating variation measures of farmers' welfare that encompass the major costs to farmers of living with wildlife, including the opportunity costs of changes in production practices caused by the threat of animal attacks, which no one has measured using the "physical" damage techniques. As the results are representative, they can be used to estimate the total cost of wildlife damage for the entire region (see Sutton, 2001). The joint WTP-shadow value approach could be used to value nearly any non-market good or public program.

The empirical results demonstrate that rural Caprivi farmers incur significant costs from living with elephants and other types of wildlife. The marginal WTP measures reveal that households are most concerned about preventing individual attacks by predators, and then by other herbivores, though elephants are typically cited as the greatest problem. It is possible that undue attention is given to the damages caused by the large, charismatic animal relative to those caused by other less obvious herbivores or predators. Other studies have focused on communities where elephant damage is acute. Because our sample was randomly selected, it also includes communities farther from elephant habitat. Since smaller wildlife species are often widely dispersed, they could still cause damage to households in those communities. The discrete WTP results also indicate that livestock generate high total costs to farmers by eating their crops. There is typically no mention of livestock damages. We included livestock in the analysis in recognition that fences would protect crops from marauding livestock as well as wildlife. Had we not done so, the results would have been seriously biased. It is not clear how widespread is this problem with livestock damage, but in the Caprivi Region the lack of property rights enforcement appears to be an important cause.

Several policy implications can be drawn from this analysis. First, Caprivi farm households incur significant costs from wildlife attacks, while research has shown that they receive few benefits from the presence of wildlife (Sutton, 2001). In contrast, since wildlife is the main tourist attraction in Namibia, the tourism industry, e.g., tour operators, lodges, restaurants, and car rental companies, and the government (tax revenues) gain greatly. For reasons of efficiency and equity, mechanisms should be developed to compensate Caprivi farmers for damages incurred from wildlife. Without such mechanisms, incentives are distorted since Caprivi farmers have motivation to kill wildlife and convert wildlife habitat, rather than preserve them, even though both are of national and global value. Similarly, income distribution is worsened. Farmers—who are predominantly poor, black and rural—bear the costs of living with wildlife while others—who are predominantly white, urban and often foreign—gain the benefits. Because wildlife contribute public as well as private benefits, funds for compensation could come from government, including the Namibian Government's Game Products Trust Fund, which generates money from the sale of stockpiled ivory and other wildlife products, as well as from the tourism industry and from national and international conservation organizations. The Game Products Trust Fund is currently allowed to fund community-level investments, but not to pay compensation to individual farmers (Barnard, 2002). Further work is warranted to evaluate policies such as the establishment of community wildlife conservancies that may provide direct benefits to villagers (e.g., Barnes *et al.*, 2001), and to determine how their scope and effectiveness may be increased. Given the WTP estimates generated here, it is unlikely that most Caprivi households could justify an electric fence, whose unsubsidized cost is about N$8.60/m (Pricewaterhouse, 1998). However, they have been shown to be effective against wildlife in trials, and a subsidy could be warranted on the grounds stated above.

Second, the results point to the importance of controlling livestock—i.e., reducing livestock crop damage—to improve the welfare of rural Caprivians. An important step in controlling livestock would be to develop well-defined property rights regarding where livestock can graze and who is responsible for damages caused when livestock graze elsewhere (Jarvis, 1984). Barbed-wire fencing of crops is more economical than electric, but might be destroyed by wildlife, e.g., elephants (see Sutton, 2001).

Third, to reduce the costs of wildlife attacks at the margin, priority should be given to developing methods to deter predator attacks. Farmers' responses indicate that predator attacks are costly, whether this is from damage to livestock or psychological costs to humans.

The damages from wildlife-human interactions estimated in this study are moderate relative to average farmer incomes, though not necessarily to the incomes of individual farmers. The damages are very small relative to the gains that wildlife create for Namibia and the world. Thus, our results call attention to the need to manage wildlife in a manner that optimizes social utility by exploiting benefits, reducing damages and rectifying inappropriate societal transfers. Over time, this issue will become increasingly important. There is vast potential for development of wildlife tourism in this region of Namibia, particularly as it provides a link for tourists seeking a variety of wildlife experiences such as those available in other parts of Namibia as well as in Botswana, Zimbabwe and South Africa. However, as Namibia develops economically, farming in this region should become increasingly intensive. Any agricultural development will result in significantly larger wildlife-human interactions of the type studied here. There is clearly need for additional study of how best to manage wildlife, but increased payments to farmers and residents in the region are an important place to begin.

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TABLES

Table 1: Descriptive Statistics for the Sample (n = 148)[6]

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

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

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 of this Model	-198.68748	
Total log-L of Naïve Model (γ=β=0)	-286.07098	
χ^2 (d.f.)	174.77 (8)	
n	148	

Table 3: Marginal Effects on Household WTP Money and Maize of One Animal Deterred and Mean Income Share, by Animal Type

Animal Type	Mean Marginal Effect	Mean Income Share
Willingness to Pay Money (N$):		
Elephant	0.91	0.01%
Other Herbivore	17.59	0.24%
Predator	150.60	2.13%
Livestock	77.59	1.10%
Willingness to Pay Maize (kg):		
Elephant	2.09	0.01%
Other Herbivore	40.17	0.24%
Predator	343.89	2.13%
Livestock	177.18	1.10%

Table 4: Discrete Effects on Annual Household WTP Money and Maize of a 100% Reduction in One Type of Animal Attack and Mean Income Share

Animal Type	Mean Discrete Effect	Mean Income Share
Willingness to Pay Money (N$):		
Elephants	32.81	0.5%
Other Herbivores	194.04	2.7%
Predators	185.86	2.6%
Livestock	1,289.44	18.2%
Willingness to Pay Maize (kg):		
Elephants	74.92	0.5%
Other Herbivores	443.07	2.7%
Predators	424.39	2.6%
Livestock	2,944.36	18.2%