Four Essays on Non-Market Valuation

by

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B.A., Jilin University, 2000
M.A., York University, 2001

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ABSTRACT

This dissertation addresses issues in non-market valuation related to preference uncertainty and to the divergence between willingness to accept (WTA) and willingness to pay (WTP) in contingent valuation method. The contributions are two fold. First, the dissertation contributes to development in non-market valuation by comparing emerging approaches addressing preference uncertainty in the standard contingent valuation framework and by introducing a promising approach, the fuzzy random utility maximization model. Further, the study provides empirical support for the observed divergence between WTA and WTP using a simultaneous equation regression model. Second, the dissertation provides policy implications. The non-market valuation model was calibrated with a survey of western Canadian landowners in 2000 to determine their willingness to accept compensation for planting trees to mitigate climate change. WTA values were then used to analyze the cost effectiveness of sequestering carbon by converting agricultural land to forestry. While estimates of WTA are less than foregone agricultural values, average costs of creating carbon credits still exceed their projected value under a CO_2-emissions trading scheme. Another results from the survey of Nevada ranchers that asked about WTP for public forage and WTA compensation to part with grazing rights indicate that ranch size, public grazing allotment, financial distress, and long term commitment to ranching are all significant influences on the disparity between WTA and WTP, which gives valuable information to ranch policy.

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Chapter 1

General Introduction

1.1 Introduction

This thesis addresses interesting issues in non-market valuation, especially related to the contingent valuation method. In this chapter, I first provide a general introduction to non-market valuation, followed by a brief summary of the contingent valuation method. The topics focused on in this study are then described in section 1.4. Three surveys are used in the analysis, and these are briefly described in section 1.5. An outline of the thesis follows in section 1.6.

1.2 Introduction of Non-market Valuation

Valuing non-market goods is probably one of the most controversial research topics in economics; however, its importance has been increasingly realized by the public. For example, The Earth Summit at Rio de Janeiro in 1992 called for revised measures of gross national product (GNP) to reflect the concern of sustainable development. The issue of money valuation of environmental goods thus arises. Further, cost-benefit analysis plays a key role in many public policies. Given that many policies do have environmental impacts, the process of extending cost-benefit analysis to include environmental costs and benefits is important, which again calls for the quantification and valuation of environmental changes.

Conceptually, non-market values associated with environmental goods can be decomposed into use value and non-use value. Use values include consumptive use values such as hunting and fishing, and non-consumptive use values such as hiking and sight seeing. Non-use values include existence value, bequest value and option value. Existence value is the value of simply knowing that an environmental amenity of particular quality exists, while bequest value arises from intergenerational altruism and is the value an individual derives from preserving environmental quality for future generations. Option value is the value an individual places on preserving the option to make use of an environmental amenity in the future.

Theoretically, we can measure the value of a change in environmental quality using either equivalent surplus (ES) or compensating surplus (CS), depending on the implicit assignment of property rights. For example, let the vector q denote environmental quality.[1] We assume that individuals maximize utility given q and market prices p for other goods.[2] Let u^0 denote the maximum utility corresponding to a given q^0. Then the expenditure function e(q^0, u^0) specifies the minimum level of expenditure needed to achieve u^0 given q^0. We can measure the value of a change in environmental quality, from q^0 to q^1, using either ES or CS. CS measures the amount of compensation to be given (willingness to accept) or the amount of income to be taken away (willingness to pay) after the change in q to leave the individual at the same level of utility as at q^0. That is, $CS = e(q^1, u^0) - e(q^0, u^0)$. ES also measures an individual's minimum willingness to

[1] Environmental quality q could reflect the flow of emissions, the amount of protected forestland, whether or not a species goes instinct, etc.

[2] For simplicity, we assume the environmental quality change is not large enough to change market prices and thus omitted it from our notation.

accept compensation, or the maximum amount she is willing to pay, to forgo a move from the initial to the final situation. In this case, however, the reference level of utility is the utility derived at q^1, so that $ES = e(q^1, u^1) - e(q^0, u^1)$.

How does one derive an individual's willingness-to-pay (WTP) or willingness-to-accept (WTA) empirically? There are two approaches: Revealed Preference and Stated Preference. In recent years, economists have been interested in combining revealed preference and stated preference methods in environmental economics (Adamowicz et al. 1997, Haener et al. 2001, Whitehead 2005). In the Revealed Preference method, individuals' preferences for a non-market good are revealed through the inspection of other markets. The travel cost and hedonic price methods are the main examples of the revealed preference approach. Stated Preference methods use surveys to elicit directly an individual's WTP for more of a public good or her WTA compensation to forgo or have less of the public good. Approaches in this stream include primarily the contingent valuation method (CVM) and choice experiments.

The travel cost method is a type of revealed preference method where the value of the non-market good is drawn from expenditures made by individuals to consume the environmental good, such as the cost of traveling to the site, entry fee, on-site expenditures, etc. The travel cost method emerged as perhaps the first technique to quantify environmental value. It can be traced back to Hotelling's (1947) report to the U.S. National Parks Service about the worth of National Parks, although his response was ignored by the National Parks Service. Ten years later it resurfaced, first in a study of recreational use of the Feather River in California (Trice and Wood 1958). Since then, hundreds of travel cost studies have been carried out, mainly in the United States where various pieces of legislation have required that the benefits of recreation sites be demonstrated before funding is provided. The travel cost method has been refined and techniques have been extended to cover benefit estimation in the context of multiple recreational sites.

The hedonic price method is another important form of revealed preference. It relates to property markets—land and housing markets. Property prices can be decomposed into values of each of the characteristics. For example, market house prices can be decomposed into attribute values such as house and property size, proximity to parks, views, air quality, noise level, etc. Hedonic price analyses have been reported as early as Waugh's (1928) analysis of quality factors influencing asparagus pricing. Later on, Lancaster (1966) laid the economic foundation for methods to value attributes of goods. This approach has been applied to markets as varied as automobiles, computers, VCRs, and appliances, and agricultural commodities (Taylor 2003).

Unfortunately, revealed preference methods have some limitations: first, they are confined to measuring use values. Second, the market data these approaches rely on do not always exist. So economists have ventured into the alternative, the stated preference approach. Stated preference approaches use surveys to elicit directly an individual's WTP or WTA values. The stated preference method is attractive because it elicits both use value and non-use value of policy decisions; it is also controversial because it is hypothetical in nature. Manski (2000) argues that well-designed surveys can avoid many (but not all) of the potential problems of the stated preference method and surveys are often the most effective way to understand people's preferences. If economics is to address important issues involving nonmarket goods, it must accept the challenge of refining stated preference methods.

Contingent valuation and choice experiments are the main stated preference methods. The contingent valuation method will be introduced in more detail in the next section. The choice experiment method finds its conceptual foundation in the “hedonic” method, which has been refined by developments in random utility theory, econometrics and experimental design into a powerful approach. The first application seems to be that of Louviere and Woodworth (1983), and it has become increasingly popular since then. This approach has emerged across disciplines including marketing, psychology, transportation and economics. In non-market valuation application, respondents are asked to choose between different bundles of environmental goods, which are described in terms of their attributes and the levels that these take.

1.3 The Contingent Valuation Method

The Contingent Valuation Method (CVM) is the topic of this dissertation. It is a survey-based method that elicits individual’s WTP to obtain the nonmarket amenity, or WTA to forgo the change in the level of the public good. CVM has been applied to environmental valuation for at least 40 years and there are many published empirical studies. The first contingent valuation study was probably Davis’s (1963) study valuing big game hunting opportunities in Maine, even though the original idea can be traced back to Ciriacy-Wantrup (1947). [3] Later on, Hammack and Brown (1974) applied

[3] Ciriacy-Wantrup believed that the prevention of soil erosion provides some ‘extra market benefits’ that are public in nature, and therefore, one possible way of estimating these benefits is to elicit individuals’ willingness to pay for these benefits through a survey method (see Portney 1994; Hanemann 1994).

contingent valuation to valuing waterfowl hunting. Randall, Ives, and Eastman (1974) applied it to value visibility in the Four Corners region of the Southwest. This method gained popularity after option and existence values were recognized as important components of total economic value in environmental economics, and as a result of the Exxon Valdez oil spill.

Most applications occurred in the United States because various pieces of legislation and court assessments on environmental damages allowed (even called for) such methods to be used. For example, "CVM has been approved by the US Department of the Interior for implementing regulations under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 and its amendments of 1986. In 1990, the US Oil Pollution Act extended liability to oil spills (as oil was not considered a hazardous waste). A 1989 decision by the District of Columbia Court of Appeals involving CERCLA in the case of Ohio v. Department of Interior affirmed the use of CVM and permitted inclusion of nonuse values in the assessment of total compensate damages" (van Kooten and Bulte 2000, p.122).

The key elements of a CVM survey include a description of the good to be valued; a hypothetical payment vehicle such as user fee or tax increases; and a set of questions to obtain data on preference and socioeconomic factors that are likely to affect valuation (including interest in nature, income, education, age, etc.). There are several types of CVM surveys according to different elicitation methods: payment card, open-ended and discrete choice. A payment card survey introduced by Mitchell and Carson (1984) provides a range of WTP (or WTA) values for the good to be valued and asks respondents to choose their maximum WTP (or minimum WTA) value. An open-ended survey simply asks the respondent to state directly her maximum WTP (or minimum WTA) for a change in environmental quality. A discrete choice survey provides the respondent with less latitude: the respondent is asked to state "yes" or "no" as to whether she is willing to pay (or willing to accept) a particular amount, known as the "bid value". Modified versions of the discrete choice approach have been increasingly introduced: double-bounded dichotomous choice (Hanemann 1984, 1985; Carson 1985; Carson and Steinberg 1990; Hanemann et al. 1991); multiple-bounded dichotomous choice (Gonzales-Caban and Loomis 1997; Loomis and Gonzales-Caban 1996, 1997; Loomis and Ekstrand 1997); polynomial choice (Ready, Whitehead and Blomquist 1995; Wang 1997; Welsh and Poe 1998; Alberini, Boyle and Welsh 2003); dichotomous choice with a follow-up certainty confidence (Loomis and Ekstrand 1998; Champ et al. 1997; Blumenschein et al. 1998; Johannesson, Liljas and Johansson 1998; Loomis and Ekstrand 1998; Ekstrand and Loomis 1998; Ready, Navrud and Dubourg 2001); and multiple-bounded polynomial choice format (Welsh and Poe 1998; Evans, Flores and Boyle 2003). The discrete choice approach and its various modifications are increasingly becoming the method of choice in most CVM studies because it most closely approximates a real market setting, in which consumers either buy or do not buy the good at a specified price, and so is more familiar to respondents.

There are many advantages to using CVM: it evaluates both the use value and non-use value of non-market goods; it is incentive compatible under some assumptions (Hoehn and Randall, 1987); and a respondent's task is to provide a one-time answer to a question, which is relative easy. However, there is skepticism and criticism about contingent valuation as well. The contingent valuation method has been criticized because it requires an individual to respond to hypothetical situations. As a result, various types of bias may occur.

Venkatachalam (2004) provides a nice summary of the various critiques and debates over this method. These can be summarized as the following:

1. Embedding or scope effects. This occurs when the WTP value for a particular good differs insignificantly with the WTP value for a more inclusive good (Harrison 1992). Earlier CVM studies had widely reported the occurrence of embedding (Kahneman 1986; Kahneman and Knestch 1992; Nickerson 1993; Desvousges et al. 1993; Randall and Hoehn 1996; Bateman et al. 1997; Diamond and Hausman 1994). The occurrence of embedding violates the fundamental principle that a rational consumer prefers more of a good to less and then pays more for a larger quantity compared to a lesser quantity (Desvousges et al., 1993).
2. Sequencing effect. Sequencing occurs if the WTP for one good differs depending on the sequence order of the goods (Samples and Hollyer 1990; Kahneman and Knestch’s 1992; Hammitt and Graham 1999; McFadden 1994).
3. Information effect. Information that reminds respondents about their budget constraint, substitutes or complements has been found to influence stated WTP (e.g. Whitehead and Blomquist 1990; Adamowicz et al. 1993; Neil 1995, Ajzen et al. 1996).
4. Strategic bias. Survey respondents have an incentive to misrepresent their WTP depending on how and to what degree they believe the actual payment will be tied to their stated valuation. There are two forms of strategic behaviour— free riding and overpledging (Mitchell and Carson 1989). Free riding occurs when

respondents try to understate their valuation on the expectation that others would pay enough for that good. Overpledging occurs when respondents try to overstate their valuation to ensure the environmental quality is improved.

5. Hypothetical bias. This refers to the divergence between real and hypothetical payments (Cummings et al. 1986). Some CVM studies found that hypothetical WTP was much greater than real WTP (Brown et al. 1996, Neill et al. 1994; Kealy et al. 1990; Bishop and Heberlein 1979; Duffield and Paterson 1991; Seip and Strand 1992; Foster et al 1997; Brookshire and Coursey 1987; Brown et al 1996), while others found that stated WTP was less than real WTP (Bishop and Heberlein 1979).

6. Divergence between WTP and WTA. From economic theory, either WTP or WTA could be used interchangeably to elicit individual's value in a public or environmental good (Willig 1976). Yet, researchers found that empirical measures of WTA exceed WTP by a substantial amount (Shorgen et al. 1994; Coursey et al. 1987; Knestch and Sinden 1984).

In responding to the various criticisms, defenders of contingent valuation methods argue that these biases can be removed or minimized through rigorous survey design and practice (Hanemann 1994; Arrow et al. 1993). For example, in the case of embedding effects, it is observed that the fundamental flaws in the design of a survey instrument, improper implementation of the survey, improper sampling procedure and respondents' lack of understanding of the survey questions were some of the factors that caused this problem (Hanemann 1994; Smith 1992; Harrison 1992).

In the case of sequencing effects, improper administration of the survey (Mitchell and Carson 1989) and the 'familiarity' of the respondents with the 'good' under consideration (Boyle et al 1993) play a role in minimizing the sequencing effect.[4]

Results regarding the information effect are mixed. Given the information effect exists, the crucial question will be: What will be the optimal level of information provided to the respondents? There is no simple answer to this question. It depends on the intention of the CV practitioner, the nature of the good to be valued, the cost of obtaining information and so on.

Studies identifying strategic bias are few and the theoretical basis for strategic bias in a survey context is weak, which indicates that it may not be a problem (Griffin et al. 1995; Schulze et al. 1981; Mitchell and Carson 1989).

Many studies suggest that the 'familiarity issue' plays an important role when it comes to hypothetical bias (Mitchell and Carson 1989; Whittington et al 1991). Champ et al. (1997) also found that hypothetical bias could be addressed by considering preference uncertainty. Their WTP estimates were quite similar to actual cash WTP if preference uncertainty is taken into account by converting all 'yes' responses where the individual was not very certain about their answer to 'no' responses.

As to the divergence between WTP and WTA, Willig (1976) argued it could be attributed to the 'income effect'. That is, the WTP for a good is constrained by income, whereas the WTA compensation is not. Hanemann (1991) argued that not only the

[4] Substitution and income effect are also factors attributed to sequencing effects (Carson et al. 2001). That is, the respondents may substitute the first good for other goods in the sequence and leave less money for consuming the other goods in the sequence after spending on the first good.

income effect but also the substitution effect explains the divergence. Since there are few substitutes for many environmental amenities and biological assets, one actually expects a divergence between WTA and WTP. Out of the bounds suggested by traditional theory, Knetsch (1995) found that the endowment effect plays an important role in explaining the divergence between WTP and WTA. Individuals become attached to a particular endowment, requiring a higher level of compensation to part with something than they would pay to obtain it. Whatever the explanation, the disparity between the two valuation measures has been an accepted phenomenon in the CVM literature. Apart from theoretical aspects, weak experimental aspects such as familiarity, hypothetical payments, etc. are also found to affect the WTA/WTP disparity (Horowitz and McConnell 2002; Shogren et al. 1994).

To conclude, Mitchell and Carson (1989) state that contingent valuation studies require very careful design and data analysis. A casual contingent valuation study can be truly misleading, while a well-designed study can provide important insights to guide public policy.

1.4 Focus and Objectives

The main objective of this dissertation is to provide further insights into CVM issues related to the preference uncertainty and the divergence between WTP and WTA.

1.4.1 Preference Uncertainty

Preference or respondent uncertainty arises in a number of different ways: unfamiliarity with the public good or contingency to be valued, unpredictability of the prices of substitutes and complements, improper survey design, hypothetical scenarios of CVM and inability to make a tradeoff between the amenity in question and monetary value. While some uncertainty can be resolved by better informing respondents, or working with them one-on-one, some uncertainty can never be resolved. A number of methods have been developed for incorporating preference uncertainty in empirical applications while maintaining the Random Utility Maximization (RUM) framework. These methods either used a follow-up question to a dichotomous-choice valuation question that asked respondents how certain or confident they were of their previous 'yes'/'no' answer, or imbedded information about preference uncertainty directly in the multiple response options to the valuation question. This thesis will compare some of the emerging approaches and propose a new approach, the Fuzzy Random Utility Maximization approach.

1.4.2 Divergence between WTA and WTP

Research finds that, when people are asked to value changes in the availability of a public or environmental good, WTA compensation exceeds WTP by a substantial amount, contrary to expectations from economic theory. The availability of substitutes and endowment effects are the main possible reasons discussed in the literature. Hanneman (1991), building on earlier work by Randall and Stoll (1980), demonstrates that public goods such as health, species diversity and nature preserves have few substitutes, which results in a divergence between WTA and WTP. Yet, evidence from contingent valuation surveys and experimental markets suggests that individuals become attached to a particular endowment, requiring a higher level of compensation to part with something than they would pay to obtain it (Knetsch 1995). The problem is not on the supply side, but lies with preferences. Indifference curves are somehow 'kinked' (and not continuously differentiable) at the endowment. This study will examine the disparity in further detail in the context of a survey of Nevada ranchers that concerned access to grazing on public lands.

1.5 Three Surveys

In order to explore these two research topics, this study uses three different surveys: a tree planting survey of western Canada landowners, a forest conservation survey of Swedish residents (Li and Mattsson 1995), and a survey of public grazing permit holders in Nevada (van Kooten et al. 2006a,b).

1.5.1 Survey of Western Canada Landowners

A survey of landowners in Canada's Prairie region elicited willingness to accept compensation for a tree-planting program on marginal agricultural land. A questionnaire was mailed in July 2000 to randomly selected landowners in the grain belt region of Manitoba, Saskatchewan, Alberta and northeastern British Columbia. The survey included a cover letter explaining the role of tree planting and carbon credits in mitigating climate change. It elicited detailed information on farmers' agricultural operations (including activities on marginal fields), opinions about and awareness of climate change issues and carbon credits, and personal characteristics and demographics. In the survey, landowners were presented a hypothetical 10-year contract to plant trees on their most marginal land. In the absence of *a priori* valuation information, the compensation offers were selected on the basis of results from a pilot study, and ranged from $1 to $60 per acre per year. In a follow-up to the dichotomous-choice valuation question, the respondents were asked to rate the certainty of their responses on a scale of '1' for not certain to '10' for very certain. More information on the survey design, descriptive variables and the comparison with Census can be found in chapter 2.

1.5.2 Survey of Swedish Residents

A survey of Swedish residents asked respondents whether they would be willing to pay a stated amount to continue to visit, use and experience the forest environment found in the northern part of the country (Li and Mattsson 1995). Bid amounts took one of the following values: 50, 100, 200, 700, 1000, 2000, 4000, 8000 and 16,000 SEK. A follow-up question asked how certain the respondent was about her 'yes'/'no' answer on a percent scale with 5% intervals. The survey also collected data on respondents' age, gender, number of forest visits, education, and household income.

1.5.3 Nevada Ranch Survey

The Nevada ranch survey elicited both WTA and WTP responses for public grazing. It also included questions dealing with the ranch operation, community activities, experience with wildfire, investments in range improvements, attitudes toward the public land agencies, the future of public land-based ranching, income, education, and so on. The context of the survey was the reduction in AUMs of public grazing to protect environmental amenities. Ranchers were asked about their WTP for access to public forage and their WTA compensation for sale of grazing privileges. These questions were embedded in the survey and required a 'yes'/'no' response to a proposed bid. More information on the survey design, response rates and descriptive variables can be found in Thomsen (2002).

1.6 Dissertation Outline

The dissertation is organized into six chapters. Chapter 2 provides a simple application of CVM to a survey of western Canadian landowners that asks them about planting trees on marginal agricultural land. CVM is used to determine the probability of landowners' participation and corresponding mean willingness to accept (WTA) compensation. A discrete choice model is used to first examine the effects of various factors on farmer participation in agricultural tree plantations for economic, environmental, social and carbon-uptake purposes. The estimated WTA from the model is then compared with the net returns to current agricultural activities on marginal agricultural land based on the idea that, although farmers are unwilling to plant blocks of trees on their land without financial incentives, these incentives may be less than the net returns to current agricultural activities on marginal agricultural land because farmers may receive net non-market benefits from growing trees. Finally, the cost-effectiveness of creating carbon sinks of planting trees on marginal agricultural land in western Canada is examined.

In Chapter 3, we examine the impact of uncertainty on contingent valuation responses using both the survey of Canadian landowners and a survey that asked Swedish residents about their willingness to pay for forest conservation. Five approaches for incorporating respondent uncertainty are discussed and compared to the traditional RUM model with assumed certainty. The empirical results indicate that incorporating uncertainty has the potential to increase goodness of fit, but that it could also introduce additional variance. While some methods for addressing respondent uncertainty are an improvement over traditional approaches, we caution against systematic judgments about the effect of uncertainty on contingent valuation responses.

Fuzzy logic is applied to contingent valuation in Chapter 4. In seeking to value environmental amenities and public goods, individuals often have trouble trading off the (vague) amenity or good against a monetary measure. Valuation in these circumstances can best be described as fuzzy— both in terms of the amenity valued, perceptions of property rights, and the numbers chosen to reflect values. Employing a fuzzy clustering approach for incorporating preference uncertainty obtained from a follow-up certainty confidence question, we develop a Fuzzy Random Utility Maximization (FRUM) framework where the perceived utility of each individual is fuzzy in the sense that an individual's utility belongs to each cluster to some degree. The model is then applied to both the survey of Swedish residents and the survey of western Canada landowners. The results from fuzzy models are compared with those obtained using usual techniques of valuation.

Further empirical results for the contention that there is a divergence between WTA and WTP are provided in Chapter 5. The research is based on the 2002 survey of Nevada ranchers that asked about WTP for public forage and WTA compensation to part with grazing rights. WTP and WTA are estimated simultaneously and the hypothesis of significant divergence between WTP and WTA is tested directly. Reasons for the divergence between WTP and WTA are tested empirically to show that ranchers may indeed be valuing different "goods" in their responses to WTP and WTA. The simultaneous estimation also allows us to identify ranch characteristics that influence the discrepancy in valuations.

Finally, the main conclusions of the study are discussed in Chapter 6. Suggestions for further research and policy implications are also provided.

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Chapter 2

Are Agricultural Values a Reliable Guide in Determining Landowners' Decisions to Create Forest Carbon Sinks?[5]

2.1 Introduction

As a result of the U.S.'s withdrawal from the Kyoto process, the EU relented to the inclusion of CO_2 uptake in terrestrial sinks, and thus a role for land use and forestry activities in lieu of carbon dioxide emission reductions in meeting Kyoto targets during the first commitment period (2008-12). At COP7 in November 2001 at Marrakech, the annual cap on carbon (C) uptake in biological sinks for 2008-12 was set at 219 Mt C (151 Mt C if the U.S. is left out). Thus, such sinks could conceivably account for more than 80% of the 250 Mt C annual reduction from 1990 levels required of Annex B countries, although the proportional reduction required is much lower when compared to projected business-as-usual emissions. It is not clear, however, whether carbon credits created through changes in land use are economically competitive with CO_2 emission reductions (van Kooten et al. 2004).

Significant carbon credits can be obtained by planting trees on marginal agricultural land. In addition to providing carbon-uptake and potential commercial timber benefits, tree planting provides non-market benefits from reduced soil erosion, improved

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[5] Based on "Are Agricultural Values a Reliable Guide in Determining Landowners' Decisions to Create Carbon Forest Sinks?" with S.L. Shaikh and G.C. van Kooten, under review at the Canadian Journal of Agricultural Economics.

water quality, increased wildlife habitat, riparian buffer zones and aesthetic appeal.[6] In 2002, the U.S. Farm Bill extended the Conservation Reserve Program (CRP) with an initiative that would restore up to 500,000 acres of floodplains by planting bottomland hardwood trees on private lands.[7] The initiative preserves the CRP's goals of reducing soil erosion and improving wildlife habitat, while extending the program to the potential sequestration of 100 Mt CO_2 (USDA 2003).

The focus of the current study, however, is on the costs of planting trees on marginal agricultural land in western Canada. Since forgone returns from agricultural activities are an unreliable measure of the willingness of landowners to plant trees (e.g., see Stavins 1999), we first examine the compensation landowners in western Canada might require for converting pasture and cropland to forestry.[8] Determining compensation is not straightforward because: (1) there is uncertainty about the costs of tree planting, actual yields and stumpage values due to geographical differences in

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[6] There may also be negative externalities associated with tree planting, including loss of soil moisture, adverse changes in micro-climates, reduced aesthetic amenities due to changes in the prairie landscape, and possible negative impacts on prairie-adapted wildlife and biodiversity.

[7] The Conservation Reserve Program was established in 1985 and has been an ongoing program to reduce soil erosion and improve land quality through voluntary participation in idling land.

[8] Note that current tree planting is unlikely to have much effect in terms of attaining Kyoto targets for 2008-12. Incremental growth at that time will be too small. Ongoing negotiations regarding monitoring may, nonetheless, enable suppliers of carbon sink credits to use expected average annual growth over the entire rotation rather than current growth. Today's tree planting may, however, be applied to targets in subsequent commitment periods.

proximity to saw mills or pulp mills; (2) some returns to tree planting accrue in the distant future, causing disruptions in income flows that could increase compensation demanded; (3) farmers may feel that their ability to participate in current and future government agricultural programs is threatened by tree planting because capacity to produce agricultural commodities is reduced; and (4) landowners have varying preferences towards managed forests versus agricultural ecosystems.[9] The compensation amount required will be higher if landowners realize non-market benefits from agriculture, worry about the lack of guaranteed payments between the end of a contract period and the time trees are harvested, and/or believe that planting contracts have higher transaction costs. Alternatively, compensation demanded might be lower if annual forestry payments reduce landowners' risks (even if such payments stop some years before trees mature), forestry provides non-market (e.g., aesthetic) benefits, and/or transaction costs are not significant. In any event, compensation set equal to agricultural rents (including any price support or subsidy payments) may not be appropriate for convincing landowners to change their land use to forestry.

Information from a contingent valuation survey is valuable in this context, because it is able to incorporate non-market values and risk attitudes, as well as unobservable transaction costs, into the compensation amount. Rather than rely on returns to agricultural activities, which are an unreliable guide to the willingness of landowners to convert farmland to forestry, we employ data from a survey of western Canadian farmers to provide estimates of the possible costs of creating carbon offsets on

[9] Stavins (1999) provides a slightly different list of reasons, which include concerns about irreversibility and liquidity constraints.

marginal agricultural land. The survey explicitly asked landowners about their willingness to accept (WTA) compensation for participation in tree-planting programs.

Second, we are interesting in comparing the costs of carbon uptake when compensation demanded is used instead of the opportunity cost of land to determine if tree planting is a cost-effective means of achieving Kyoto-type targets. The purpose is to identify the potential magnitude of the cost differences per ton of CO_2 removed from the atmosphere when WTA as opposed to opportunity costs of land is used in the calculations. For sensitivity analysis, we consider fast-growing hybrid poplar and slow-growing native tree species.

The paper is organized as follows. A general overview of the theory in the context of tree planting is presented in the next section, followed by a discussion of the data and an explanation of the empirical model. Using our estimates of WTA compensation and opportunity costs of land, the cost-effectiveness of a potential tree planting program is then examined. The paper concludes with a discussion of policy implications and considerations for further research.

2.2 Model for analyzing decisions to convert farmland to forestry

In this study, a discrete-choice random utility maximization framework is used to model the decision of a landowner to convert farmland to forests. The landowner will accept a bid to afforest marginal agricultural land (land contributing the least to net returns) as long as the compensation offered is at least as much as the opportunity cost of not producing plus any positive or negative non-market/risk benefits that he/she gets from planting trees, plus any transaction costs the landowner expects to incur. This decision can be modeled as follows: Landowner i will accept a tree-planting project ($a = 1$) as long as $v_{i,1}(m+\Delta m, \mathbf{s}) + \varepsilon_{i,1} > v_{i,0}(m, \mathbf{s}) + \varepsilon_{i,0}$, where Δm is the compensation or bid (*B*) offered minus forgone expected annual net returns in agriculture (*OC*). Since utility is a random variable, the probability that a farmer's choice to accept the bid can be written (suppressing subscript *i*) as (Hanemann 1984; Greene 2000):

(2.1) $\Pr(a=1) = \Pr\{v_1(m+\Delta m, \mathbf{s})+\varepsilon_1 > v_0(m, \mathbf{s})+\varepsilon_0\} = \Pr\{(\varepsilon_1 - \varepsilon_0) > -[v_1(m+\Delta m, \mathbf{s}) - v_0(m, \mathbf{s})]\}$. Replacing $[v_1(m+\Delta m, \mathbf{s}) - v_0(m, \mathbf{s})]/\sigma$ with Δv and $(\varepsilon_1 - \varepsilon_0)/\sigma$ with ε, where $\varepsilon \sim N(0,1)$ is i.i.d. because ε_1 and ε_0 are i.i.d., yields the probit model:

(2.2) $\Pr(a=1) = \Pr(\varepsilon > -\Delta v) = F_\varepsilon (\Delta v)$,

where F_ε is the normal cumulative distribution function (cdf).

Timber benefits accrue in the distant future and their realization depends on what landowners do after the expiration of the contingency contract, with contracts usually of ten years duration.[10] For example, landowners might sell the land and realize the value of the standing timber plus carbon benefits, or they might choose to hold the land until harvest perhaps renting or leasing the carbon offset credits to a third party (e.g., large industrial emitter) in the meantime. The costs of possibly converting land back to agriculture at the time of harvest will at least partially offset the timber returns. These costs consist of stump removal and root raking plus the foregone returns of lost

[10] The ten-year time frame is selected because this is the longest contract length with which farmers may have experience, and the only term that one can reasonably expect a farmer to agree to. Further, at the time of the survey, the federal government was not interested in the period beyond 2012, so any contracts to sequester or retain carbon beyond that time may not be important.

agricultural (or forestry and carbon) production for a period of one to two years. Timber returns also occur relatively far in the future, thus creating a considerable risk premium further offsetting any timber benefits. The alternative to converting the land back to agriculture is keeping it in forestry, which requires a farmer's long-term commitment to growing trees and learning about forestry practices and timber marketing (see Plantinga 1997 for further discussion). As a result, we do not include timber benefits in the Δm measure. Rather, we expect landowners take into account such benefits in formulating their responses to a question eliciting willingness to accept compensation for a tree-planting program. Positive expected forest rents are one factor that will lower WTA.

The decision to accept the proposed compensation is based on the returns from the least productive parcel of land, with the least productive (lowest earning) acres assumed to be the ones a landowner would commit to a tree planting program. Thus, the landowner will compare $v_1(m+B\text{–}OC, \mathbf{s})$ against $v_0(m, \mathbf{s})$, where B is the bid and OC is the opportunity cost of foregone agricultural production on a per acre basis and $\Delta m = B - OC$. While the opportunity cost represents foregone agricultural net returns from accepting a tree planting program, the total compensation required by the farmer may be increased by other non-market values associated with keeping the land in agriculture (e.g., the landowner may prefer an agricultural landscape or feels committed to an earlier generation that cleared the land) and/or reduced by non-market (say, aesthetic) values associated with forestry. Compensation demanded is also affected by landowners' perceptions about the reduced risk of fixed annual payments (at least over the contract period), increased risks associated with forest and carbon markets (assuming these develop) after the initial contract period, transaction costs and so on.

We follow Hanemann's (1984) linear-in-parameters utility specification, so that welfare calculations are derived in a manner compatible with utility maximization. Hanemann suppresses the **s** vector by allowing the parameters on the constant and income to be functions of individual characteristics (Hanemann 1984, p.334). When the least productive acre of land is considered (i.e., the first acre to be made available for tree planting), the deterministic parts of the utility functions in each state for a given individual can be written as:

(2.3) $v_1(m+B–OC, \mathbf{s}) = \alpha_1 + \beta(m+B–OC)$

(2.4) $v_0(m, \mathbf{s}) = \alpha_0 + \beta' m$

where parameters α_a and β are implicitly assumed to be functions of individual characteristics. Subtracting v_1 from v_0 and dividing by σ gives:

(2.5) $$\Delta v(B–OC, \mathbf{s}) = \frac{\alpha_1 - \alpha_0}{\sigma} + \frac{\beta}{\sigma}(\mathrm{B} - \mathrm{OC}),$$

which can be rewritten as

(2.6) $\Delta v(B–OC, \mathbf{s}) = \alpha + \beta\ (B–OC)$

where $\alpha=(\alpha_1–\alpha_0)/\sigma$, $\beta=\beta/\sigma$. This provides an empirical estimate of Pr(a=1) that is also the conditional mean probability of a. $E[a| X]$ is then equal to:

(2.7) $$E[a| X] = \Pr(a=1) = F_\varepsilon(\Delta v) = \int_{-\infty}^{+\infty} \phi(\Delta v) = \int_{-\infty}^{+\infty} \frac{1}{\sqrt{2\pi}} e^{\frac{-\Delta v}{2}}\, d\Delta v\,,$$

where $E[a| X]$ is the conditional mean probability, X is a vector of exogenous variables, F_ε is the standard normal cdf and ϕ is the corresponding probability density function. The log-likelihood function is given generally by:

$$\text{(2.8)} \quad \log L(\Delta v) = \sum_{i=1}^{n} \left\{ a \log\left[\int_{-\infty}^{(\Delta v)} h(z_1) dz_1 \right] + (1-a)\log\left[\int_{-\Delta v}^{(\infty)} h(z_1) dz_1 \right] \right\},$$

where $h(\cdot)$ represents a standard normal distribution function.

Landowners' minimum WTA compensation, denoted by B^*, is determined as the amount of money needed to keep the farmer indifferent between accepting the bid and retaining marginal land in agriculture. One can express this indifference by setting the probability of accepting a bid in (1) equal to 0.5 and solving for B^* – the median willingness to accept compensation.

2.3 Survey of Canadian Farmers

A questionnaire was mailed in July 2000 to 2,000 randomly selected Canadian farmers from the grain belt region of northeastern British Columbia, Alberta, Saskatchewan and Manitoba. Reminder cards were sent out three weeks after the first mailing.

The effective response rate (corrected for returned/undelivered surveys) was 13%; higher than the 12% rates reported by the Environics Research Group (2000) in their study of stewardship of Canadian farmers and by Bell et al. (1994).[11,12]

The survey included a brief, personalized cover letter explaining the purpose of the questionnaire and a definition of carbon offset credits. In addition to willingness to accept compensation for tree planting, the survey also elicited detailed information on a farmer's agricultural operations including activities on marginal fields, farmers' opinions about and awareness of climate change issues and carbon credits, and personal characteristics and demographics (Suchánek 2001). Personal and demographic information can be compared with similar data from Canada's 2001 Census of

[11] While undesirable, the low response rate is not atypical of farm surveys as the respective surveys of Canadian and Tennessee farmers indicate. Importantly, response rates for executives of small firms are notoriously low (see Friedman and Singh 1989), and farms must be viewed as small firms. But even for individuals response rates may be low as indicated, e.g., by Riddel and Shaw (2003) who report a response rate of 24% for those who previously agreed to participate in a telephone survey about nuclear waste, implying an even lower effective response rate.

[12] Clearly, there was something wrong with the mailing list we purchased from Watts Brokerage Listing, which had the only publicly available list of landowner addresses. A large number of surveys were returned as undelivered (about 1 in 5) and several respondents indicated that they had moved and were retired. This suggests that the mailing information was seriously outdated and likely an unknown number of surveys were forwarded to addresses where the receiver was not the addressee or, if they were, did not bother to respond because they were no longer farming. Hence, our response rate is a lower limit with the true response rate likely much higher.

Agriculture.

Direct comparisons between Census and survey data are difficult because the survey used a much finer grid for age and net worth than reported in the Census of Agriculture. The survey employed ten age and net worth categories, while the Census reports three age and five net worth categories. Education is reported in the Census as the proportion of individuals with education levels according to the following four categories: “less than grade 9”, “grade 9 to 13” (Ontario used grade 13), “post-secondary, non-university”, and “university”. The survey asked respondents to indicate the number of years of post-secondary education, with categories ranging from 0 to 7+ years. The average age of respondents in the survey is 56.5 years, while it is 52 years in the Census; the average net worth of survey respondents is $587,000, whereas the Census average for the Prairie Provinces (excluding BC) is $628,000. Survey respondents completed an average 1.44 years of post-secondary education, while the comparable average education level of prairie farmers in the 2001 Census was about one year of post-secondary education (assuming that “post-secondary, non-university” equals 2 years and “university” equals 4 years). However, our tests of the differences between survey and Census net worth, age and education discerned no statistically significant differences.

The first series of questions in the survey was meant to reduce information biases by familiarizing respondents with the topic and issues under investigation before asking them about their willingness to plant trees. Landowners were presented a hypothetical tree-planting program that covers all costs of tree planting while compensating for lost agricultural production. A compensation amount was offered to convert their least productive land to forest under a 10-year contract. (The actual question used in the survey is provided in the Appendix.) The hypothetical program offered landowners was considered as attractive as the hardwood tree initiative of the CRP. Initial payment amounts for early CRP programs were determined through test programs and auctions with landowners. The bid compensation amounts for this study were selected on the basis of results from a pilot study, and range from $1 to $60 per acre per year (see Suchánek 2001). The distribution of these bids is skewed towards the lower bound of the range in order to provide more efficient estimates of WTA (Cooper 1993). The contingent contract indicates that farmers have no right to harvest the trees before the contract expires, but trees become their property at the end of the contract period. The contract provides no compensation for the conversion of land back to agriculture.

2.4 Variable Description

The explanatory variables of greatest interest are the level of the bid and the opportunity cost of the (least productive) field that would be planted to trees if the bid is accepted. Together these form the actual compensation that a landowner might expect. A summary of the posted bids and response frequencies is provided in Table 2.1. Nearly 45% of respondents accepted the bid, suggesting that the survey offers were balanced, and, as expected, acceptance rates increased as bids rose (except in the $51-$60 category).

The calculation of opportunity cost deserves further attention. Farmers were asked to provide information for up to four of their least productive fields. Land uses were combined into three categories: pasture, hay and grain, with the latter including wheat, canola, barley, rye, oats, flax, lentils, peas and summer fallow. Net returns to each land use vary according to soil zone and region. Survey data on costs of production and returns by region and agricultural activity are available for Alberta. We constructed weighted averages of net returns for agricultural activities on marginal farmland (weighted by number of farmers providing information to extension agents) for five regions in Alberta (Table 2.2) and apply these to the landowners in our survey. Notice that cropping may not always be the most profitable activity on marginal land, but farmers will nonetheless crop the land because, under Canada's grain marketing system, they receive quota for cropland but not for land in perennial hay or pasture. We assign an opportunity cost for tree planting on the basis of the region in which a respondent is located and the land use on their marginal field.[13] Since distances to market, climatic and other factors influence production costs, the values in Table 2.2 must be seen as representative of general conditions only.[14]

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[13] All respondents in northeastern BC and northwestern Alberta are assigned to the Peace Region. This region is isolated from other agricultural regions in Western Canada, and is not part of the Canadian Shield although part of the boreal forest (with mainly grey soils). Soil maps are used to assign all other landowners to the remaining regions in Table 1.

[14] An alternative means of calculating foregone returns to agriculture is provided in Suchánek (2001), but these turn out to have no impact on the decision to accept or reject a bid.

Table 2.1: Acceptance Rate by Bid Category

Bid Category	**Responses**	**Acceptances**	**Acceptance rate**
$1 to $10	26	1	3.9 %
$11 – $20	14	4	28.6 %
$21 – $30	21	12	57.1%
$31 – $40	15	10	66. 7%
$41 – $50	7	5	71.4%
$51 – $60	20	13	65.0%
Total	**103**	**45**	**43.7 %**

Table 2.2: Net Returns to Agricultural Activities on Marginal Agricultural Lands, by Region or Soil Zone ($ per acre)[a]

	Land Use		
Soil Zone	Crop	Hay	Pasture
Brown Soil Zone	20.54	43.46	37.39
Dark Brown Soil Zone	32.63	68.96	52.81
Black Soil Zone	45.36	83.12	86.00
Peace Region	34.54	88.17	26.40
Grey-Wooded Soil Zone	35.11	63.67	Not available

[a] Opportunity costs are calculated from data provided by Alberta Agriculture, Food and Rural Development.

In addition to opportunity cost of land variable, a number of control variables were employed as regressors. Two provincial indicators are used to account for differences in jurisdictional factors across provinces (with policy in northeastern B.C. generally following that in Alberta). Soil zone dummy variables are used to take into account weather, terrain, soil fertility and other productivity differences. One would expect farmers in the black soil zone to require greater compensation than those in the dark brown and brown soil zones. The reason is that the black soil zone demarcates the transition between the boreal forest and grain belt. While there is a greater capacity to grow trees in this zone, landowners have spent significant effort clearing trees and would likely be the most hesitant to replant (van Kooten et al. 2002). The brown soil zone is characterized by drier conditions, so drought tolerant species will need to be planted; farmers are more likely to view trees more positively for their soil conservation benefits (reducing wind erosion).

A visual scale variable is used to incorporate farmer opinions about the aesthetic benefits of tree cover, which is likely to influence acceptance positively. The value of the visual variable ranges on an integer scale from 1, if the respondent considers increased tree cover in the region to enhance the visual appeal of the landscape, to 5 if she considers additional trees to be visually unappealing.

As the number of acres of farmland covered by trees increases, we postulate that the likelihood of accepting the bid amount will increase for several reasons. Extant tree cover could indicate some preference for forest, but it could also indicate that soils in the region are better suited to forest than agriculture, although we control for the latter by including soil zone dummy variables. Owners of existing forests may also be more likely to accept a particular bid because an increase forest area leads to economies of scale in timber production. However, landowners with higher proportions of land in forest may have a lower marginal utility from non-market forest amenities, which would serve to reduce their likelihood of accepting a bid amount.

Likewise, whether or not a respondent had previous experience with a tree-planting contract is thought to have a positive effect on the probability of accepting the bid to plant trees. Respondents were asked to indicate whether they would adapt to climate change by leaving agriculture altogether. We postulate that those who expressed a greater likelihood to leave agriculture as a response to climate change would be more likely to accept the bid amount. These are probably farmers who are already struggling to stay in the sector, perhaps because they are not the 'best' farmers, or they had a few bad years that they attribute to weather conditions. Such farmers may see forestry as a means to leave the sector without losing their land, or they may be interested in greater income stability, which a tree-planting contract could offer.

Further, a farmer's age would likely influence participation positively, as contracts reduce workloads while ensuring a steady income.[15] Increased education, on the other hand, could influence the likelihood of accepting the bid amount negatively, because those with a higher education are more likely to view tree plantations as a

[15] Morin and Suarez (1983) found that, on average, risk aversion increased with age. They also found that, for those with low net worth, risk aversion increased with age; however, for those with high net worth, risk aversion decreased with age. To explore the interaction effect of age and net worth, we included the product of these explanatory variables in the regression analysis, but this interaction term turned out to be statistically insignificant and was dropped from further consideration.

restriction on future land-use flexibility. More educated landowners are likely more knowledgeable about the disputes concerning the Canadian Wheat Board marketing system and opportunities afforded should it be abandoned in the future. They may also be more knowledgeable about the WTO process and the impact future trade agreements will have on future grain markets and prices.

Rather than planting trees, a farmer who expects to bequeath the farm to an heir may be better off to maximize annual returns and invest the proceeds in the capital market. However, agricultural landowners tend to invest in land, with which they are familiar. This increases farm size and results in increasing returns to scale, but also exposes the landowner to greater risks, some of which can be diversified by planting more trees and creating carbon offset credits. Further, the form in which land is passed on to an heir may be important: A diversified farm with forests that provide ecosystem amenities that benefit agricultural production is a form of investment that provides an heir with greater opportunities in the future. If this is the case and standing timber is considered a form of financial and non-financial wealth, those who expect to bequeath the farm are more likely to participate in tree planting. On the other hand, tree-planting contracts reduce the long-term flexibility of land use and this might be considered to reduce the future options available to an heir. Which of these effects has the greatest influence on the probability of accepting a contract offer to plant trees can only be determined empirically.

Summary statistics for the explanatory variables are provided in the last column of Table 2.3. Not all returned surveys were used in the probit estimation. The design of the survey did not permit those respondents unwilling to accept any compensation to answer the contingent valuation questions. While these responses could be construed as a ‘no’ response for any bid amount, they were not included in this analysis as we are primarily interested in those willing to convert their land. Further research explores these responses as part of the relevant sample. As a result of this and some missing data, 103 observations were used to estimate WTA.

Table 2.3: Probit Estimation Results (103 observations)[a]

Explanatory Variable	General Estimated coefficient	Restricted Estimated coefficient	Restricted Marginal effect[b]	Mean
Constant	-3.363*** (1.283)	-3.663*** (0.924)	—	
Compensation offered ($/ac)	0.048*** (0.009)	0.044*** (0.008)	0.017***	25.409
Opportunity cost ($/ac)	0.005 (0.010)	—	—	48.408
Alberta (=1; =0 otherwise)	-0.224 (0.371)	—	—	0.308
Manitoba (=1; =0 otherwise)	-0.149 (0.529)	—	—	0.126
Brown soil zone (=1; =0 otherwise)	1.454** (0.586)	1.029*** (0.365)	0.511***	0.165
Dark Brown soil zone(=1;=0 otherwise)	0.145 (0.393)	—	—	0.258
Forest landscape visually unappealing (1 = very appealing to 5=very unappealing)	-0.235 (0.167)	-0.237 (0.149)	-0.101	2.151
Acres of farmland covered with trees	0.007*** (0.003)	0.007*** (0.002)	0.003***	39.202
Respondent would leave agriculture if climate change became a reality (=1; =0 otherwise)	0.127 (0.493)	—	—	0.25
Respondent previously participated in a tree-planting program (=1; =0 otherwise)	-0.128 (0.339)	—	—	0.618
Years of post-secondary education (0 to 7+)	-0.088 (0.101)	—	—	1.436
Age (median category variable from 33 to 68 years with 5-year intervals)	0.044*** (0.016)	0.040*** (0.014)	0.016***	56.547
Respondent expects a heir to continue farming (=1; =0 otherwise)	-0.063 (0.344)	—	—	0.715
# of observations	103	103		
Log likelihood	-43.993	-57.992		
Likelihood ratio χ^2(df)		2.10(8)		
McFadden $\bar{R}^2$	0.161	0.260		

[a] Numbers below coefficient estimates are the Huber/White/sandwich robust standard errors. *** indicates statistical significance at the 1% level or better; ** indicates significance at 5% level or better; * indicates significance at 10% level or better. $\bar{R}^2 = 1-(L_w-K)/L_\Omega$ where L_Ω is the log-likelihood in the null case (all coefficients except the constant assumed to be zero), L_w is the unrestricted log-likelihood, and K equals to the number of parameters in the model.

[b] Marginal effect for a continuous variable is given by its slope evaluated at sample means. For a dummy variable (*dum*), $\partial E[y|dum]/\partial dum = \Pr[Y=1|\bar{X}, dum=1] - \Pr[Y=1|\bar{X}, dum=0]$, where matrix $\bar{X}$ represents all the other variables evaluated at their sample means. See Greene (2000, p.815).

2.5 Estimates of WTA Compensation for Planting Trees

A general and a restricted regression model were estimated and the results provided in Table 2.3. The general model includes all of the explanatory variables available from the survey instrument and potentially able to explain the willingness of respondents to accept the offered bid. The restricted model is derived in iterative fashion by eliminating the least significant variable in each stage, continuing until the likelihood ratio χ^2 statistic falls below a critical significance level (see Table 2.3), in which case the restricted model is preferred to the general one. This is confirmed by McFadden's (1974) $\bar{R}^2$ goodness of fit measure.

Surprisingly, the opportunity cost variable, whose construct was described in the preceding section, has no statistical impact on the probability of accepting the hypothetical tree-planting program. Perhaps the range of opportunity costs in Table 2.2 was insufficient, but more likely the respondents did not consider the potential loss of direct income from their marginal fields to be an important consideration in choosing to plant trees on those fields. Rather, it might be the contribution of marginal fields to the total enterprise (the indirect income effect, perhaps operating through Canada's grain quota system) that was important to those who chose not to take up the offered bid, or lack of contribution for those who did. The marginal effects of the explanatory variables are also provided in Table 2.3.

All coefficient estimates are significant at the 1% significance level (Table 2.2). As expected, per acre compensation has a significant positive effect on the probability that a respondent accepts the bid amount. A one-dollar increase in the offered bid implies an increase of between one and nearly two percent in the probability of accepting the bid.

The variable that has the greatest positive impact on the probability of accepting a tree-planting program is whether land is located in the brown as opposed to the black soil zone (which is the reference case in the regression, along with Saskatchewan). Trees occur naturally and are common in the black (most northerly) and dark brown soil zones, but are less common in the (most southerly) brown soil zone. It is not surprising, therefore, that landowners in the brown soil zone, who have spent less time removing trees, are more likely to accept the bid amount. As shown by van Kooten et al. (2002), farmers in the black soil zone even appear negative towards tree planting because trees are seen as an obstacle to farm operations, while in the drier brown soil zone they act as shelterbelts and watersheds. It may be the ecosystem functions that cause landowners in the brown soil zone to be more receptive to planting of trees on marginal lands. The probability that landowners in the brown soil zone accept a bid to plant trees is some 50% higher at the margin.

The more trees a farmer already has as a proportion of all owned land, the more likely she is to accept the opportunity to plant more trees, providing support for the notion that respondents have some preference for forest. While it might also indicate that the farmer is already producing timber and more forest area leads to economies of scale in timber production, this is unlikely the situation given that so few landowners practice commercial forestry in the region (although this has been changing rapidly in the past several years). However, the effect of an additional acre of tree cover produces only a small (less than 0.5 percent) increase in the likelihood that the respondent accepts the bid to plant more area to trees.

Finally, the coefficient on age is statistically significant at the 5% significance level. Older agricultural producers are more likely to accept a tree-planting program that provides more secure and consistent annual payments, as hypothesized. An increase in age category increases the probability of accepting the offered compensation by about 1½ percent.

The visual variable is negative and, although statistically insignificant, an important factor explaining the likelihood a respondent would accept the offered compensation (as it could not be removed from the restricted model). This implies that, for a farmer who perceives further increases in local tree cover as visually unappealing, the probability of accepting a bid to plant trees is lower than for a farmer who is fond of trees. The marginal effect on the probability to accept for a one-step increase on the scale of the visual variable is approximately ten percent. So the difference in probabilities of accepting a bid to plant trees between a farmer who very much enjoys the visual aesthetics of trees and one who prefers a more open landscape can be as high as 20%.

Provincial dummy variables turned out to be statistically insignificant, possibly because soil zone captures some of this impact, but also because agricultural programs tend to be similar across the Canadian Prairies, despite the different political jurisdictions and separate agricultural ministries. Whether the landowner will pass the farm to an heir does not appear to be a significant variable, suggesting that continuation of the family farm is unimportant in explaining the decision to accept a tree-planting program – the benefit of passing along added wealth in the form of standing timber may be offset by the loss of flexibility in the way offspring can use land. Further, neither previous experience with a tree-planting program nor education affects the likelihood of accepting the proposed bid.

By setting Pr(a=1)=0.5 and solving, it is possible to calculate the expected median compensation level for each respondent in the sample. We calculate median WTA for each respondent and provide the mean, standard deviation, minimum and maximum values in Table 2.4. The average compensation required to get farmers to plant blocks of trees is $33.42 per acre, or $33.59/ac if estimated parameter values are random and Monte Carlo simulation is used. The estimated maximum compensation required, on the other hand, could be as high as approximately $74 per acre (or higher). It is important to keep in mind, however, that this pertains to the least productive acres and that compensation to plant large blocks of trees might well be much higher as increasingly better agricultural land is converted to tree cover. However, WTA compensation is often below the foregone earnings of the land, which most economists would use as the appropriate measure for estimating costs of carbon uptake.

Table 2.4: Estimated Median Willingness to Accept a Tree-planting Program ($/acre)[a]

	Median	Standard Deviation	Minimum	Maximum
Estimated parameter values fixed; WTA based on farmers' covariates	$33.42	$18.49	–$23.84	$74.06
Estimated parameter values random; representative farmer covariates (Monte Carlo simulation: n= 10,000)	$33.59	$2.25	$25.45	$41.42

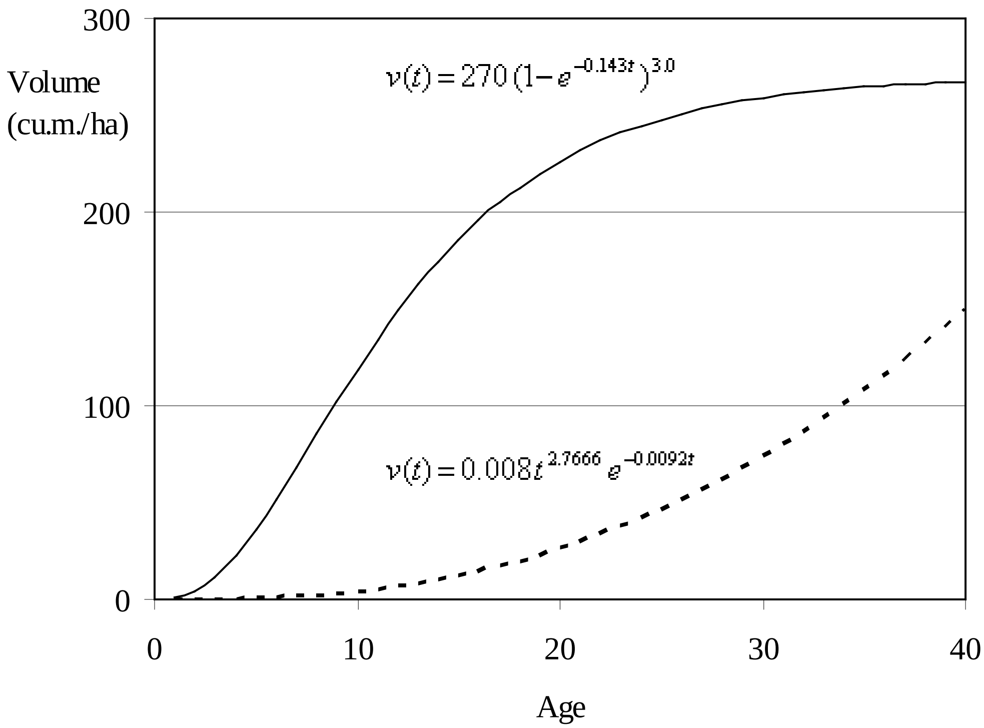
[a] Estimated using the restricted model in Table 2.2.

2.6 Cost-effectiveness of tree planting on agricultural lands

In this section, we determine for western Canada the potential magnitude of the cost differences per ton of CO_2 removed from the atmosphere when WTA (obtained from Table 2.4) as opposed to opportunity costs of land (Table 2.2) is used in the calculations. Since the calculations are necessarily crude, we consider fast-growing hybrid poplar and slow-growing native tree species as a sensitivity analysis as growth rates will have a great impact on costs. We employ a 40-year time horizon using growth functions from van Kooten et al. (1999, 1995) and illustrated in Figure 2.1. [16] The growth function representing hybrid poplar reaches maximum standing biomass at about 25 to 30 years of age, but its financial (Faustmann) rotation age would be somewhat below 20 years. For the growth function for native species, trees do not reach their maximum standing biomass until some 100 years, but can be optimally harvested for financial gains at between 40 and 50 years of age. Native species are also generally more attractive from a visual and ecological perspective.

[16] We recognize that, in the WTA question, tree-planting contracts were specified to run for 10 years, not 40 years. Yet, we employ the longer time horizon, implicitly assuming contracts are renewed under the same conditions, in order to estimate the costs of creating carbon credits. Alternatively, it can be assumed that landowners incur the same cost as given by WTA for keeping the land in forest until harvest at 40 years.

Figure 2.1: General Timber Growth Functions for a Fast-growing Hybrid Poplar (solid line) and Slow-growing Native Species (dashed line)



Carbon in wood biomass amounts to 0.187 metric tons of carbon (tC) per m^3 for hybrid poplar and 0.203 tC/m^3 for the native species. In addition, a factor of 1.57 is assumed to account for total above ground biomass, while soil carbon is assumed to increase at a rate of 0.96 tC per ha per year when marginal agricultural land is converted to forest (van Kooten et al. 1999).

Unlike a reduction in CO_2 emissions, which results in a permanent decrease in the rise of atmospheric CO_2, carbon uptake in sinks is not permanent (land can easily be converted back to agriculture releasing stored carbon). To take into account the ephemeral nature of tree planting, the IPCC (2000) recommends using ton-years, with the conversion factor ranging from one permanent ton being equivalent to 50 to 150 ton-years of temporary storage. Many observers have condemned the ton-year concept on various grounds, and it has been rejected by most countries, primarily because it disadvantages carbon sinks relative to emissions avoidance (Dutschke 2002, p.395).

A second method that has been proposed is the use of temporary carbon emission reduction credits, which under an EU proposal would last for a period of five years. A country claiming such credits during Kyoto's first commitment period would be held responsible for them in ensuing commitment periods.

A third proposal for dealing with the ephemeral nature of biological carbon sinks is due to Marland et al. (2001), and Sedjo and Marland (2003). They suggest that the temporary nature of carbon uptake in sinks can be addressed via a rental market for credits, where the rental rate (r) is simply the price of a permanent emission credit (P) multiplied by the discount rate (δ), which equals the established financial rate of interest adjusted for the risks inherent to carbon uptake (e.g., fire risk, slower than expected tree growth, etc.). Thus, $r = P \times \delta$, which is the well-known bond formula. If emissions trade for \$15 per t CO_2, say, and the risk-adjusted discount rate is 10%, then the annual rental for a metric ton of CO_2 in a terrestrial sink would be \$1.50. Like the ton-year concept, this approach may make terrestrial sink projects less attractive than they might be under some other political solution.

Since we do not know the value at which CO_2 emissions trade, we employ the ton-year concept, using a conservative conversion factor of 50 ton-years of temporary to one ton of permanent removal of atmospheric CO_2. Since all that is important is the amount and length of time that carbon is held in a terrestrial ecosystem, any carbon released after or even during the life of the project is not counted as a debit.[17] Costs of carbon uptake are calculated using estimated planting costs of $1,050 per hectare and costs half that amount (see Krcmar et al. 2001),[18] and annual payments to landowners (in lieu of opportunity costs) from Table 2.3. Costs are discounted at 4%, while physical carbon is discounted at rates of 0%, 2% and 4%.[19] Krcmar et al. (2003) estimate stumpage rates in Alberta (using Government of Alberta methodology) of $8.52 per cubic meter for coniferous wood used in lumber production and $0.50/m^3 for deciduous timber used for OSB. Since these are conservative as they are rates intended to capture the resource rent, we also assume higher net stumpage value (returns after harvest costs) of $20/m^3 and $30/m^3 for conifers (natives) and $10/m^3 and $20/m^3 for poplar (van Kooten et al. 1999).

In Table 2.5, we provide estimates of the costs of carbon uptake in Canadian dollars per metric ton of CO_2 for low, medium and high stumpage values, three different rates for discounting future CO_2 removals from the atmosphere (above and below ground biomass

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[17] Carbon stored in post-harvest products in the case of hybrid poplar should legitimately be counted as a credit, but not if post-harvest biomass is burned for electricity (see Marland et al. 2001). Since native species and the second crop of hybrid trees are harvested after the project ends, post-harvest use of wood can be ignored. We also ignore post-harvest use of biomass from the first crop of hybrid trees.

[18] Cost data are from a 1997 study by the Agricultural Utilization Research Institute, University of Minnesota, Crookston (http://www.hybridpoplar.org/EMCosts.htm, 3 August 2003), and are converted from acres and USD to Canadian dollars per hectare.

[19] Weighting of physical flows of a resource as to when they are available is well established in the natural resource economics literature (Ciriacy-Wantrup 1968). On the discounting of physical carbon, see van Kooten et al. (2004, pp.241-42) for a discussion.

are included in calculations of carbon uptake), two tree planting options, and alternative plantation establishment costs. In addition, we compare results where the landowner is paid according to willingness to accept compensation and an opportunity cost of land of $54.78 per acre, with the latter determined as a weighted average of land in pasture (40%), hay (40%) and grain (20%) further averaged over regions. The costs of carbon uptake by afforestation in western Canada range from net benefits from tree planting to a cost of nearly $70 per t CO_2 for fast-growing hybrid species, to some $30.50–$135.00 per t CO_2 for slow-growing native species, and then only if compensation is based on landowners' WTA. If landowners are compensated according to estimated foregone net returns to extant agricultural activities, costs rise to $34.33–$84.09 per t CO_2 for hybrid species under a low (but perhaps most realistic) stumpage value scenario, to $5.71–$30.10 per t CO_2 for the most optimistic stumpage value scenario.

Table 2.5: Estimated Costs of Carbon Uptake from Tree-planting in Western Canada (C$ per t CO_2) [a]

Item	Low Stumpage ($8.52/m³ natives; $0.50/m³ poplar)			Medium Stumpage ($20/m³ natives; $10/m³ poplar)			High Stumpage ($30/m³ natives; $20/m³ poplar)		
C discount rate[b]	0%	2%	4%	0%	2%	4%	0%	2%	4%
WTA = $33.50 per ha per year									
Planting cost of $1050 per ha									
Slow growth	58.59	90.64	134.96	50.18	77.63	115.58	42.85	66.30	98.71
Rapid growth	36.40	51.24	68.68	22.46	31.62	42.38	7.79	10.96	14.69
Planting cost of $525 per ha									
Slow growth	46.24	71.53	106.50	37.83	58.57	87.13	30.50	47.19	70.26
Rapid growth	26.16	36.82	49.35	12.22	17.19	23.05	++	++	++
Opportunity cost = $54.78 per ha per year									
Planting cost of $1050 per ha									
Slow growth	78.28	121.11	180.30	69.87	108.10	160.94	62.54	96.76	144.07
Rapid growth	44.57	62.73	84.09	30.63	43.11	57.79	15.96	22.46	30.10
Planting cost of $525 per ha									
Slow growth	65.93	102.00	151.86	57.52	88.99	132.49	50.19	77.65	115.61
Rapid growth	34.33	48.31	64.76	20.38	28.69	38.46	5.71	8.04	10.77

[a] For hybrid-poplar, trees are harvested after 20 years and again after 40 years, with the ton-years of carbon adjusted accordingly. ++ indicates benefits of tree planting so there are no carbon uptake costs.

[b] Discounting is combined with the ton-years conversion factor as follows: If 1 tC is stored during the first year of growth, it is assumed to remain stored for 40 years (native tree species) and counted as 40 ton-years C. In the second year, storing 1 tC is counted as 39 ton-years C, but it is discounted by one period (if the discount rate > 0%). The same is true for subsequent years.

Emission reduction permits are expected to trade in the range of $15 to $30 per t CO_2.[20] In that case, the results suggest that landowners in western Canada are unlikely to make a major contribution to Canada's Kyoto targets even if marginal agricultural lands are planted to fast-growing hybrid species. If stumpage prices for poplar are similar to those of conifers or higher, planting costs are not 'too high', and landowners are compensated according to their willingness to accept compensation as opposed to the opportunity cost of land, then some planting of hybrid poplar will be competitive with emission reductions for mitigating climate change. Clearly, there is no room to plant native species as these will not be able to compete with emission reduction strategies. Nonetheless, our cost estimates for native species are not outside the range of estimates of the costs of carbon uptake in forest sinks found in the literature (van Kooten et al. 2004).

2.7 Conclusions

Farmers are unwilling to plant blocks of trees on their land without incentives. In addition to planting trees in exchange for agricultural subsidies and/or inputting taxes, financial incentives can be used to get farmers to plant trees. These incentives could be less than the net returns to current agricultural activities on marginal agricultural land (compare Tables 2.2 and 2.4). This is because some farmers may receive benefits from growing trees that do not show up in market transactions. These benefits relate to potential reductions in risk from assured annual payments, environmental spillover benefits from forests that may enhance sustainable agricultural production, aesthetic

[20] The Government of Canada has capped what large final emitters will have to pay at $15 pet t CO_2, while emission reductions were trading in Europe at just under $30/t CO_2 in June 2005.

benefits, and so on. Thus, if governments or large final emitters seeking offset carbon credits through biological sinks wish to minimize outlays, they should consider compensating landowners according to their WTA instead of observed net returns to extant land use. This could save between one-third and two-thirds of the costs of implementing an afforestation program, or result in more carbon sequestered for the same cost, an important consideration when programs have a budget constraint. However, it will require identifying those landowners who would be willing to participate in tree-planting programs, which could be done through a bidding process.

This research also demonstrates that, even when landowners have some preference for forests, the cost of providing carbon offset credits by planting native tree species on marginal agricultural land in western Canada is likely higher than socially desirable: estimates of the costs of creating carbon credits by planting trees are more than likely to exceed the price projected under CO_2 emissions trading schemes. This is generally but not always true even if farmers' WTA compensation is below foregone returns to agricultural activities, because they receive other benefits (environmental amenities, reduced risk, potential earnings from sale of timber) from planting trees.

Finally, further research needs to examine other important factors that influence farmer decisions and, in turn, the amounts of land available for tree planting in Canada. Critical in this regard is the attitude of landowners and environmental groups to large-scale planting of fast-growing hybrid species, an object of future contingent valuation research. Also critical are the mechanisms and institutions used to compensate landowners, such as whether farmers receive direct payments from government, a private corporation or an environmental NGO, whether they can sell emission offset in open markets and/or whether they form cooperatives to market carbon credits or tree plantations.

2.8 Appendix

The following background information was provided at the beginning of the valuation section: "Hybrid poplar grows quickly with trees reaching maturity in 10-15 years. To achieve such growth, hybrid poplar requires more water than slower-growing species, such as spruce or pine, that generally require more than 40 years to reach maturity. Similar to hybrid poplar, spruce grows best on moist, well-drained, rich-in-nutrients soils. In contrast to hybrid poplar and spruce, pine tolerates low-nutrient conditions and does well in relatively dry environments."

This was followed by several questions related to previous experience with tree planting contracts, current interest in voluntary planting, and experience harvesting and selling trees. Then respondents were asked to provide a 'yes'/'no' response to: "Suppose you were to enter a contract that permits someone to plant trees on (some proportion of) your land. All direct costs of tree planting (e.g. establishment, monitoring, management, maintenance costs) are covered, AND you are provided annual compensation. You DO NOT have any right to harvest the trees before the contract expires. However, when the contract ends, trees become your property. Now suppose a block tree-planting program is available, and at least one of your fields is identified as a potential site for tree plantations. Would you be willing to accept *annual* compensation of $___ per acre for a 10-year contract?" The 'bid' amounts varied across respondents.

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Chapter 3

The Effect of Uncertainty on Contingent Valuation Estimates: A Comparison[21]

3.1 Introduction

The impact of uncertainty on contingent valuation estimates has been discussed in the literature on both a theoretical and empirical level. McFadden (1973) first incorporated observer uncertainty about individuals’ preferences using a random utility maximization (RUM) framework. The RUM model postulates that, from the point of view of the analyst, an individual’s utility consists of a deterministic component plus an unobservable random error term. Hanemann (1984) applied this idea to the valuation of non-market amenities using a contingent valuation device where a respondent is faced with a choice to accept or reject an offered ‘bid’ for an improvement in the level of the amenity. However, this approach addresses uncertainty on the part of the investigator, not uncertainty on the part of the respondent.

Hanemann and Kriström (1995) argue that, if respondents truly know their valuation of a contingency, an open-ended question format should be used to elicit this information. Yet, the dichotomous-choice format is generally preferred because it better simulates a ‘take it or leave it’ marketplace situation, and results in lower variance than estimates from an open-ended format. But there is also, in our view, an implicit

[21] This chapter is based on "The Effect of Uncertainty on Contingent Valuation Estimations: A Comparison" with S.L.Shaikh and G.C. van Kooten.

recognition with dichotomous choice that the random component of the respondent's utility function is the result of preference uncertainty, or perhaps more appropriately, respondent uncertainty about the answer provided. In this paper, we use the term preference uncertainty to denote this uncertainty. As noted below, uncertainty about the answer provided to a valuation question implies uncertainty about the tradeoff between the amenity in question and the monetary good.

Uncertainty arises in a number of different ways. It might originate with the public good or contingency that is to be valued. Respondents may be uncertain about what it is that they are valuing, having no experience with it and perhaps never having seen it. The value an individual assigns to the specified non-market amenity is influenced by prices of both substitutes and complements, if they even exist, and markets for these goods may behave in ways that are unpredictable to the individual (Wang 1997). Uncertainty can also originate with the questionnaire used to elicit information, although this problem can be overcome to some extent by improved survey design. Nonetheless, it is generally accepted that the contingent valuation method (CVM) contributes to potential measurement error, because it relies on hypothetical scenarios (Loomis and Ekstrand 1998). Over and above the hypothetical nature of the CVM, individuals may simply be unable to make a tradeoff between the amenity in question and monetary value. They may also not understand the contingency in question and the manner in which it would be achieved, perhaps being hesitant about the policy (tax, subsidy, etc.) proposed for addressing the environmental spillover. Additionally, uncertainty may be prevalent in programs related to climate change, say, because of the scientific uncertainty and perceived non-immediacy of its effects.

While some uncertainty can be resolved by better informing respondents, or working with them one-on-one, some uncertainty can never be resolved. This is why some prefer situations where a facilitator helps stakeholders identify their preferences and/or enables disparate groups of stakeholders to make a decision concerning environmental amenities (Gregory, Lichtenstein and Slovic 1993).

A number of methods have been developed for incorporating preference uncertainty in empirical applications while maintaining the RUM framework. The first to do so were Li and Mattsson (1995) who used a follow-up question to a dichotomous-choice valuation question that asked respondents how certain or confident they were of their previous 'yes'/'no' answer. A similar 'follow-up' strategy for addressing preference uncertainty was employed by a number of other researchers (Champ et al. 1997; Blumenschein et al. 1998; Johannesson, Liljas and Johansson 1998; Loomis and Ekstrand 1998; Ekstrand and Loomis 1998; van Kooten, Krcmar and Bulte 2001).[22] Ready, Whitehead and Blomquist (1995), Wang (1997), Welsh and Poe (1998), Ready, Navrud and Dubourg (2001), and Alberini, Boyle and Welsh (2003) did not use a follow-up strategy, but instead imbedded information about preference uncertainty directly in the response options to the valuation question, thereby jettisoning the straightforward 'yes'/'no' choice. The methods used by researchers to deal with respondent uncertainty vary considerably, but they all appear somewhat ad-hoc in their approach.

While these disparate approaches for treating respondent uncertainty have

[22] Note that the follow-up questions used in this literature are not designed to increase the confidence of the estimated welfare measure, as with the double-bounded approach (see Kanninen 1993).

evolved, there has been no consensus over the appropriate treatment and there have been few attempts to compare approaches using independent data. The current study seeks to fill this gap in the empirical literature using data from two very different surveys: (1) a survey of landowners in western Canada that asked about willingness to accept (WTA) compensation for converting marginal agricultural land to forestry for carbon uptake purposes, and (2) a Swedish survey that asked people their willingness to pay for forest protection. The data are analyzed using five different methods of addressing preference uncertainty, and comparing these to the standard RUM approach with assumed respondent certainty. The research presented here does not develop the methods for treating uncertainty and therefore does not discuss the theoretical appropriateness of each method. The objective of this study is to compare methods in the literature using two independent datasets in order to assess and compare the performance of each suggested method. While economic intuition and previous studies suggest that the inclusion of uncertainty will lower WTP and raise WTA, results indicate that estimates of average WTA or WTP vary substantially across approaches.

The paper is organized as follows. Models incorporating uncertainty into dichotomous choice CVM are reviewed in Section 2, while the two surveys employed in the analysis are described in Section 3. The empirical results are provided in Section 4, followed by a discussion of policy implications and considerations for further research.

3.2 Models Incorporating Uncertainty

This paper analyzes dichotomous-choice CVM surveys that rely on a certainty follow-up question to address respondent uncertainty. Five econometric methods for incorporating respondent uncertainty into the RUM framework are examined, as is the fuzzy method proposed by van Kooten, Krcmar and Bulte (2001). The various approaches are reviewed in this section.

3.2.1 Weighted Likelihood Function Model (WLFM)

Li and Mattsson (1995) were the first to implement an empirical framework for addressing preference uncertainty within the RUM model. They retain the assumption that individuals have a true value for the amenity, v_i, but they have incomplete knowledge about that value. Survey respondents arrive at some value, $\tilde{v}_i = v_i + \xi_i + \varepsilon_i$, where v_i is the individual's true valuation of the resource and ξ_i and ε_i are stochastic disturbances arising from uncertainty related to the respondent and the observer, respectively. Observer uncertainty is treated the same as it is in the standard RUM model, but a post-valuation question is used to elicit information about the respondent's preference uncertainty. The standard certainty model likelihood function for the dichotomous-choice RUM model is modified generally for the uncertain case as:

$$(3.1) \qquad L = \sum_{i=1}^{N} w_i \left\{ \, (y_i \ln(\Phi_{wtp})) + (1 - y_i) \ln(1 - \Phi_{wtp}) \, \right\}$$

where N is the number of survey respondents. The initial dichotomous choice is given as y=1 for a 'yes' and y=0 for a 'no' answer, and Φ is the cumulative distribution function of the maximum WTP. The weights, w_i, are used as a measure of certainty determined by the response to the follow-up question.

Li and Mattsson constructed a post-decisional confidence rating for assessments of the preservation value of forests in northern Sweden using a follow-up question that elicited a respondent's certainty on a scale ranging from 0% to 100% (with 5% intervals).

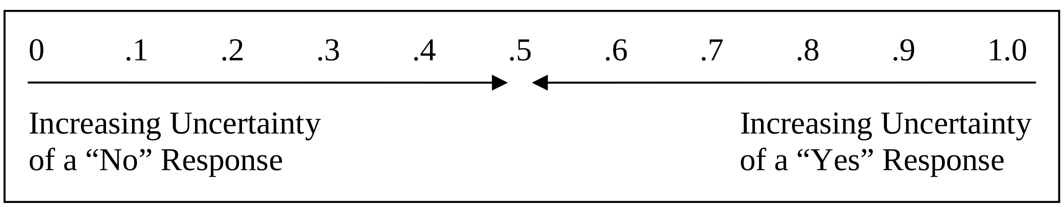
The certainty percentages were used to weight the individual dichotomous-choice responses directly in the likelihood function. Before doing so, however, certainty responses were recoded so that, for example, a ‘yes’ (‘no’) response with 40% certainty was also recoded to a ‘no’ (‘yes’) response with 60% certainty. A ‘yes’ or ‘no’ with absolute certainty in this case results in the standard dichotomous-choice model with certainty.

3.2.2 Asymmetric Uncertainty Model (ASUM)

Champ et al. (1997) developed an alternative approach for incorporating the certainty follow-up response. Using a scale of 0 (very uncertain) to 10 (very certain), they elicited responses to the follow-up rating question: “How certain are you that you would donate the requested amount [in the valuation question]?” All ‘yes’ responses were recoded as a ‘no’ if the respondent was not completely certain (providing a rating of 10). Ready, Navrud and Dubourg (2001) estimated the value of avoiding episodes of respiratory illness using both dichotomous-choice and payment-card survey techniques. In both cases, the WTP question was posed using the following choices: (1) ‘almost certainly yes’ (95% sure ‘yes’), (2) ‘most likely yes’, (3) ‘equally likely yes and no’, (4) ‘more likely no’, and (5) ‘almost certainly no’ (95% sure ‘no’). Like Champ et al., responses were recoded so that only an ‘almost certainly yes’ (choice 1) was treated as a ‘yes’, but the other four categories were considered ‘no’ responses. In both of these studies, the initial ‘yes’ response is only considered a valid ‘yes’ if it is with near perfect certainty. As a result, Loomis and Ekstrand (1998) refer to this type of model as an ‘asymmetric uncertainty model’ (ASUM). This model would be most appropriate if respondents answering ‘no’ are quite certain they would not pay, but those answering 'yes' are more uncertain about their response. As discussed below, evidence of asymmetry exists in the willingness to accept a tree planting program data (Figure 3.1), suggesting that the ASUM will perform well in this case.

3.2.3 Symmetric Uncertainty Model (SUM)

The symmetric uncertainty model (SUM) of Loomis and Ekstrand (1998) provides an alternative to the ASUM by attempting to preserve the initial 'yes' or 'no' response to the dichotomous-choice question. To estimate the benefits of preserving Mexican spotted owl habitat, they pose a dichotomous-choice referendum question with a certainty scale follow-up rating question: "On a scale of 1 to 10, how certain are you of your answer to the previous [valuation] question?" Respondents are instructed to answer 1 for 'not certain' to 10 for 'very certain'. As in the other cases, responses are recoded for estimation purposes, but in this case the recoding converts the dichotomous-choice dependent variable into a 'continuous' variable taking on values over the closed interval [0 1]. The symmetric nature of the recoding is illustrated in the following figure:



A 'no' response with perfect certainty takes on the usual value of 0, while a 'yes' with perfect certainty equals 1. If a 'yes' or 'no' answer to the dichotomous-choice valuation question has an associated certainty of 50% or less, it is assigned a value of 0.5. For a 'yes' response with certainty level greater than 50%, the dependent variable takes on the value associated with the expressed certainty level; thus, a 'yes' response with a follow-up certainty response of 60% is coded 0.6. In contrast, for a 'no' response with certainty level greater than 50%, the dependent variable takes on the value of 100% minus the expressed certainty level; thus, a 'no' response with a follow-up certainty response of 60% is coded 1–0.6=0.4. Following Loomis and Ekstrand, the SUM can be estimated directly using a maximum-likelihood procedure.

3.2.4 Random Valuation Model (RVM)

Wang (1997) views the value that an individual attaches to any amenity (including market traded goods) to be a random variable with an unspecified probability distribution. He assumes that each respondent has in mind an implicit distribution of values rather than a single true value. A respondent will accept to pay a particular amount for an increase in the level of the amenity only if the latent compensating surplus (CS) is 'sufficiently large' relative to the bid, and reject the proposed payment if latent CS is 'sufficiently small'. A 'don't know' (DK) response occurs if latent CS lies in a 'grey area' where CS is either not sufficiently large or sufficiently small relative to the proposed payment. Since the valuation question permits a DK response, no follow-up question is needed to elicit the uncertainty of the response. Then, defining the mean value of WTP function as $v_i = x_i\beta + \varepsilon_i$, and assuming ε_i is normally distributed, the log likelihood function for the three response categories and a proposed one-time payment is:

(3.2) $$\log L = \sum_{i\in yes}\log\left[1-\Phi\left(\frac{t_i + a_i - x_i\beta}{\sigma}\right)\right] + \sum_{i\in no}\log\left[\Phi\left(\frac{t_i - b_i - x_i\beta}{\sigma}\right)\right]$$
$$+\sum_{i\in DK}\log\left[\Phi\left(\frac{t_i + a_i - x_i\beta}{\sigma}\right) - \Phi\left(\frac{t_i - b_i - x_i\beta}{\sigma}\right)\right],$$

where t_i is the bid level assigned to respondent i, and $a_i = v_i - S1_i$ and $b_i = S2_i - v_i$, where S1 and S2 are the lower and upper bounds of the DK region, respectively. If S1 and S2 are constants, maximization of (2) effectively amounts to estimating an ordered probit model. The assumptions can be relaxed to allow *a* and *b* to be functions of the variables thought to affect individual variation distributions. Wang also estimated the model by treating the DKs as ‘no’ responses, similar to the approaches of Ready, Navrud and Dubourg (2001) and Champ et al. (1997), and also by deleting them from the sample. Not surprisingly, Wang found estimated WTP to be significantly lower when all DKs were recoded as ‘no’ responses.

3.2.5 Multiple-bounded Discrete Choice (MBDC)

Although not implemented in the current study, an extension of Wang’s approach was implemented by Welsh and Poe (1998), and Alberini, Boyle and Welsh (2003). They adopt a ‘multiple-bounded discrete choice’ (MBDC) approach that directly incorporates certainty levels through a two-dimensional decision matrix: One dimension specifies dollar amounts that individuals would be required to pay on implementation of the policy, and the second dimension allows individuals to express their level of voting certainty via four response options – ‘definitely no’, ‘probably no’, ‘not sure’, and ‘definitely yes’. This expands to four the three options available in Wang (1997).

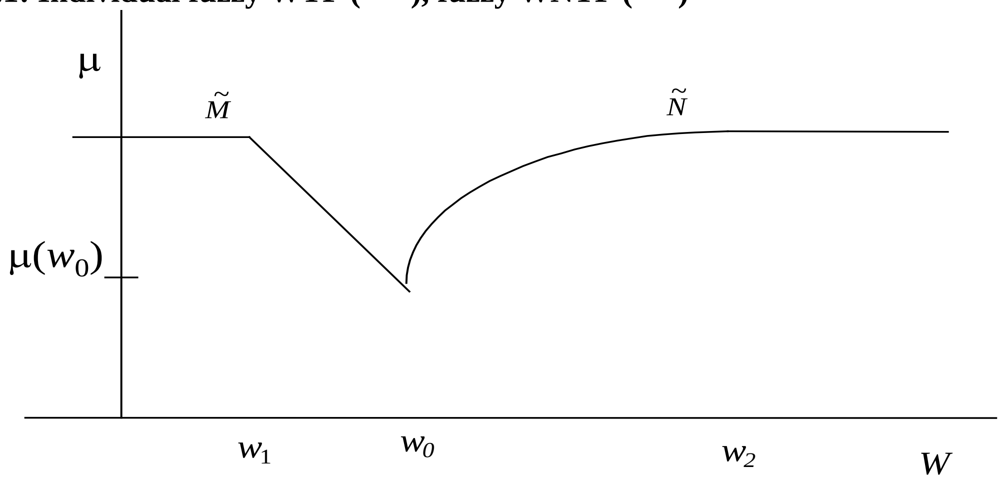
3.2.6 Fuzzy Model (FM)

Like Wang, van Kooten, Krcmar and Bulte (2001) also assume that an individual does not know the amenity’s precise (‘crisp’) value, and will never know it with certainty. A respondent only knows the level above which she will certainly reject the proposed payment and the level below which she will certainly accept it. In between these levels, the preferences of the respondent are ‘vague’, so that the respondent’s WTP and willingness not to pay (WNTP) are best viewed as fuzzy sets (Jang, Sun and

Mizutani 1997) as shown in figure 3.1. That is, rather than assuming the individuals know the distribution of the true value, but not the precise value itself, the researchers assumed that CS can be a member of both the WTP and WNTP fuzzy sets at the same time (which is a characteristic of fuzzy set theory). In their application, follow-up information about how confident or certain the respondent is about her response to the valuation question is used to estimate both WTP and WNTP fuzzy membership functions $\mu(w)$.

Van Kooten, Krcmar and Bulte (2001) employ the same data as Li and Mattsson (1995). The latter assume that an individual *k* who is 40% certain of a 'yes' response is also 60% certain of a 'no' response, so w_k=0.6 and y_k=0 in (1) or w_k=0.4 and y_k=1, but not both. The former assume, however, that *k*'s response is a member of the WTP fuzzy set with membership value 0.4 and a member of the WNTP fuzzy set with value 0.6. That is, the post-decisional confidence of a response is used to determine the membership values of the WTP and WNTP fuzzy sets. The intersection of the estimated WTP and WNTP membership functions corresponds to the 'comfort' level of the associated welfare estimate. Fuzzy estimates of WTP to protect forests in northern Sweden were well below those estimated using the WLFM approach of Li and Mattsson.

Figure 3.1: Individual fuzzy WTP ($\tilde{M}$), fuzzy WNTP ($\tilde{N}$)



3.3 Survey Data

For our empirical application, we employ data from two surveys, one of which elicited WTA compensation for planting trees on marginal agricultural land and the other WTP for preservation of forest ecosystems. We chose to use two different surveys—one with WTA and the other with WTP—in order to observe any consistent patterns across the various treatments of uncertainty. The surveys are briefly discussed in the following paragraphs.

3.3.1 Tree Planting in Western Canada

A survey of landowners in Canada's Prairie region elicited willingness to accept compensation for a tree planning program on marginal agricultural land. A questionnaire was mailed in July 2000 to randomly selected landowners in the grain belt region of Manitoba, Saskatchewan, Alberta and northeastern British Columbia. The survey included a cover letter explaining the role of tree planting and carbon credits in mitigating climate change. It elicited detailed information on farmers' agricultural operations (including activities on marginal fields), opinions about and awareness of climate change issues and carbon credits, and personal characteristics and demographics. Initial questions were meant to reduce information biases by familiarizing respondents with the topic and issues under investigation before asking about willingness to accept compensation for planting trees. More information on the survey design and descriptive variables can be found in Chapter 2.

Summary statistics for the explanatory variables are provided in Table 3.1. The choice of explanatory variables is based on previous research (Chapter 2). Not all returned surveys were used in the estimation as the survey design did not permit those respondents who were unwilling to consider a tree planting program to answer the valuation questions. Landowners might have rejected the option to plant trees because they were located in a dry area (southern grain belt) where trees are less likely to survive or grow large, or in a region where land clearing for agricultural purposes is still ongoing (northern grain belt). While these responses could be construed as a ‘no’ response for any bid amount, they are not included in this analysis because we are primarily interested in those indicting a potential willingness to convert their land. Research to examine this issue further is important but outside the scope of the current study. After excluding those who did not proceed to answer the valuation question or failed to provide other information required for the current analysis (failed to answer the follow-up question, did not provide data on marginal fields, etc.), 122 questionnaires were available for estimating WTA.

Table 3.1: Variable Statistics for Tree-planting Program (n=122)

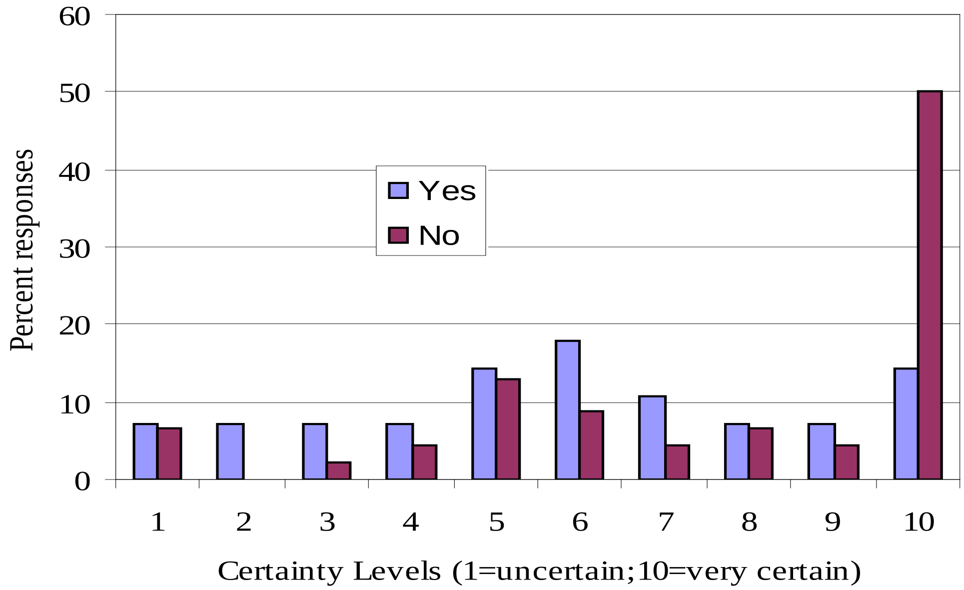
Explanatory Variable	Mean	S.D.	Min	Max
Compensation offered ($ per ha)	26.090	16.860	3.00	60.00
Brown soil zone (=1, 0 otherwise)	0.156	0.364	0.00	1.00
Forest landscape thought visually unappealing (1=very appealing to 5= very unappealing)	2.008	1.032	1.00	5.00
Acres of farmland covered with trees	41.861	72.901	0.00	525.00
Age (median category variable from 33 to 68 years with 5-year intervals)	55.541	9.690	33.00	68.00

In the survey, landowners were presented a hypothetical 10-year contract to plant trees on their most marginal land. The contract would pay up-front planting costs and provide an annual payment to compensate for lost agricultural production. The contingent contract indicated that farmers had no right to harvest the trees before the contract expired, but trees became their property at the end of the contract period. No compensation was provided for conversion of land back to agriculture; instead, it was explicitly noted in the survey that a market for selling carbon credits might have developed by that time or landowners could simply sell the trees thereby covering the cost of converting land back to agriculture if necessary. In the absence of *a priori* valuation information, the compensation offers were selected on the basis of results from a pilot study, and ranged from $1 to $60 per acre per year. The distribution of these bids is skewed towards the lower end of the range in order to provide more efficient estimates of WTA (Cooper 1993). In a follow-up to the dichotomous-choice valuation question, the respondent was asked to rate the certainty of her response on a scale of ‘1’ for not certain to ‘10’ for very certain. Both questions are provided in the Appendix.

As indicated in Figure 3.1, around 50% of those answering ‘no’ were very certain of their answers, compared to only 15% of those responding ‘yes’. As was the case for

Welsh and Poe (1998), if respondents to a one-shot dichotomous-choice question are unsure whether they would pay the dollar threshold, they are most likely to report they would vote ‘yes’ – an indicator of ‘yea saying’.

Figure 3.2: Comparison of certainty of yes and no responses.



3.3.2 Forest Conservation in Northern Sweden

Li and Mattsson (1995) used a contingent valuation survey to assess the preservation value of forests. The survey asked respondents what they would be willing to pay to continue to visit, use and experience the forest environment in northern Sweden. Bid amounts took one of the following values: 50, 100, 200, 700, 1000, 2000, 4000, 8000 and 16000 SEK. A follow-up question asked how certain the respondent was about her ‘yes’/‘no’ answer on a 0-100 percent scale with 5% intervals. About 14% of the ‘yes’ respondents and 11% of the ‘no’ respondents reported confidence levels below 50%. Similar to the Canadian survey, some 35% of the ‘yes’ and 16% of the ‘no’ respondents indicated that they had complete confidence in their response to the valuation question.

The Swedish survey also collected data on respondents' age, gender, number of forest visits, education and household income. The sample made available to us by Li and Mattsson consisted of 389 usable surveys, which, following their lead, was reduced to 344 observations by excluding observations with reported income levels below 11,000 SEK and above 300,000 SEK, and with education levels below 1 year and above 25 years.

3.4 Comparing Uncertainty Models

In this section, we compare the results of five approaches for addressing preference uncertainty, beginning with the survey of western Canadian landowners. The ASUM of Champ et al., Li and Mattsson's WLFM, Loomis and Ekstrand's SUM, and Wang's RVM are all estimated as described earlier. (Lack of information prevents the use of the MBDC approach.) However, we expand on the estimation procedure of the fuzzy model because it is likely the least familiar and it involves a distinct estimation procedure.

3.4.1 Tree Planting in Western Canada

The results of the standard certainty RUM model and the four non-fuzzy methods for addressing uncertainty (WLFM, ASUM, SUM and RVM) are provided in Table 3.2. The conversion of our data and estimation methods are straightforward for the WLFM, ASUM and SUM models as they exploit information from the follow-up question in straightforward fashion. For the RVM method, the certainty information is exploited in a less direct fashion. Two approaches are possible: Wang (1997) provided three choice options, while Welsh and Poe (1998), and Alberini, Boyle and Welsh (2003), provided four options. The difference had to do with the intensity of the 'yes'/'no' response. We could best mimic the RVM approach of Wang (1997) by recoding a 'yes' response followed by an expressed certainty greater than 7 (see Appendix) as a 'certain yes', a 'no' followed by an expressed certainty greater than 7 as a 'certain no', and any in-between response as 'don't know'. We do not consider the alternative RVM scaling associated with the MBDC approach.

Table 3.2: Estimation Results for Tree-planting Program (n=122)[a]

Explanatory Variable	Preference Certainty	Preference Uncertainty			
		ASUM[b]	WLFM	SUM[b]	RVM[b]
Constant	-3.663***	-3.829***	-8.489***	-1.483*	—
	(0.924)	(0.982)	(2.052)	(0.812)	
Compensation offered	0.044***	0.035***	0.098***	0.037***	0.036***
	(0.008)	(0.009)	(0.018)	(0.008)	(0.006)
Brown soil zone (=1; =0 otherwise)	1.029***	0.128	1.314**	0.462	0.291
	(0.365)	(0.398)	(0.669)	(0.367)	(0.261)
Forest landscape visually unappealing	-0.237	-0.082	-0.309	0.076	0.030
	(0.149)	(0.152)	(0.302)	(0.131)	(0.096)
Acres of farmland covered with trees	0.007***	0.004*	0.014***	0.003	0.005***
	(0.002)	(0.002)	(0.004)	(0.002)	(0.002)
Age (median category variable from 33 to 68 years with 5-year intervals)	0.040***	0.031**	0.089***	0.015	0.030***
	(0.014)	(0.015)	(0.027)	(0.013)	(0.011)
Log likelihood	-57.992	-45.232	-36.765	-62.663	-107.218
Pseudo R^2	0.301	0.193	**0.356**	0.153	0.157
Root MSE	**0.400**	0.500	0.406	0.509	0.763
MAE	0.315	0.364	**0.302**	0.430	0.582
Correct predictions	**94**	75	**94**	73	51
	(77.05%)	(61.48%)	**(77.05%)**	(59.84%)	(41.80%)

[a] The difference in the number of observations between chapter 1 and chapter 2 is because we use the restricted model derived from chapter 1 directly, and thus some observations with missing values in the dropped variables are recovered. Standard errors are provided in parentheses: ***, ** and * indicate statistical significance at the 1%, 5% and 10% or better levels, respectively. The "best" model based on the criterion is indicated in bold.

[b] In the ordered logit model, the estimated coefficients of the two cuts are not reported here.

The coefficients on the bid are statistically significant with the expected positive signs at the 0.05 level or better in all models (Table 3.2). By more fully incorporating information about respondent uncertainty according to the WLFM approach of Li and Mattsson, we obtain the highest pseudo R^2 (=0.356), although pseudo R^2 in the certainty model is only slightly lower (=0.301). For the asymmetric uncertainty, random valuation and symmetric uncertainty models pseudo R^2s are substantially lower – 0.193, 0.157 and 0.153, respectively. WLFM also performs best based on mean absolute error (MAE), while the certainty model performs best on the basis of Root MSE. They both have the same number of correct predictions.

For fuzzy CVM, membership functions for aggregated WTA and WNTA are estimated from available survey data of western Canadian landowners using a statistical approach, as opposed to aggregating individually-constructed WTA and WNTA membership functions. The follow-up certainty data (see Appendix) are interpreted as the degree of membership in the fuzzy sets WTA and WNTA. Linear and exponential specifications for the fuzzy WTA and WNTA membership functions were chosen to cover a broad range of applications. To obtain the membership functions, we regress the respondents' post-decisional certainty ('comfort') levels for the respective 'yes' and 'no' responses on the relative bid. For the exponential and linear membership functions, we employed MLE and OLS estimation to obtain the following membership functions for WTA and WNTA:

Exponential:

$$\mu_{wta}(w) = \frac{1}{1 + \exp(0.0816 - 0.0168w)}$$

$$\mu_{wnta}(w) = \frac{1}{1 + \exp(-1.6661 + 0.0186w)}.$$

Linear:

$$\mu_{wta}(w) = 0.4936 + 0.0037w$$

$$\mu_{wnta}(w) = 0.8380 - 0.0029w.$$

A membership value of 0 in the fuzzy set WTA ($\mu_{\text{WTA}} = 0$) indicates that the respondent is completely certain that the bid is unacceptable, while $\mu_{WTA} = 1$ indicates complete certainty that it is acceptable. A similar (but opposite) explanation holds with respect to fuzzy WNTA.

A crisp representation of the *minimum* value of the willingness of landowners to accept a tree planting program is determined at the point where the membership functions of WTA and WNTA intersect. At this point, membership in the fuzzy sets 'WTA the bid' and 'WNTA the bid' is identical.[23] If the bid is lower, μ_{WNTA} is higher while μ_{WTA} is less. Of course, the minimum WTA where both μ_{WNTA}=0 and μ_{WTA}=1 occur can also be considered a crisp representation of the landowners' WTA, but it could be infinite. Rather, using the fuzzy choice rule of van Kooten, Krcmar and Bulte (2001), the crisp value that is found at the point of intersection between the fuzzy sets WTA and WNTA provides a minimum welfare measure that has the greatest comfort level. In this application, for the exponential functional form, the intersection occurs at a value of $49.38 per acre and comfort level (membership) of 0.679; for the linear model, it occurs at a value of $52.28/ac and comfort level of 0.685. The comfort level conveys information about the remaining uncertainty, which can never be completely removed except at unreasonably high levels of compensation.

The estimated median WTAs for each of the 'standard' statistical models are reported in Table 3.3. Monte Carlo simulation over the parameter estimates was used to calculate the distribution of WTA at the means. The fuzzy results are also reported in the table for comparison. The median compensation needed to get farmers to plant blocks of

[23] This interpretation can be considered as similar to the use of median WTA as a welfare measure.

trees in the preference certainty case is $32.83 per acre (or $33.07/ac if estimated parameter values are random and Monte Carlo simulation is used). The estimated median willingness to accept is $59.51 (or $61.92/ac based on simulation) for the ASUM and $34.45/ac ($34.78/ac) for the WLFM. The results for the SUM and RVM approaches are much lower at $7.89/ac ($7.48/ac) and $14.78 /ac ($14.71 /ac), respectively. As will be described below, the estimates of WTA using the fuzzy approach are not sensitive to functional form and range from $49.38/ac to $52.28/ac. In summary, the estimated WTA ranges from $7.48 to $61.92 per acre.

Table 3.3: Estimated Median Willingness to Accept a Tree-planting Program ($/acre)[a]

Model and item	Median	Standard Deviation	Minimum	Maximum
Preference certainty				
Estimated parameter values fixed; WTA based on farmers' covariates	$32.83	$16.20	–$38.15	$65.92
Estimated parameter values random; representative farmer covariates[a]	$33.07	$3.39	$21.94	$44.98
ASUM				
Estimated parameter values fixed; WTA based on farmers' covariates	$59.51	$11.19	$9.78	$83.87
Estimated parameter values random; representative farmer covariates[a]	$61.92	$13.06	$44.23	$264.44
WLFM				
Estimated parameter values fixed; WTA based on farmers' covariates	$34.45	$13.96	–$32.61	$62.79
Estimated parameter values random; representative farmer covariates[a]	$34.78	$2.85	$25.71	$44.34
SUM				
Estimated parameter values fixed; WTA based on farmers' covariates	$7.89	$7.97	–$29.70	$20.36
Estimated parameter values random; representative farmer covariates[a]	$7.48	$5.32	–$29.36	$19.63
RVM				
Estimated parameter values fixed; WTA based on farmers' covariates	$14.78	$13.46	–$58.22	$37.30
Estimated parameter values random; representative farmer covariates[a]	$14.71	$4.51	–$11.29	$28.79
Fuzzy Method	Value	Comfort Level		
Exponential membership function	$49.38	0.679		
Linear membership function	$52.28	0.685		

[a] Except for the fuzzy model, results are based on bootstrapping with *n*= 10,000.

One expects that the inclusion of preference uncertainty will lower WTP estimates, but raise WTA results. This is unambiguously the case only in the ASUM and fuzzy models, while the WLFM yields estimates of WTA that are not statistically different from those of the certainty RUM model.

3.4.2 Forest Conservation in Northern Sweden

We also compare the results of the standard certainty RUM model and the five approaches for addressing preference uncertainty in the case of forest preservation in northern Sweden. The estimation results are reported in Table 3.4. Consistently, the WLFM approach of Li and Mattsson results in the highest pseudo R^2 (=0.283), with pseudo R^2 for the certainty, asymmetric uncertainty, random valuation and symmetric uncertainty models equaling 0.203, 0.237, 0.167 and 0.121, respectively. WLFM also performs best on the basis of MAE, Root MSE and number of correct predictions.

Table 3.4: Estimation Results for Forest Protection in Northern Sweden (n=344)[a]

Explanatory Variable	Preference Certainty	Preference Uncertainty ASUM[b]	WLFM	SUM[b]	RVM[b]
Constant	-2.260***	-2.069***	-2.354***	-1.488**	—
	(0.608)	(0.643)	(0.650)	(0.635)	
Bid	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Annual number of forest visits	0.002**	0.003***	0.003***	0.001	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Education	0.227***	0.151***	0.229***	0.182***	0.177***
	(0.052)	(0.054)	(0.055)	(0.053)	(0.046)
Income	0.011***	0.008**	0.012***	0.013***	0.010***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)
Income × Education	-0.001***	-0.001**	-0.001***	-0.001***	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log likelihood	-189.856	-172.484	-133.307	-176.495	-311.133
Pseudo R^2	0.203	0.237	**0.283**	0.121	0.167
Root MSE	0.430	0.456	**0.429**	0.491	0.683
MAE	0.373	0.384	**0.355**	0.409	0.472
Correct Predictions	253	237	**255**	219	180
	(73.55%)	(68.90%)	**(74.13%)**	(63.66%)	(52.33%)

[a] z-statistics are provided in parentheses: ***, ** and * indicate statistical significance at the 1%, 5% and 10% or better levels, respectively. The “best” model based on the criterion is indicated in bold.
[b] In the ordered logit model, the estimated coefficients of eliminated variables are not reported here.

For the fuzzy model, we employed MLE and OLS estimation to obtain the following membership functions for WTP and WNTP:

Exponential:

$$\mu_{wtp}(w) = \frac{1}{1 + \exp(-0.8805 - 0.00006w)}$$

$$\mu_{wntp}(w) = \frac{1}{1 + \exp(-1.5614 + 0.00014w)}.$$

Linear:

$$\mu_{wtp}(w) = 0.8367 - 0.00003w$$

$$\mu_{wnta}(w) = 0.7118 + 0.00001w.$$

A crisp representation of the maximum value of the willingness to pay for forest protection is determined at the point where the membership functions of WTP and WNTP intersect. At this point, membership in the fuzzy sets ‘WTP the bid’ and ‘WNTP the bid’ is identical. In this application, for the exponential functional form, the intersection occurs at a value of 3385.81 SEK and comfort level (membership) of 0.749; for the linear model, it occurs at a value of 3112.06 SEK and comfort level of 0.743.

For each of the ‘standard’ models, the estimated median willingness to pay is reported in Table 3.5. Again, bootstrapping was used to calculate the distribution of WTP at the means. The median WTP in the preference certainty case is 3899 SEK (or 3915 SEK if bootstrapped). The estimated median WTP is 814 SEK (772 SEK) for the ASUM and 3643 SEK (3640 SEK) for the WLFM. The result from SUM is much higher at 11,598 SEK (11,882 SEK), as it is for the RVM at 2719 SEK (6801 SEK). As indicated above, the estimates of WTP using the fuzzy approach are not sensitive to functional form and range from 3112 to 3386 SEK. In summary, the estimated WTP for forest preservation ranges considerably from 772 to 11,882 SEK.

Table 3.5: Estimated Median Willingness to Pay for Forest Protection in Sweden (SEK)[a]

Model and item	Median	Standard Deviation	Minimum	Maximum
Preference certainty				
Estimated parameter values fixed; WTP based on respondents' covariates	3899.01	2709.68	-5335.72	15145.47
Estimated parameter values random; representative respondent covariates[a]	3915.05	601.78	1607.82	6271.53
ASUM				
Estimated parameter values fixed; WTP based on respondents' covariates	813.76	1713.09	-4007.63	6103.45
Estimated parameter values random; representative respondent covariates[a]	771.83	449.42	-1390.25	2055.18
WLFM				
Estimated parameter values fixed; WTP based on respondents' covariates	3643.10	2358.13	-3504.61	11515.67
Estimated parameter values random; representative respondent covariates[a]	3640.14	467.27	2212.35	5255.04
SUM				
Estimated parameter values fixed; WTP based on respondents' covariates	11597.50	3453.25	-1515.63	22735.89
Estimated parameter values random; representative respondent covariates[a]	11881.70	1706.68	8342.57	23530.26
RVM				
Estimated parameter values fixed; WTP based on respondents' covariates	2719.20	2446.44	-5275.69	11991.92
Estimated parameter values random; representative respondent covariates[a]	6801.26	677.42	4598.72	8945.75
Fuzzy Method	Value	Comfort Level		
Exponential membership function	3385.81	0.749		
Linear membership function	3112.06	0.743		

[a] Except for the fuzzy model, results are based on bootstrapping with *n*= 10,000.

Again, the literature indicates that WTP estimates are likely biased upwards if uncertainty is not taken into account. The inclusion of uncertainty lowers WTP estimates, as expected, for the ASUM, WLFM and fuzzy models, although the difference between the certain estimates and those of the WLFM cannot be considered to be different. These same approaches led to expected higher WTA estimates when preference uncertainty was included in the tree-planting survey.

3.5 Discussion

Differences clearly exist between valuation estimates based on a model that assumes preference certainty and preference uncertainty models that exploit additional information available from certainty ratings. Nonetheless, as Loomis and Ekstrand (1998) point out, there are two conditions that need to be satisfied if the predictive accuracy of intended behavior is to be improved when uncertainty information is taken into account. First, respondents must be able to assess the certainty of their valuation with some degree of accuracy, but this may be difficult due to general lack of cognitive ability in responding to dichotomous-choice valuation questions. Second, respondents must all interpret the certainty scale equivalently – those who provide a rating of four, say, must all have the same level of preference uncertainty. This is unlikely the case, with the incomparability of rating responses across individuals potentially adding more noise than signal. Thus, the approach adopted to reflect respondent uncertainty could potentially introduce additional variance into the analysis.

Our results show that the inclusion of preference uncertainty information can improve predictive accuracy. However, the means used to incorporate uncertainty information is crucial. Evidence from the two surveys presented here supports the WLFM approach of Li and Mattsson, because WLFM outperforms the other statistical methods for incorporating preference uncertainty on the basis of several goodness-of-fit criteria. On this basis, it also outperforms the traditional RUM certainty model. However, the WLFM results are also closest to those of the certainty model (in both cases welfare measures are not statistically different), which suggests that the inclusion of preference uncertainty has only a minimal impact on welfare estimates.

The fuzzy approach leads to welfare estimates that are ‘close’ to those of the WFLM method (at least closer than other approaches for addressing preference uncertainty), and, by interpreting a respondent’s certainty level as a membership value in both the WTA (WTP) and WNTA (WNTP) fuzzy sets, it addresses the points raised by Loomis and Ekstrand. The problem with the fuzzy method, however, is that there is no means for comparing it with the other approaches. Even though the estimated fuzzy WTA (WTP) falls within the range of values derived from the other models and is closest to those from the WLFM, which also has the best goodness-of-fit, there are no grounds to judge it relative to the other approaches.

3.6 Summary and Further Research

Manski (1995) recommends directly eliciting the percent or likelihood of some action, arguing that even if expectations are not rational, probabilistic intentions data may have greater predictive power than binary data. Evidence in favor of incorporating respondents’ preference uncertainty into CVM surveys is increasingly found in empirical studies. Beginning with Li and Mattsson (1995), studies show that mean estimates of willingness to pay are seriously biased upwards if preference uncertainty is ignored. Champ et al. (1997) found that WTP estimates were quite similar to actual cash WTP if all ‘yes’ responses where the individual was not very certain were recoded to ‘no’ responses, while Ready, Nvrud and Dubourg (2001) found convergence of dichotomous choice and payment card formats using a similar approach. The results of this study show that incorporating preference uncertainty does have the potential to increase goodness of fit, but, depending on the empirical method used to incorporate the uncertainty follow-up, it could introduce additional variance into the analysis.

An important result of the comparisons made here is that willingness to accept compensation and willingness to pay under uncertainty can be higher or lower than the associated measure under certainty. While previous studies have generally shown that models assuming certainty result in WTP estimates that are biased upwards, the WLFM, ASUM and fuzzy approaches are the only ones that confirm this result – inclusion of respondent uncertainty increases WTP and decreases WTA. The RVM and SUM approaches lead to the opposite result. Hence, the results of this analysis caution against systematic judgments about the directional effect of uncertainty on contingent valuation responses. Further, while several methods have been suggested in the literature for treating uncertainty, there is little evidence that one method is generally superior to another, thereby warranting additional developments in this area.

Given that the WLFM approach to the inclusion of uncertainty is associated with the ‘best’ performance but results in welfare measures not distinguishable from those of the certainty RUM model, several questions come to mind. Are individuals truly uncertain about the tradeoff between the money metric and the proposed contingency? If so, are current methods for treating this uncertainty in deriving welfare measures up to the task? This research treats uncertainty as an empirical question only. A full representation of preference uncertainty would require its incorporation into a utility maximization model, from which a new form of WTA (WTP) would be derived and estimated. It would also require better means for eliciting preference uncertainty in CVM-type questionnaires. To our knowledge, these issues have not been explored fully within the CVM literature and remain important concerns for further research.

3.7 Appendix

Valuation Question:

Suppose a block tree-planting program (planting of entire fields) is available, and at least one of your fields is identified as a potential site for tree plantations. Would you be willing to accept ANNUAL compensation of **$ <to be filled in>** per ACRE for a 10-year contract? (**Please circle**)

YES NO

Follow-up Question:

On a scale 1 to 10, how certain are you of your answer to the previous question? **Please circle** the number that best represents your answer if **1= not at all certain** and **10 very certain.**

1 2 3 4 5 6 7 8 9 10

not at all certain	Somewhat certain	very certain

3.8 References

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Chapter 4

Fuzzy Logic and Preference Uncertainty in Non-market Valuation[24]

4.1 Introduction

The impact of uncertainty on contingent valuation estimates is both a theoretical and empirical concern. McFadden (1973) first incorporated uncertainty about individuals' preferences using a random utility maximization (RUM) framework. The RUM model postulates that, from the point of view of the analyst, an individual's utility consists of a deterministic component plus an unobservable random error term. Hanemann (1984) subsequently applied this idea to the valuation of non-market amenities using a contingent valuation device where a respondent is faced with a choice to accept or reject an offered payment ('bid') for an improvement in the level of an environmental amenity or public good. This approach addresses uncertainty on the part of the investigator, not preference uncertainty on the part of the respondent.

Preference or respondent uncertainty arises in many different ways. Uncertainty might originate with the non-market commodity or contingency that is to be valued; respondents may be uncertain about what it is that they are valuing, having no experience with it and perhaps never having 'seen' it. The value an individual assigns to the specified non-market amenity is influenced by prices of both substitutes and

[24] This chapter is an expanded version of the paper "Fuzzy Logic and Preference Uncertainty in Non-market Valuation" with G.C. van Kooten.

complements, if they even exist, and markets for these goods may behave in ways that cannot be predicted by the individual (Wang 1997). Uncertainty can also originate with the questionnaire used to elicit information, although this problem can be overcome to some extent by improved survey design. Nonetheless, it is generally accepted that the contingent valuation method (CVM) contributes to potential measurement error, because it relies on hypothetical scenarios (Loomis and Ekstrand 1998). Over and above the hypothetical nature of CVM, individuals may simply be unable to make a tradeoff between the amenity in question and monetary value. They may not understand the proposed contingency and the way it is to be achieved, perhaps even unsure about the success that the public program (e.g., setting aside more habitat for a species) or government policy (e.g., tax, subsidy) will have in bringing about the change. Further, they may not understand or may even object to the proposed payment mechanism.

While some preference uncertainty can be resolved by better informing respondents, or working with them one-on-one, some uncertainty can never be resolved. This is why some prefer situations where a facilitator helps stakeholders identify their preferences and/or enables disparate groups of stakeholders to make a decision concerning environmental amenities (Gregory, Lichtenstein and Slovic 1993).

A number of methods have developed for incorporating preference uncertainty in empirical applications while maintaining the RUM framework. The first to do so were Li and Mattsson (1995) who used a follow-up question to ask respondents how certain or confident they were of the ‘yes’/‘no’ answer they provided to the preceding valuation question. The same ‘follow-up’ strategy for addressing preference uncertainty was employed by a number of other researchers (e.g., Champ et al. 1997; Blumenschein et al.

1998; Johannesson, Liljas and Johansson 1998; Loomis and Ekstrand 1998; Ekstrand and Loomis 1998; Ready, Navrud and Dubourg 2001), but the seemingly ad hoc methods used for converting the follow-up responses for inclusion in the RUM econometric framework varied considerably.[25] Another approach imbedded information about preference uncertainty directly in the response options to the valuation question, thereby jettisoning the straightforward 'yes'/'no' choice (Ready, Whitehead and Blomquist 1995; Wang 1997; Welsh and Poe 1998; Alberini, Boyle and Welsh 2003). This enabled the researchers to employ an ordered probability distribution function, such as ordered probit or logit, instead of the standard binary one.[26] Despite the somewhat makeshift manner in which responses are often treated, what these lines of inquiry did recognize is the need to address respondent uncertainty.

Our view is that the apparent precision of standard WTP or WTA estimates may mask the underlying vagueness of preferences and lead to biased outcomes. Valuation can best be described as fuzzy in terms of perceptions about the property rights to the good, the amenity being valued (vagueness about what it is), and the actual tradeoffs between the amenity and the money metric. Although widely applied in engineering, computer science and bioinformatics, fuzzy logic has been largely ignored in economics, particularly in the area of non-market valuation where its use might be considered most

[25] Note that the follow-up questions used in this literature are not designed to increase the confidence of the estimated welfare measure, as with the double-bounded approach (Kanninen 1993). They are meant specifically to address respondent uncertainty.

[26] Ready, Whitehead and Blomquist (1995) were an exception as they converted their responses back to a binary-type framework.

appropriate. Paliwal et al. (1999) and van Kooten, Krcmar and Bulte (2001) may have been the first to apply fuzzy logic in this context. The former proposed a fuzzy hedonic method to value land degradation as explanatory factors – suitability, compatibility and operability – were assessed by experts using linguistic terms that were represented by fuzzy numbers. The researchers found that fuzzy as opposed to conventional regression significantly improved the mean squared error. Van Kooten et al. applied fuzzy logic in the context of the contingent valuation method. Using the same data as Li and Mattsson (1995, hereafter L&M), they specified the fuzzy sets willingness to pay ($W\tilde{T}P$) and willingness not to pay ($W\tilde{N}TP$), and then found an aggregated measure of the change in welfare. Their estimates of the value of forest preservation in Sweden were about half those of L&M's original measures. Differences in the nature of the preference uncertainty assumptions and measures of welfare were the main reasons for the different estimated values in these two studies, although, in this paper, we show that the differences are in fact much smaller than indicated.

In the current paper, instead of fuzzifying WTP and WNTP on the basis of responses to a dichotomous choice with follow-up certainty confidence procedure, we fuzzify respondent utility functions from the beginning. We employ a fuzzy clustering approach for incorporating preference uncertainty based on follow-up certainty confidence information and develop a Fuzzy Random Utility Maximization (FRUM) framework where the perceived utility of each individual is fuzzy in the sense that an individual's utility belongs to each cluster to some degree.

Cluster analysis is commonly used for pattern recognition (Bezdek 1982), soft learning (Karayiannis 2000), information control (Ruspini 1969), signal analysis (Leski

2005) and other engineering applications. In economics, it is mainly used to segment markets by incorporating heterogeneous preferences. Thus, in modeling choice of shopping trips, Salomon and Ben-Akiva (1983) classified people into different lifestyle clusters based on social, economic and demographic information, while Swait (1994) segmented individuals choosing beauty aids according to latent socio-demographic and psycho-graphic variables. In both cases and more generally, results indicate that the explanatory power of the latent segmentation model is greater than that of traditional approaches. In the context of non-market valuation, Boxall and Adamowicz (2002) applied latent segmentation to the choice of wilderness recreation sites, identifying latent classes by incorporating motivation, perceptions and individual characteristics. They found significant differences in welfare measures with the segment model. Fuzzy clustering analysis provides an alternative to the latent segmentation model that addresses non-linearity in a flexible way.

In this study, we use a fuzzy clustering approach that incorporates certainty confidence information to construct a fuzzy random utility maximization model. The model is then applied to both L&M's survey of Swedish residents' willingness to pay for enhanced forest conservation and the survey of western Canada landowners' willingness to accept compensation for converting marginal agricultural land to forestry for carbon uptake purposes. To demonstrate the feasibility, effectiveness and advantages of the proposed FRUM approach, the fuzzy results are compared with those obtained from a traditional RUM model in which no attempt is made to address respondent uncertainty, as well as L&M's model. Results indicate that the FRUM 'performs' as well or better than traditional methods of non-market valuation.

The paper is organized as follows. In the next section, we present a brief background to fuzzy logic and apply it to individuals' preferences. Our empirical model is described in section 3, where we introduce fuzzy c-means clustering and Takagi-Sugeno fuzzy inference. These concepts are applied in the context of a fuzzy random utility maximization model, which is also developed in section 3. The empirical results are provided in section 4, followed by some conclusions and further discussion.

4.2 Fuzzy set theory and fuzzy preferences

Multivalued or fuzzy logic was first introduced in the 1920s and 1930s to address indeterminacy in quantum theory. The Polish mathematician Jan Lukasiewicz introduced three-valued logic and then extended the range of truth values from {0, ½, 1} to all rational numbers in [0,1], and finally to all numbers in [0,1]. In the late 1930s, quantum philosopher Max Black used the term 'vagueness' to refer to Lukasiewicz' uncertainty and introduced the concept of a membership function (Kosko 1992, pp.5-6). Subsequently, in 1965, Lofti Zadeh introduced the term 'fuzzy set' and the fuzzy logic it supports. The theory was refined and further developed by Kaufman (1975), Kandel and Lee (1979), Dubois and Prade (1980), and many others.

4.2.1 Fuzzy Set Theory

Fuzzy logic starts with the concept of a fuzzy set. A fuzzy set has no crisp or clearly defined boundary as it can contain elements that have only partial membership in the set. Consider the set of "tall" people as an example. Most would agree that someone taller than two meters is an element of the set "tall". What about someone who is only 1.8 meters tall? To a basketball player, this person is not tall, although someone who is 1.5 m would consider them to be "tall". The point is that a person who is 1.8 m is not a member of the set "tall" to the same extent as someone who is more than 2 m tall (the former is a partial member of the set "tall"), while a person who is 1.5m is simply not a member of the set "tall" (or a partial member with very low degree of membership). Fuzzy logic is valuable because it permits the truth of any statement to be a matter of degree.

Consider the idea of fuzzy set and partial membership more formally. An element x of the universal set X is assigned to a fuzzy set $\tilde{A}$ via the membership function $\mu_{\tilde{A}}$, such that $\mu_{\tilde{A}}(x) \in [0,1]$.[27] Thus, the closer the value of $\mu_{\tilde{A}}(x)$ is to unity, the higher the grade of membership of x in $\tilde{A}$. When A is an ordinary set, its membership function can take on only two values, 0 and 1, with $\mu_A(x) = 1$ or 0 according as the element does (full membership) or does not (no membership) belong to A.

The intersection and union of two fuzzy sets $\tilde{A}$ and $\tilde{B}$ are defined by Zadeh (1965) as:

(4.1) Intersection: $\mu_{\tilde{A}\cap\tilde{B}}(x) = \min\{\mu_{\tilde{A}}(x), \mu_{\tilde{B}}(x)\} \forall x \in X$,

(4.2) Union: $\mu_{\tilde{A}\cup\tilde{B}}(x) = \max\{\mu_{\tilde{A}}(x), \mu_{\tilde{B}}(x)\} \forall x \in X$,

The intersection $\tilde{A} \cap \tilde{B}$ is the largest fuzzy set that is contained in both $\tilde{A}$ and $\tilde{B}$, and union $\tilde{A} \cup \tilde{B}$ is the smallest fuzzy set containing both $\tilde{A}$ and $\tilde{B}$. Both union and intersection of fuzzy sets are commutative, associate and distributive as is the case for ordinary or crisp sets. Further, the complement $\tilde{A}^c$ of fuzzy set $\tilde{A}$ is defined as:

[27] We use a ~ to denote a fuzzy set; thus, A denotes an 'ordinary' set, while $\tilde{A}$ denotes a fuzzy set.

(4.3) $\mu_{\tilde{A}^C}(x) = 1 - \mu_{\tilde{A}}(x)$.

Fuzzy logic deviates from crisp or bivalent logic because, if we do not know $\tilde{A}$ with certainty, its complement $\tilde{A}^c$ is also not known with certainty. Thus, $\tilde{A}^C \cap \tilde{A} \neq \phi$ (ϕ is the null set) unlike crisp sets where $A^C \cap A = \phi$, so fuzzy logic violates the 'law of non-contradiction'. It also violates the 'law of the excluded middle' because the union of a fuzzy set and its complement does not equal the universe of discourse – the universal set. $\tilde{A}$ is properly fuzzy if and only if $\tilde{A}^C \cap \tilde{A} \neq \phi$ and $\tilde{A}^C \cup \tilde{A} \neq X$, where X is the universal set (Kosko 1992, pp.269-72).

A fuzzy number $\tilde{F}$ is defined on the real line, and has a membership function $\mu_{\tilde{F}}(x) \in [0,1]$, while a fuzzy variable has fuzzy numbers as its values. It is in this form that fuzzy set theory is used to define fuzzy utility, which is modeled as a fuzzy number with a certain membership function.

4.2.2 Fuzzy Preferences

Consumers often reveal their preferences using verbal statements such as: "I prefer the car with dark blue color." "I like that restaurant very much." "I would prefer to see more protection of forestland." Everyday statements about preferences are expressed in a fuzzy manner, as 'fuzziness' is inherent in human thinking, especially where people are asked to state a preference for one item over another (where one of them is a money metric), as opposed to making the actual choice itself. Stated preferences are different than revealed preferences, and it is the former that contingent valuation surveys address. Over and above the hypothetical nature of CVM, individuals may simply be unable to make a tradeoff between the amenity in question and a monetary value. Further, they may not understand the environmental quality change in question and the manner in which the questionnaire proposes that it would be achieved or paid for. Valuation in these circumstances can best be described as fuzzy.

Let X be a finite collection of alternatives and let $x,y \in X$. Traditionally, we define the preference relation as x weakly dominates y if $x \succeq y$, and x strongly dominates y if $x \succ y$. On the same set of alternatives X, the fuzzy preference relation $\tilde{R}(x,y)$ is defined as a fuzzy set, with membership function $\mu_{\tilde{R}}(x, y)$ representing the degree to which x is at least as good as y. It is clear that the crisp preference relation is the limit of the fuzzy preference relation where membership $\mu_{\tilde{R}}(x, y)$ can only take on values 0 (y strongly preferred to x) or 1 (x strongly preferred to y). A fuzzy preference relation that satisfies the following properties is called a fuzzy preference ordering:

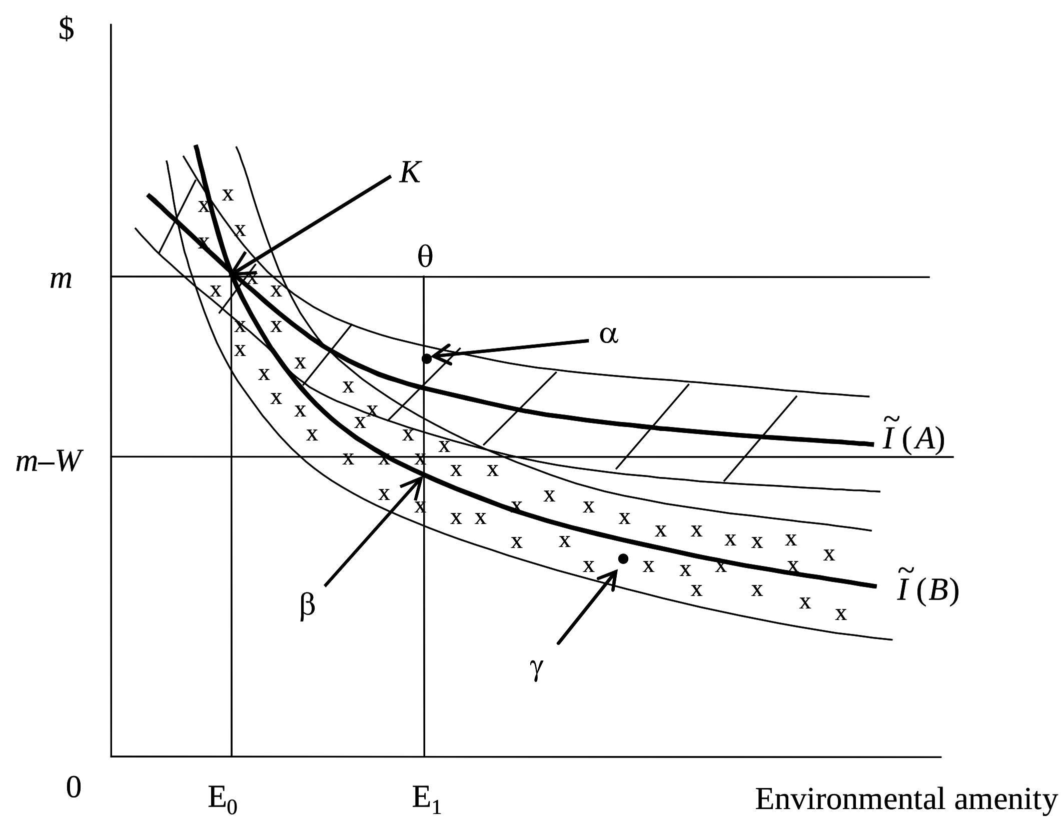
- Reflexivity: $\forall\, x \in X,\ \mu_{\tilde{R}}(x, x) = 1$.
- Connectedness (completeness): $\forall\, x,y \in X,\ \mu_{\tilde{R}}(x, y) + \mu_{\tilde{R}}(y, x) \geq 1$.
- Max-min transitivity: $\forall\, x,y,z \in X,\ \mu_{\tilde{R}}(x, z) \geq \min[\mu_{\tilde{R}}(x, y), \mu_{\tilde{R}}(y, z)]$.

Accordingly, the individual's utility function, indifference curve and compensating/ equivalent surplus are fuzzy as well.

A graphical illustration of a fuzzy indifference curve is provided in Figure 4.1. The figure is also used to illustrate fuzzy compensating surplus. Income and the amount of the environmental amenity are assumed to be well defined or crisp. Representative fuzzy indifference curves are provided in the figure for two individuals (*A* and *B*) faced with the opportunity of paying an amount *W* to increase the availability of an environmental amenity from E_0 to E_1, or remaining at the status quo level of the amenity

(E_0) at point *K*. Combinations of income and the environmental amenity located on the dark lines have memberships equal to 1.0 in the fuzzy indifference sets, $\tilde{I}(A)$ and $\tilde{I}(B)$. Points located off the dark lines but in the respective bounded areas have a degree of membership in the fuzzy indifference level that is less than 1.0 but greater than 0. For the respondent with fuzzy indifference curve $\tilde{I}(B)$, the new consumption set represented by β has a membership in $\tilde{I}(B)$ of 1.0, while $\mu_{\tilde{I}(B)}(\gamma) = 0.70$, say, and $\mu_{\tilde{I}(B)}(\alpha) = 0$. For the individual with fuzzy indifference curve $\tilde{I}(A)$, $\mu_{\tilde{I}(A)}(\alpha) = 0.30$, say.

Figure 4.1: Interpretation of dichotomous-choice answers with fuzzy utility



When a respondent's indifference curve is crisp (i.e., described only by the dark line), then *W* will be accepted ('yes' answer) when the indifference curve at E_1 is below the line *m*–*W*. This is the case for respondent *B*, who would be expected to answer 'yes' because her compensating surplus (=θβ) exceeds *W*, but not for respondent *A*, whose crisp compensating surplus is less than *W*. Figure 4.1 illustrates the potential problems in answering a dichotomous-choice question regarding the bid amount *W* when a respondent's indifference curve and hence compensating surplus *S* is also fuzzy. Respondent *A* will always reject the opportunity to pay *W* for more of the environmental amenity. For the environmental amenity level E_1, respondent *B*'s fuzzy indifference curve intersects the interval that contains the *m*–*W* value. Consequently, some points of the intersecting interval are below and others above the line *m*–*W*; thus, $0 < \mu_{\tilde{S}(W)}(\gamma) < 1$, where $\tilde{S}(W)$ is the fuzzy set "compensating surplus equals *W*". *B*'s response to a dichotomous-choice question is therefore subject to the individual's interpretation of the verbal description of the contingency, the vagueness of the tradeoff, and so on. These factors dictate her 'yes'/'no' response, with either answer consistent with her preferences. The RUM model based on crisp preferences (utility) may be misleading in these circumstances.

4.3 Empirical Model

4.3.1 Fuzzy c-Means Clustering and Takagi-Sugeno Fuzzy Inference

The fuzzy c-means clustering (FCMC) algorithm was proposed by Bezdek (1973) as an improvement over an earlier 'hard' c-means algorithm to classify inputs into *c* categories. In contrast to the crisp classifications of 'hard' c-means clustering, fuzzy c-means clustering allows each data point to belong to a cluster to a degree specified by a grade of membership and allows a single data point to be a member of more than one cluster.

The objective of the FCMC algorithm is to partition a collection of *n* data points x_k, k=1, …, *n*, into *c* fuzzy sets or clusters ($\tilde{A}_1$, …, $\tilde{A}_c$) in a way that best fits the structure of the data. Let $\mu_{\tilde{A}_i}(x_k)$ be the degree of membership of data point x_k in cluster $\tilde{A}_i$, where the sum of degrees of belonging for a data point always equal unity by imposing the following normalization:

(4.4) $$\sum_{i=1}^{c} \mu_{\tilde{A}_i}(x_k) = 1, \forall k = 1,...,n.$$

The objective function is then to minimize the criterion function:

(4.5) $$J_m(U,V;X) = \sum_{i=1}^{c}\sum_{k=1}^{n}\left(\mu_{\tilde{A}_i}(x_k)\right)^m \left\| v_i - x_k \right\|^2,$$

where $0 \leq \mu_{\tilde{A}_i}(x_k) \leq 1$ and *U* is the matrix of possible memberships; $v_i \in V$ is the cluster center of the fuzzy set *i* with *V* the vector of all cluster centers; $\left\| v_i - x_k \right\|$ is the Euclidean distance between the i^{th} cluster center and k^{th} data point; and $m \in [1,\infty)$ is a weighting exponent. There is no prescribed value for *m*, but it is common to choose *m*=2 (Giles and Draeseke 2003). In the case of crisp sets *m*=1.

Minimization of (5) subject to condition (4) yields two necessary first-order conditions that can be solved to give:

(4.6) $$\mu_{\tilde{A}_i}(x_k) = \frac{1}{\sum_{j=1}^{c}\left(\frac{\|v_i - x_k\|}{\|v_j - x_k\|}\right)^{2/(m-1)}}.$$

(4.7) $$v_i = \frac{\sum_{k=1}^{n}\left(\mu_{\tilde{A}_i}(x_k)\right)^m x_k}{\sum_{k=1}^{n}\left(\mu_{\tilde{A}_i}(x_k)\right)^m}.$$

The FCMC algorithm consists of iterations alternating between (6) and (7) that converges either to a local minimum or saddle point of J_m (Bezdek 1973). It involves the following steps (Giles and Draeseke 2003; Jang 1997):

1. Fix the number of clusters c, $2 \leq c \leq n$, and the threshold level ξ.

2. Initialize the cluster centers v_i.

3. Compute the membership matrix according to (4.6).

4. Update the cluster centers by calculating $\bar{v}_i$ according to equation (4.7).

5. Calculate the defect measure: $D=\left|\bar{v}_i - v_i\right|$.

6. Stop if D< ξ; otherwise, go to step 3.

7. Defuzzify the results by assigning every observation to that cluster for which it has maximum membership value – the 'home' cluster.

Next consider Takagi-Sugeno fuzzy inference. Suppose that we can classify inputs x into c fuzzy sets, $\tilde{A}_1$, …, $\tilde{A}_c$, with associated membership functions $\mu_{\tilde{A}_1(x)}$, …, $\mu_{\tilde{A}_c(x)}$. Suppose further that we can assign crisp functions to each of the clusters such that, if $x \in \tilde{A}_i$, then $y=f_i(x)$. Then, according to Takagi-Sugeno fuzzy inference, the combined effect is represented by (Takagi and Sugeno 1985):

(4.8) $$y = \frac{\sum_{i=1}^{c} \mu_{\tilde{A}_i}(x) f_i(x)}{\sum_{i=1}^{c} \mu_{\tilde{A}_i}(x)}.$$

The conjunction of the FCMC method with Takagi-Sugeno fuzzy inference enables construction of models in a flexible way. Giles and Draeseke (2003) employed this method to model econometric relationships. In their research, the sample observations for *x* were clustered into fuzzy sets using the FCMC algorithm such that the similarity within a set is larger than that among sets. Correspondingly it also defines an implicit partition of the data for output *y*. The relationship of interest is estimated over each set using the data for the set separately, and then with Takagi-Sugeno inference each sub-model is combined into a single overall model. We employ a similar approach in the empirical analysis to derive the Fuzzy Random Utility Maximization model.

4.3.2 Fuzzy Random Utility Maximization (FRUM) model

We proportion the sample observations into clusters based on information from the follow-up certainty confidence question using the fuzzy c-mean clustering method. That is, individuals with similar certainty confidence are grouped into one cluster, the 'home' cluster. These clusters have fuzzy boundaries because each observation can, at the same time, belong to other clusters to some degree smaller than their membership in the 'home' cluster.

The fuzzy random utility maximization model is based on Figure 4.1 in much the same way as the standard RUM model (Hanemann 1984). Individual *k*'s fuzzy utility function $\tilde{u}_k$ can be specified as a function of a fuzzy deterministic component $\tilde{w}_k$ and a crisp additive stochastic component ε_k :

(4.9) $\tilde{u}_k(z,m;s) = \tilde{w}_k(z,m;s) + \varepsilon_{z,k}$,

where $z \in \{0, 1\}$ is an indicator variable that takes on the value 1 if the individual accepts the proposed change in the amenity and 0 otherwise, m is income, s is a vector of the respondent attributes, and ε is the stochastic disturbance arising from uncertainty on the part of the observer.[28] Each individual's utility function is fuzzy in the sense that it belongs to every cluster to some degree. The probability of saying 'yes' for each observation is then:

$$\text{(4.10)} \quad \begin{aligned} \Pr_k(yes) &= \Pr\{\tilde{w}_k(1,m;s) + \varepsilon_{1k} > \tilde{w}_k(0,m;s) + \varepsilon_{0k}\} \\ &= \Pr\{(\varepsilon_{1k} - \varepsilon_{0k}) > -[\tilde{w}_k(1,m;s) - \tilde{w}_k(0,m;s)]\} \end{aligned}$$

Replacing $[\tilde{w}_k(1,m;s) - \tilde{w}_k(0,m;s)]/\sigma$ with $\Delta\tilde{w}_k$ and $(\varepsilon_{1k} - \varepsilon_{0k})/\sigma$ with ε_k, where $\varepsilon_k \sim$ N(0,1) is i.i.d. because ε_{1k} and ε_{0k} are i.i.d., yields the fuzzy probit model:

(4.11) $\Pr_k(yes) = \Pr(\varepsilon_k > -\Delta\tilde{w}_k) = F_\varepsilon(\Delta\tilde{w}_k)$

Assuming a linear utility function, the change in the 'deterministic' part of the utility function between the two states is then given as

(4.12) $\Delta\tilde{w}_k = \tilde{\alpha}_k + \tilde{\beta}_k M_k + \tilde{\gamma}_k^{/} s_k$,

which is estimated based on the information from each cluster. Once the sample observations are proportioned into c fuzzy clusters, we can use the data for each fuzzy

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[28] Notice that the error term ε addresses uncertainty on the part of the observer, while the fuzzy component (referred to as the deterministic component in standard RUM) deals with respondent or preference uncertainty.

cluster separately and specify each individual's utility at the 'home' cluster as:

(4.13) $u_{ij} = w_{ij} + \varepsilon_{ij}$; $j = 1, \ldots, n_i$; $i = 1, \ldots, c$.

Note that an individual's utility is fuzzy since it is estimated from the coefficient estimates for each cluster, as in equation (4.15) below, but the utility is assumed to be crisp within each cluster so that it is possible to employ a standard probability framework within each cluster. A linear specification of the indirect utility function can be assumed (as in RUM) and the change in the deterministic parts of the utility functions between the two states is then given as:

$$(4.14) \quad w_{ij} = \alpha_i + \beta_i M_{ij} + \gamma_i^{/} s_{ij} + \varepsilon_{ij} ,$$

where M_{ij} is the bid, s_{ij} is a vector of observable attributes, ε_{ij} is a random component, and α, β and vector γ constitute parameters to be estimated. A standard probit (or logit) model can be estimated within each cluster. Using Takagi-Sugeno inference (8), the fuzzy indirect utility is then:

$$(4.15) \quad \Delta\tilde{w}_k = \tilde{\alpha}_k + \tilde{\beta}_k M_k + \tilde{\gamma}_k^{/} s_k = \frac{\sum_{i=1}^{c} \alpha_i \mu_{\tilde{A}_i}(x_k)}{\sum_{i=1}^{c} \mu_{\tilde{A}_i}(x_k)} + \frac{\sum_{i=1}^{c} \beta_i \mu_{\tilde{A}_i}(x_k)}{\sum_{i=1}^{c} \mu_{\tilde{A}_i}(x_k)} M_k + \frac{\sum_{i=1}^{c} \gamma_i^{/} \mu_{\tilde{A}_i}(x_k)}{\sum_{i=1}^{c} \mu_{\tilde{A}_i}(x_k)} s_k ,$$

where $k = 1, \ldots, n$. And probability of saying 'yes' for each observation can be rewritten as:

$$(4.16) \quad \Pr_k(yes) = F_\varepsilon(\tilde{\alpha}_k + \tilde{\beta}_k M_k + \tilde{\gamma}_k^{/} s_k) = F_\varepsilon\left[\frac{\sum_{i=1}^{c} (\alpha_i + \beta_i M_k + \gamma_i^{/} s_k) \mu_{\tilde{A}_i}(x_k)}{\sum_{i=1}^{c} \mu_{\tilde{A}_i}(x_k)}\right],$$

where k = 1, …, n and F(.) is the cumulative distribution function of the stochastic term.

The median WTP of each individual based on FRUM is then given as:

$$(4.17)\quad WTP_k = \frac{(-\tilde{\alpha}_i - \tilde{\gamma}_i^{/} s_k)}{\tilde{\beta}_i} = \frac{-\sum_{i=1}^{c} \alpha_i \mu_{\tilde{A}_i}(x_k) - \sum_{i=1}^{c} \gamma_i^{/} \mu_{\tilde{A}_i}(x_k) s_k}{\sum_{i=1}^{c} \beta_i \mu_{\tilde{A}_i}(x_k)},\ k = 1, \ldots, n.$$

That is, based on the FRUM model, the predicted probability or median WTP is a certain form of weighted average information for the fuzzy clusters, with the weights varying continuously throughout the sample. This is different from the traditional RUM model, where the predicted probability or median WTP is derived from a homogeneous model with an underlying assumption that utility is crisp.

4.4 Empirical Results

We apply the FRUM model to two contingent valuation surveys: a survey of Swedish residents by Li and Mattsson (1995) that elicited willingness to pay to conserve forests and a survey of western Canadian landowners that elicited willingness to accept compensation for a tree planting program.

4.4.1 Survey of Swedish residents

We first apply the FRUM model to a survey of Swedish residents that asked respondents whether they would be willing to pay a stated amount to continue to visit, use and experience the forest environment found in the northern part of the country (Li and Mattsson 1995). Bid amounts took one of the following values: 50, 100, 200, 700, 1000, 2000, 4000, 8000 and 16,000 SEK. A follow-up question asked how certain the respondent was about her ‘yes’/‘no’ answer on a percent scale with 5% intervals. Some

14% of the ‘yes’ respondents and 11% of the ‘no’ respondents reported confidence levels below 50%. Only about 35% of the ‘yes’ and 16% of the ‘no’ respondents had complete confidence in their response to the valuation question. The survey also collected data on respondents’ age, gender, number of forest visits, education, and household income. The sample is identical to that of L&M and consists of 344 observations.

The results of assuming two to five fuzzy clusters are summarized in Tables 4.1 through 4.4, respectively[29]. As in L&M, the regressors include respondents’ average annual forest visits, education, household income and the interaction of income and education. From the tables, we see that the sub-model estimates based on the separate fuzzy clusters can differ fundamentally. In Table 4.5, we compare the four fuzzy models with a traditional RUM model that assumes respondent certainty (i.e., ignores the follow-up question) and with L&M’s approach for incorporating the follow-up uncertainty responses. Approaches that include information about respondent uncertainty perform better than the RUM model that ignores such uncertainty. The fuzzy models with three and five clusters outperform the other models based on the percentage of correct predictions (76.4% and 77.0%, respectively), while the fuzzy model with five clusters also has the lowest root mean square error and mean absolute error. The fuzzy model fits the data better than the traditional RUM model and the approach of L&M. The membership functions for fuzzy regressions with various clusters are plotted in Figures 4.2 through 4.5.

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[29] We treat the number of clusters as exogenously determined here. Formal tests can be undertaken to determine the “optimal” number of clusters, which is beyond the scope of this research. Feng (2006) proposed the use of Bayesian Posterior Odds to determine the number of fuzzy clusters to be used in the fuzzy regression analysis.

Table 4.1: Fuzzy Regression Results for Swedish Forest Protection Survey (c=2; m=2)[a,b]

Fuzzy cluster	Obs (# yes)	Cluster center	β_0	β_1	β_2	β_3	β_4	β_5	# of correct predictions (%)
1	90	41.321	-1.637	-0.000	-0.000	0.227	0.006	-0.001	55
	(48)		(-1.24)	(-0.66)	(-0.86)	(1.91)	(0.76)	(-1.24)	(61.1%)
2	254	91.714	-2.672	-0.000	0.003	0.239	0.015	-0.001	202
	(132)		(-3.28)	(-6.89)	(2.68)	(0.07)	(3.18)	(-3.04)	(79.5%)

[a] The t-statistics associated with the estimated β s are provided in parentheses.
[b] β s are coefficients for constant, average annual forest visits, education, household income and the interaction of income and education respectively.

Table 4.2: Fuzzy Regression Results for Swedish Forest Protection Survey (c=3; m=2)[a,b]

Fuzzy cluster	Obs (# yes)	Cluster center	β_0	β_1	β_2	β_3	β_4	β_5	# of correct predictions (%)
1	36	20.655	-0.788	0.000	-0.002	0.113	0.006	-0.001	24
	(21)		(-0.31)	(1.22)	(-0.92)	(0.56)	(0.37)	(-0.52)	(66.7%)
2	81	60.628	-1.178	-0.000	0.001	0.155	0.004	-0.001	50
	(38)		(-0.87)	(-3.14)	(0.53)	(1.25)	(0.60)	(-0.78)	(64.2%)
3	227	94.189	-2.674	-0.000	0.003	0.249	0.015	-0.001	185
	(121)		(-3.15)	(-6.67)	(2.67)	(3.42)	(2.96)	(-2.93)	(81.5%)

[a] The t-statistics associated with the estimated β s are provided in parentheses.
[b] β s are coefficients for constant, average annual forest visits, education, household income and the interaction of income and education respectively.

Table 4.3: Fuzzy Regression Results for Swedish Forest Protection Survey (c=4; m=2)[a,b]

Fuzzy cluster	Obs (# yes)	Cluster center	β_0	β_1	β_2	β_3	β_4	β_5	# of correct predictions (%)
1	26	16.328	0.450	0.000	-0.003	-0.010	-0.004	-0.000	17
	(15)		(0.16)	(0.97)	(-1.15)	(-0.04)	(-0.20)	(0.23)	(65.39%)
2	55	50.702	-2.361	-0.000	-0.001	0.352	0.014	-0.002	38
	(30)		(-1.25)	(-1.92)	(-0.54)	(1.83)	(1.33)	(-1.67)	(69.09%)
3	83	77.851	-2.702	-0.000	0.001	0.251	0.010	-0.001	58
	(38)		(-1.50)	(-3.34)	(0.39)	(1.78)	(1.07)	(-1.20)	(69.88%)
4	180	96.406	-3.009	-0.000	0.005	0.246	0.017	-0.001	149
	(97)		(-3.19)	(-6.37)	(3.472)	(3.014)	(2.937)	(-2.67)	(82.78%)

[a] The t-statistics associated with the estimated β s are provided in parentheses.
[b] β s are coefficients for constant, average annual forest visits, education, household income and the interaction of income and education respectively.

Table 4.4: Fuzzy Regression Results for Swedish Forest Protection Survey (c=5; m=2)[a,b]

Fuzzy cluster	Obs (# yes)	Cluster center	β_0	β_1	β_2	β_3	β_4	β_5	# of correct predictions (%)
1	26	14.960	0.450	0.000	-0.003	-0.010	-0.004	0.000	17
	(15)		(0.16)	(0.97)	(-1.15)	(-0.04)	(-0.20)	(0.23)	(65.39%)
2	43	46.791	-3.102	-0.000	-0.003	0.406	0.018	-0.002	28
	(24)		(-1.48)	(-1.00)	(-0.85)	(1.94)	(1.51)	(-1.74)	(65.12%)
3	35	65.470	-1.675	-0.000	0.005	0.168	0.005	-0.001	24
	(15)		(-0.57)	(-1.43)	(1.62)	(0.62)	(0.30)	(-0.52)	(68.57%)
4	60	82.290	-2.102	-0.000	-0.002	0.238	0.011	-0.001	44
	(29)		(-0.98)	(-2.77)	(-0.78)	(1.45)	(0.94)	(-1.06)	(73.33%)
5	180	97.023	-3.009	-0.000	0.005	0.246	0.017	-0.001	149
	(97)		(-3.19)	(-6.37)	(3.47)	(3.01)	(2.98)	(-2.67)	(82.78%)

[a] The t-statistics associated with the estimated β s are provided in parentheses.
[b] β s are coefficients for constant, average annual forest visits, education, household income and the interaction of income and education respectively.

Table 4.5: Comparing Model Performance for Swedish Forest Protection Survey[a]

Method of comparison	Standard RUM[a]	Fuzzy (c=2)	Fuzzy (c=3)	Fuzzy (c=4)	Fuzzy (c=5)	L&M's method
%RMSE	0.430	0.409	0.403	0.397	0.393	0.429
%MAE	0.373	0.340	0.336	0.325	0.321	0.355
# of correct predictions	253	254	263	260	265	255
(% correct)	(73.6%)	(73.8%)	(76.4%)	(75.6%)	(77.0%)	(74.1 %)
Mean WTP (SEK)	3899.01	3674.8	2987.2	3837.8	3176.4	3643.10

[a] Assuming crisp utility functions or certainty on the part of respondents, and estimated as a probit model.

Figure 4.2: Membership Functions for Fuzzy Regression (c=2; m=2)

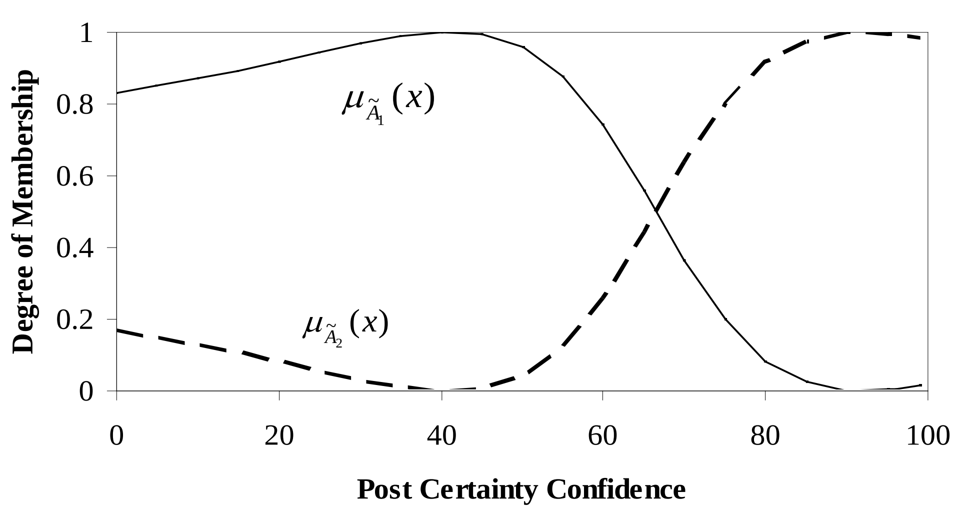


Figure 4.3: Membership Functions for Fuzzy Regression (c=3; m=2)

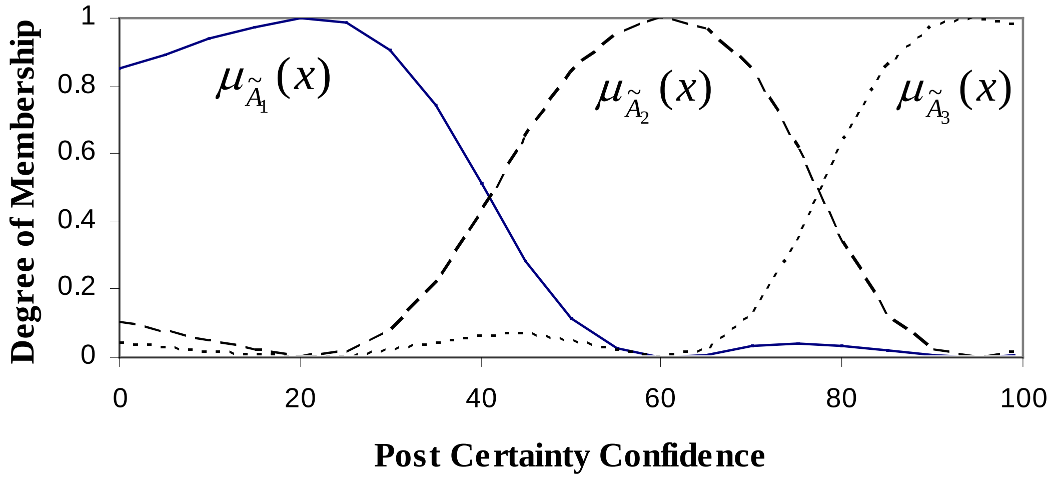


Figure 4.4: Membership Functions for Fuzzy Regression (c=4; m=2)

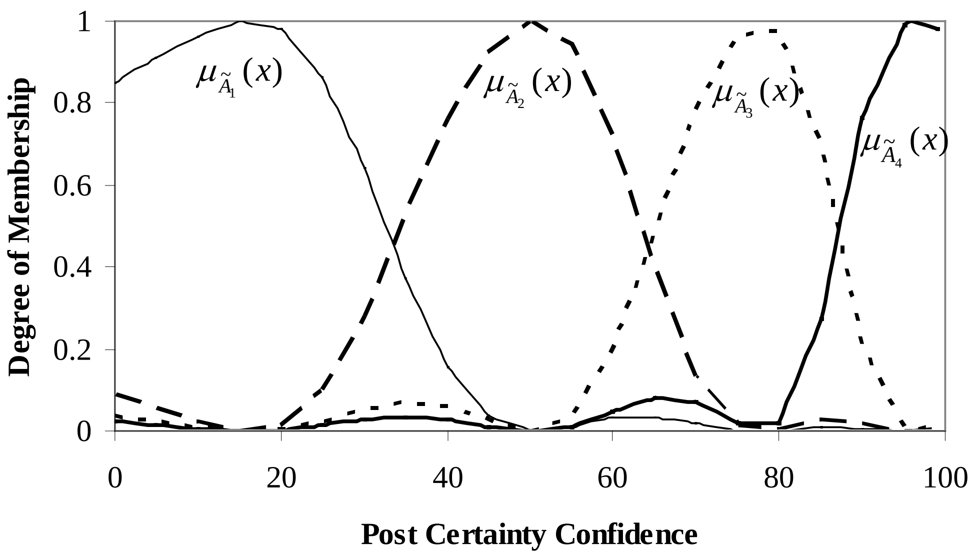
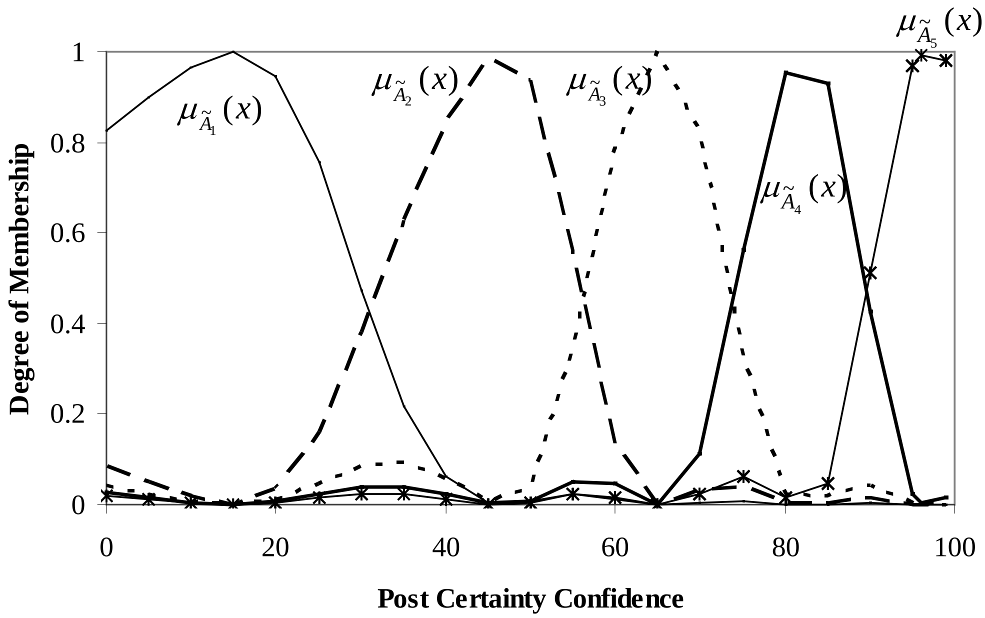


Figure 4.5: Membership Functions for Fuzzy Regression (c=5; m=2)



The derived sample means of the median WTPs from each model are also provided in Table 4.5. The sample mean of median WTPs using the L&M approach is SEK 3643, which differs significantly from L&M's original estimate of SEK 12,817 (based on overall mean) or SEK 8578 (using truncated mean). There are several reasons for this difference, but the most important is that L&M used mean WTP as a measure of welfare instead of median WTP. Further, they assumed a log-linear valuation function, while we use a linear specification of the indirect utility function. We employ the 'corrected' L&M measures for comparison purposes, rather than the original L&M estimates.

From Table 4.5, the sample mean of median WTPs for the fuzzy models range from SEK 1537 to SEK 3838, which is similar to the estimates provided by van Kooten, Krcmar and Bulte (2001). Of the fuzzy models, the one with five clusters performed 'best', and it provides an estimate of WTP of SEK 3176, which is lower than the estimate of SEK 3643 derived using L&M's method. It is also substantially lower than the estimate of SEK 3899 that one obtains from the certainty model. These results indicate that WTP estimates are lower if preference uncertainty is taken into account and, further, that the method used to take into account preference uncertainty matters.

4.4.2 Survey of Western Canadian Landowners

As a second application of the FRUM methodology, we employ WTA responses to a proposed tree planting program for grain and livestock producers in western Canada using the results from a survey of landowners in Manitoba, Saskatchewan, Alberta and northeastern British Columbia conducted in 2000. The landowner survey included a brief, personalized cover letter explaining the purpose of the questionnaire and a definition of carbon credits. In addition to willingness to accept compensation for tree planting, the survey also elicited detailed information on farmers' agricultural operations including activities on marginal fields, their opinions about and awareness of climate change issues and carbon credits, and personal characteristics. Initial questions were meant to reduce information biases by familiarizing respondents with the topic and issues under investigation before asking them about their willingness to plant trees. Only 122 observations are available for the current analysis. Compensation offered, brown soil zone, forest landscape visually unappealing, acres of farmland covered with trees, age are selected as the explanatory variables. More information on the survey design and descriptive variables can be found in Chapter 2.

In the survey, landowners were presented a hypothetical 10-year contract to plant trees on their most marginal land. The contract would pay up-front planting costs and provide an annual payment to compensate for lost agricultural production. The contingent contract indicated that farmers had no right to harvest the trees before the contract expired, but trees became their property at the end of the contract period. No compensation was provided for conversion of land back to agriculture; instead, it was explicitly noted in the survey that a market for selling carbon credits might have developed by that time or landowners could simply sell the trees thereby covering the cost of converting land back to agriculture if necessary. In the absence of *a priori* valuation information, the compensation offers were selected on the basis of results from a pilot study, and ranged from $1 to $60 per acre per year.[30] The distribution of these bids is skewed towards the lower end of the range in order to provide more efficient estimates of WTA (Cooper 1993). In a follow-up to the dichotomous-choice valuation question, the respondent was asked to rate the certainty of their response on a scale of '1' for not certain to '10' for very certain (see the Appendix to Chapter 3).

In contrast to the Swedish data, we estimate fuzzy models with only two and three clusters to ensure each cluster has a sufficient number of observations. The results are summarized in Tables 4.6 and 4.7, and Figures 4.6 and 4.7. These are further compared with the traditional RUM model and Li and Mattsson's method in Table 4.8. The two fuzzy models outperform both the standard RUM and Li and Mattsson's uncertainty corrected RUM models based on the proportion of correct predictions, root mean squared error and mean absolute error. The sample mean of the median WTA compensation for each model is also summarized in Table 4.8, and it ranges from C$18.19 to C$34.45 per acre with the value for the fuzzy model with three clusters (the 'best' performing model)

[30] Recall that the survey expressly asked respondents to identify their most marginal lands for a potential tree planting program.

surprisingly low and equal to only $18.19 per acre. If this value had been used in the analysis of Chapter 2, tree planting is a more attractive alternative to emissions reduction than indicated there.

Table 4.6: Fuzzy Regression Results of Western Canadian Landowners Survey (c=2; m=2)[a]

Fuzzy cluster	Obs (# yes)	Cluster center	β_0	β_1	β_2	β_3	β_4	β_5	# of correct predict (%)
1	51 (27)	3.967	-1.037 (-0.750)	-0.024 (1.980)	0.005 (1.368)	-0.476 (-2.300)	1.596 (2.591)	0.017 (0.765)	38 (74.51%)
2	71 (24)	9.493	-10.107 (-3.923)	0.109 (3.847)	0.015 (2.627)	0.084 (0.265)	0.399 (0.567)	0.103 (3.216)	63 (88.73%)

[a] The t-statistics associated with the estimated β s are provided in parentheses.

Table 4.7: Fuzzy Regression Results of Western Canadian Landowners Survey (c=3; m=2)[a,b]

Fuzzy cluster	Obs (# yes)	Cluster center	β_0	β_1	β_2	β_3	β_4	β_5	# of correct predict (%)
1	17 (12)	2.067	-5.309 (-0.906)	0.028 (0.801)	0.094 (1.378)	-0.181 (-0.179)	6.159 (0.153)	0.069 (1.057)	14 (82.35%)
2	39 (18)	5.499	-0.586 (-0.352)	0.035 (2.300)	0.005 (1.576)	-0.540 (-2.193)	1.034 (1.405)	0.006 (0.219)	30 (76.92%)
3	66 (21)	9.724	-10.196 (-3.775)	0.110 (3.642)	0.017 (2.755)	0.010 (0.030)	0.540 (0.762)	0.103 (3.070)	59 (89.39%)

[a] The t-statistics associated with the estimated β s are provided in parentheses.
[b] β s are coefficients for constant, compensation offered, brown soil zone, forest landscape visually unappealing, acres of farmland covered with trees and age respectively.

Table 4.8: Comparative Model Performances of Western Canadian Landowners Survey

Method of comparison	Standard RUM	Fuzzy (c=2)	Fuzzy (c=3)	L&M's method
%RMSE	0.400	0.354	0.332	0.406
%MAE	0.315	0.249	0.222	0.302
# of correct predictions (% correct)	94 (77.05%)	100 (81.97%)	102 (83.61%)	94 (77.05 %)
Mean WTA (C$)	32.83	29.58	18.19	34.45

Figure 4.6: Membership Functions for Fuzzy Regression (c=2; m=2)

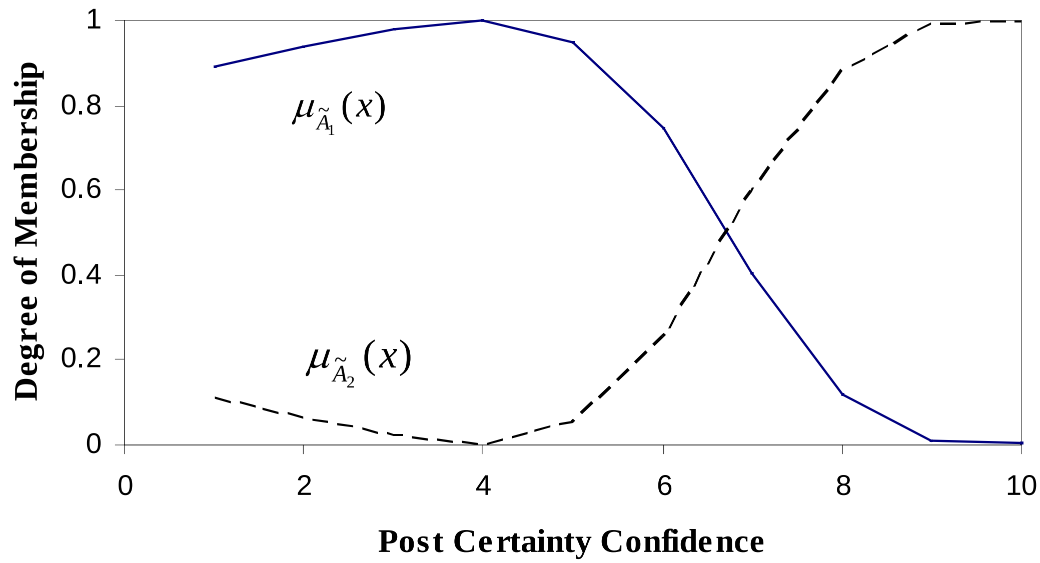
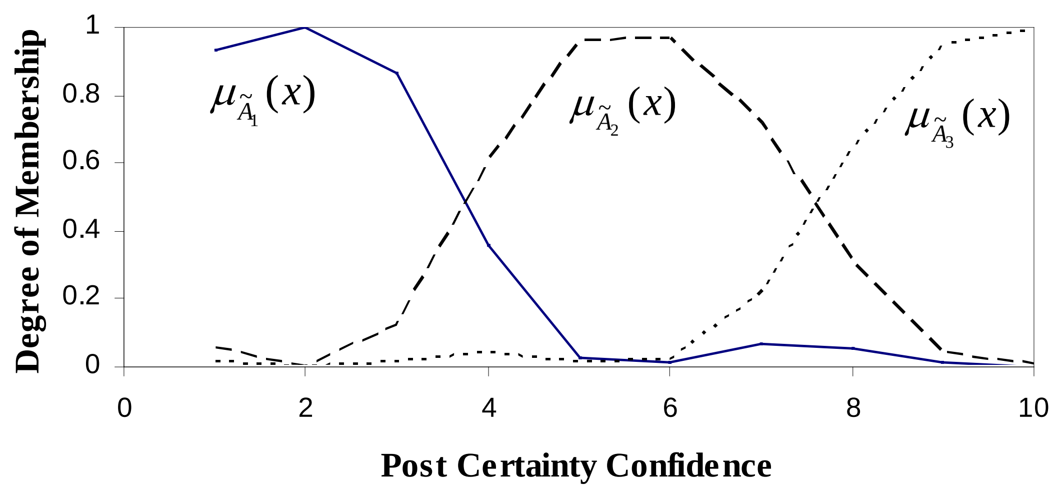


Figure 4.7: Membership Functions for Fuzzy Regression (c=3; m=2)



4.5 Discussion

Welfare measures based on revealed preferences entail little in the way of a methodological problem for economists (even though their estimation may be difficult), but analysts measuring the welfare of public goods on the basis of stated preferences are likely to encounter preference uncertainty. In the literature, such uncertainty was recognized in the framework of random utility maximization – the use of a dichotomous-choice rather than an open-ended format for the valuation question (Hanemann and Kriström 1995). However, the RUM model considers only uncertainty on the part of the observer, not the respondent. There have been attempts to incorporate respondent uncertainty into the RUM framework, but these have, for the most part, been ad hoc (e.g., Alberini, Boyle and Welsh 2003; Ready, Navrud and Dubourg 2001). In this study, an alternative approach was brought to bear on the issue, namely, one rooted in fuzzy logic that interprets uncertainty in contingent valuation in a fundamentally different way than the standard framework. By assuming that a respondent's utility is vague and can be represented by a fuzzy number in utility space, the fuzzy random utility maximization method addresses both imprecision about what is to be valued and uncertainty about values that are actually measured.

While this paper represents one of the earliest efforts to apply fuzzy set theory to non-market valuation, it is clear that much research remains to be done. For example, it is necessary to examine whether a fuzzy interpretation of utility can shed light on the persistent differences between WTP and WTA that are observed in experimental markets and contingent valuation surveys (Horowtiz and McConnell 2002). Further, the application of fuzzy set theory to non-market valuation would seem especially appropriate given that the valuation of environmental amenities and public goods is likely best done using verbal language, as noted by Evans, Flores and Boyle (2003), and fuzzy set theory is best suited to quantitative analysis of language. Yet, no contingent valuation studies have attempted to employ only language in the assessment of the tradeoff between the environment and a money metric.

4.6 References

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Chapter 5

Divergence between WTA and WTP Revisited: Livestock Grazing on Public Range[31]

5.1 Introduction

When people are asked to value changes in the availability of a public or environmental good, willingness to accept compensation (hereafter WTA) generally exceeds willingness to pay (WTP), often by a substantial amount. Hanemann (1991), building on earlier work by Randall and Stoll (1980), demonstrates that divergence between WTA and WTP is to be expected for many environmental goods. Specifically, public goods that have few if any private goods that are ready substitutes, which may be the case for environmental goods, are likely to have WTA valuations in excess of WTP valuations.[32]

Alternatively, evidence from contingent valuation surveys and experimental markets suggests that individuals become attached to a particular endowment, requiring a higher level of compensation to part with something than they would pay to obtain it

[31] This chapter is based on the paper "The Divergence between WTA and WTP Revisited: Livestock Grazing on Public Range", with G.C. van Kooten and G.M. Voss.

[32] Divergence in the welfare measures is also positively related to the income elasticity of demand for the good in question, though Hanemann argues the substitute effects are likely to be more important. More generally, the income effect is usually regarded to be insufficient to explain the observed divergences in valuations; see Hanemann (1991) and references cited therein.

(Knetsch 1995). The problem is not on the supply side (availability of substitutes), but lies with preferences. Indifference curves are somehow kinked (and not continuously differentiable) at the endowment. Thus, the observed difference between WTP and WTA remains, even for market goods where there are adequate substitutes, such as mugs and candy bars.[33]

Whatever the explanation, the disparity between the two valuation measures is well established theoretically and empirically, with the empirical evidence nicely summarized in Horowitz and McConnell (2002). The objective of this paper is to examine this disparity in further detail in the context of a recent survey of Nevada ranchers that concerned access to grazing on public lands. The survey elicits both a willingness to pay and a willingness to accept valuation for public forage; in addition it provides a rich set of information about ranch characteristics. The dual nature of the survey, both WTP and WTA, and the extensive information set on ranch characteristics allows us to examine the disparity between welfare measures in a systematic manner. We

[33] Empirical support for the endowment effect is presented in Kahneman, Knetsch and Thaler (1990) and Knetsch, Tang and Thaler (2001). Shogren et al. (1994) and List (2003, 2004) present evidence against the endowment effect; Shogren et al. use experimental data to demonstrate that, for goods for which substitutes are plentiful, WTP and WTA converge with repeated market participation, but for goods with few substitutes (such as food purchases where health risks are involved) repeated participation did not result in convergence; List finds that the endowment effect is prevalent among inexperienced traders, but not among experienced ones (in his case, trading sport memorabilia). Whether these results convincingly refute endowment effects is a matter of some debate; see Knetsch, Tang and Thaler (2001) and Donkers, Gregory and Knetsch (2004).

use a bivariate dichotomous choice framework to model the willingness to pay and accept decisions simultaneously, similar to Poe, Welsh and Champ (1997). This framework allows us to test directly the difference in welfare measures. It also allows us to examine which of the ranch characteristics contribute to the observed differences in welfare measures, providing some information about the importance of close substitutes and endowment effects. To our knowledge, this has not been done previously and is the principal contribution of the paper.

To foreshadow our principal results, we find a significant disparity between willingness to accept and willingness to pay valuations. The discrepancy between valuations is similar to previous studies, with WTA ranging from 2-12 times as large as WTP. We find a number of ranch characteristics associated with this discrepancy: (1) the size of the ranch, which we conjecture may relate to available substitutes for public grazing; (2) the size of allocation of public grazing, which is surprisingly inversely related to the discrepancy in valuations; (3) financial distress; and (4) long term commitment to ranching, either as an occupation or lifestyle. Each of these results bears on public grazing policy, providing insights into ranchers' valuation, as well as some information about the relative importance of substitution effects and endowment effects.

The remainder of the paper is organized as follows. In the next section, we provide a brief background to the issue of livestock grazing on public lands, and we provide a brief description of the 2002 Nevada Ranch Survey. The theoretical model is provided in section 3, while the WTA and WTP estimation results are provided in section 4. We conclude in section 5 with a discussion of policy implications and considerations for further research.

5.2 Grazing on Public Range and the Nevada Ranch Survey

Although open access grazing ended on some public lands around 1900, it was not until the Taylor Grazing Act of 1934 that it was halted on all public lands in the United States. Over the three decades that followed, administration of grazing on public lands evolved into a system characterized by grazing districts and allotments, limits on herd size (effectively limiting the size of ranches), and fees for public forage using the animal unit month (AUM) measure.[34] While grazing fees differed on U.S. Forest Service and Bureau of Land Management (BLM) lands until 1981, the 1978 Public Rangelands Improvement Act established that all grazing fees would be calculated as a base fee of $1.23 per AUM (established in 1966 using a cost of production approach) that was adjusted using indexes of private grazing values, livestock market prices and rancher operating costs, but with the proviso that the fee not decline below $1.35 per AUM.[35]

The grazing fee reached a high of $2.36 per AUM in 1980 falling to $1.35 in 1985, never again to exceed $2 per AUM; the grazing fee was $1.43 in 2002, falling back to $1.35 in 2003 where it had been for most of the previous decade. This despite the fact that cattle have generally increased in size and private alternatives for grazing averaged $11 per AUM in 1997 (Diez and Rothenberg 2000). In Oregon, private grazing was valued at an average of $9.23 per AUM in 2004, and an average $8.83 per AUM in the two most southeasterly counties in the State, Malheur ($2.53 per AUM) and Harney

[34] An AUM is the amount of forage needed to support one cow and calf, one horse or five sheep for a period of one month.

[35] See Torell et al. (2001) and Dietz and Rothenberg (2000).

($12.43 per AUM) counties, which border Nevada.[36] In 2003, while the BLM grazing fee was set at $1.35, the respective fees charged on state-owned lands in Oregon, Idaho and Washington were $4.16, $5.33 and $7.52 per AUM.[37]

Although rates of return to livestock production average no more than 2 percent while the return to private grazing lands is estimated to average 3.4 percent (Bartlett et al. 2002), grazing permits that give ranchers perpetual rights to graze cattle on public land have positive value.[38] In theory, the value of a grazing permit is equal to the difference between the marginal value of public forage minus the grazing fee appropriately discounted, where the discount rate takes into account the possibility of losing the right to graze livestock at some future time (Gardner 1962, 1963). Grazing permits are generally not traded, although they do get capitalized in ranch values, so it is difficult to determine their true value. However, research by Borges and Knetsch (1998) does suggest one

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[36] U.S. Department of Agriculture data for 2004 reported by Barry Adam and viewed 1 June 2004 at www.oregonstatelands.us/rangeland_audit_response.pdf. The disparity between costs of private forage in these counties is surprising. Data for Lake County (the county to the immediate west of Harney) were not available for reasons of confidentiality.

[37] Same source as in previous note.

[38] Grazing permits are considered a privilege and not a right. On May 15, 2000, the U.S. Supreme Court ruled in a unanimous decision that the appeal by the Public Lands Council et al. in opposition to Bruce Babbitt, Secretary of the Interior et al. and the Range Reform Regulations of 1995, has no legal basis. The Court rejected all the arguments that ranchers on public lands have a vested grazing right. See w3.trib.com/~phxcon/supcourtgraz1.html. Politicians have, however, acted as if the permits are a right.

reason why little trading of grazing permits occurs, namely, that those holding permits value them more highly than those wanting to buy them.

Range economists argue that private and public grazing values are not directly comparable, because operating costs are higher on public lands and private landowners provide services (not available from federal land agencies) that account for at least 30 percent of private value (Bartlett et al. 2002 p.429, Gardner 1962 p.53). Suppose private grazing sells for \$9.23/AUM (the average for Oregon), while the BLM charges \$1.35 per AUM. Then the benefit from public forage is \$5.11 per AUM (=0.7×\$9.23–\$1.35) and, using the perpetual bond formula (bond value = annual payment ÷ r, where r is the discount rate), a grazing permit would be worth about \$128 per AUM if a discount rate of 4% is used (≈\$5.11/0.04) and \$255 if a rate of 2% is used.

Ranchers' use of public lands has increasingly come under pressure from environmental groups that see livestock grazing as a contributing factor to the environmental degradation of public lands, and particularly loss of wildlife habitat. The public land agencies have reacted primarily by reducing grazing services. In Nevada, for example, AUMs of grazing have fallen by 32.7% (or some 540,000 AUMs) between 1981 and 2002, threatening the viability of some ranchers dependant upon public forage. To address the external impacts of livestock grazing on public lands while making reductions in AUMs politically palatable, Congress has recently begun to consider purchasing ranchers' grazing permits. Section 5(a) of the Voluntary Grazing Permit Buyout Act (Bill HR 3324 IH) introduced into the Congress on 16 October 2003 (108th Congress, 1st Session), for example, would have compensated ranchers \$175 per AUM, an amount well within the range calculated above.

Sale of grazing permits implies irrevocable loss of access to the public range and, in most cases, loss of a particular lifestyle. Range economists argue that, because rates of return to livestock production average no more than 2%, grazing permits have value only because they provide the owner with a quality of life benefit (Bartlett et al. 2002). That is, there is no evidence that public land ranchers are subsidized and make an inflated rate of return because of low grazing fees (Torell et al. 2001 p.6), so the value of grazing permits is equivalent to the value placed on the ranching lifestyle. Even if this is true, simple neoclassical theory indicates that ranchers should be WTP as much to purchase public forage in a world where available AUMs are declining as they would be WTA to forgo public forage forever – they should be willing to pay as much to keep the lifestyle as they would be willing to accept to forgo it.

To investigate the relationship between these welfare measures, we use the 2002 Nevada Ranch Survey, which elicited WTA and WTP responses for public grazing. It also included questions dealing with the ranch operation, community activities, experience with fire, investments in range improvements, attitudes toward the public land agencies and the future of public land-based ranching, income, education, and so on. The context of the survey was the reduction in AUMs of public grazing to protect environmental amenities (noted above). Ranchers were asked about their WTP for access to public forage and their WTA compensation for sale of grazing privileges. These questions were embedded in the survey and required a ‘yes’/‘no’ response to a proposed ‘bid’; the questions are provided in the Appendix. There were 244 usable surveys after taking into account non-respondents and those who did not complete some parts of the survey needed for the current analysis. More information on the survey design, response rates and descriptive variables can be found in Thomsen (2002) and van Kooten et al. (2005).

5.3 Empirical Model

Ranchers are asked both a willingness to pay and a willingness to accept question in the same survey. As the responses are likely related, we use a systems based approach to estimation, similar to that used by Poe, Welsh and Champ (1997) and Cameron and Quiggin (1994). Our objective is to test whether there is a divergence between WTA and WTP and to determine the factors explaining the divergence, if any.

The *i*th rancher is given randomly determined posted prices for access to grazing rights on public land. In the first instance, the question is structured in terms of willingness to accept a one time payment per AUM for loss of access to public grazing rights. The posted price is denoted p_{1i} and rancher either indicates they accept the price, y_{1i}=1, or they reject the price, y_{1i}=0. The next posted price is structured in terms of willingness to pay per AUM for access to public grazing rights.[39] The posted price is denoted p_{2i} and the rancher either indicates they are willing to accept the price, y_{2i}=1, or they reject the price, y_{2i}=0. In addition to the questions concerning willingness to accept and to pay posted offers, the survey asks a number of questions about ranchers' individual characteristics; these covariates are denoted $\mathbf{x}_i$.

Notice that the nature of the questions asked mean that the WTP and WTA questions are not eliciting immediately comparable information. The WTP is in terms of

[39] Although not explicit in the survey question (see appendix to this chapter), the context is clearly that of an annual payment for one month worth of public forage —A quantity measure.

an annual payment while the WTA is in terms of a current valued one off payment. This requires some adjustment for the different time-value, a point we return to below.

To model individual decisions in our survey, we use the random utility framework for discrete response models discussed in Hanemann (1984). Each rancher *i* is assumed to have some true unobservable surplus value v_{ji} for each scenario presented in the survey. Here as above, $j = 1$ refers to the willingness to accept scenario while $j = 2$ refers to the willingness to pay scenario. The surplus in each case is assumed to depend linearly upon a vector of observable attributes $\mathbf{x}_i$, the relevant posted prices p_{ji}, and a random component ε_{ji}:

(5.1) $$v_{ji} = \beta_j' \mathbf{x}_i + \gamma_j p_{ji} + \varepsilon_{ji}.$$

The errors are assumed to be jointly standard normal with covariance (equivalently correlation) ρ; further, the errors are independent of $\mathbf{x}_i$.[40] The covariates are assumed to be common across both surplus measures though we do allow for differing slope coefficients. To fix ideas, we expect that as offers to forgo public grazing increase, p_{1i} rises, the surplus to rancher *i* will increase, so $\gamma_1 > 0$. Similarly, as suggested payments for public grazing increase, p_{2i} rises, the surplus to rancher *i* will decrease, so $\gamma_2 < 0$.

To estimate the model, we proceed as follows. Denote the bivariate standard normal cumulative density function as $\Phi_2(z_1, z_2; \rho)$. Let $z_{ji} = \beta_j' \mathbf{x}_i + \gamma_j p_{ji}$, for $j = 1, 2$. Then the following describes the possible outcomes associated with our model; consider

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[40] The assumption of normality for the error terms allows for straightforward estimation; the common alternative, the logistic distribution, is not suitable for these purposes, see Cameron and Quiggin (1994). The unit variance is a simplifying assumption that does not affect our analysis.

first the case of both the WTP and WTA offered being accepted by individual *i*:

(5.2) $$\text{Prob}(Y_1 = 1, Y_2 = 1|\, \mathbf{x}_i) = \text{Prob}(z_{1i} + \varepsilon_{1i} \geq 0, z_{2i} + \varepsilon_{2i} \geq 0|\, \mathbf{x}_i)$$

$$= \text{Prob}(\varepsilon_{1i} \leq z_{1i}, \varepsilon_{2i} \leq z_{2i}|\, \mathbf{x}_i)$$

$$= \Phi_2(z_{1i}, z_{2i}; \rho)$$

where the second last line makes use of the symmetry of the bivariate normal distribution. By similar reasoning we get the remaining outcomes:

(5.3) $$\text{Prob}(Y_1 = 1, Y_2 = 0|\, \mathbf{x}_i) = \Phi_2(z_{1i}, -z_{2i}; \rho)$$

$$\text{Prob}(Y_1 = 0, Y_2 = 1|\, \mathbf{x}_i) = \Phi_2(-z_{1i}, z_{2i}; \rho)$$

$$\text{Prob}(Y_1 = 0, Y_2 = 0|\, \mathbf{x}_i) = \Phi_2(-z_{1i}, -z_{2i}; \rho)$$

The log-likelihood for the data is then,

(5.4) $$\ln L = \sum_{i=1}^{N}((y_{1i}y_{2i})\ln\Phi_2(z_{1i}, z_{2i}; \rho) + (y_{1i})(1-y_{2i})\ln\Phi_2(z_{1i}, -z_{2i}; \rho) + (1-y_{1i})(y_{2i})\ln\Phi_2(-z_{1i}, z_{2i}; \rho) + (1-y_{1i})(1-y_{2i})\ln\Phi_2(-z_{1i}, -z_{2i}; \rho))$$

The model parameters, including ρ, are estimated using standard maximum likelihood methods, see Greene (2002). We can also test the bivariate model against the simpler set up of two univariate models by testing the null hypothesis of $\rho = 0$. Both the univariate models and the bivariate model provide consistent estimates of the model parameters; however, if $\rho \neq 0$, then the bivariate model is more efficient, see Poe, Welsh and Champ (1997). In what follows, we report both the univariate and bivariate results as well as a likelihood ratio test of $\rho = 0$.

With the model estimated, we can calculate measures of willingness to pay and to accept and investigate what might explain any observed differences. The linear expression for the surplus value is consistent with an underlying indirect utility function that is linear in the dichotomous variable indicating access to public grazing or not, income, and other covariates. The linear indirect utility function means that the welfare measures of interest are simple linear functions of the estimated model parameters and covariates, see Hanemann (1984).

Let WTA_i denote the individual's willingness to accept and WTP_i denote the individual's willingness to pay. Then define $\tilde{p}_{1i}$ as the expectation, conditional on $\mathbf{x}_i$, of the individual's willingness to accept and $\tilde{p}_{2i}$ as the expectation, conditional on $\mathbf{x}_i$, of the individual's willingness to pay. Equivalently in our linear environment these are individual's median willingness to accept or to pay; that is, posted offers at which there is a fifty percent probability the individual rancher will accept the offer. This is easily calculated as the value of p_{ji} that sets the non-random component of the surplus measure to zero:

(5.5) $$\tilde{p}_{1i} \equiv E(WTA_i \mid \mathbf{x}_i) = -\frac{1}{\gamma_1}\beta_1' \mathbf{x}_i$$

(5.6) $$\tilde{p}_{2i} \equiv E(WTA_i \mid \mathbf{x}_i) = -\frac{1}{\gamma_2}\beta_2' \mathbf{x}_i$$

where the expectation is taken over the marginal distribution of ε_{1i} in the first equation and ε_{2i} in the second equation. Taking expectations over the sample with $\mathbf{x}_i$ respect to the random covariates gives the standard measures of mean WTP and WTA:

(5.7) $$\overline{WTA} = -\frac{1}{\gamma_1}\beta_1' \overline{\mathrm{x}}$$

(5.8) $$\overline{WTP} = -\frac{1}{\gamma_2}\beta_2' \overline{\mathrm{x}}$$

Estimates of either individual or sample contingent valuations are obtained by substituting the ML parameter estimates, denoted $\hat{\gamma}_j$ and $\hat{\beta}_j$. In this study, we focus on the sample measures.

Estimates of mean WTP and WTA provide information concerning the relationship between these variables and the covariates used in estimation, which is one area of interest. We are primarily interested, however, in the differences between willingness to pay and to accept and how these might be explained by the covariates. To explore this, we need first to make the two measures comparable, as one is in terms of a flow (willingness to pay) while the other is in terms of a stock (willingness to accept). If we assume that all ranchers have the same discount rate r, then our hypothesis is:

$$(5.9) \quad \overline{WTP} / r = \overline{WTA}$$

where we have interpreted the WTP payment as a perpetual flow. In terms of the model parameters, this is

$$(5.10) \quad H_0\text{: } \frac{1}{\gamma_1}\beta_1^{'}\,\overline{\mathrm{x}} - \frac{1}{\gamma_2}\beta_2^{'}\,\overline{\mathrm{x}} / r = 0$$

where we now let $\overline{\mathrm{x}} = \frac{1}{N} \sum_i \mathbf{x}_i$. This hypothesis can be tested using a standard Wald test.[41]

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[41] The Wald test we construct is based upon a delta method approximation, which may not be ideal. An alternative is to use bootstrap methods to estimate the distribution of the individual or across sample valuation measures, as discussed in Poe, Welsh and Champ (1997). We leave this for future work.

The next issue is to consider what factors, that is which of the attributes $\mathbf{x}_i$, systematically contribute to the divergence between our measure of willingness to pay and to accept. For any individual *i* we can again write,

$$(5.11) \quad \tilde{p}_{1i} - r\tilde{p}_{2i} = -\frac{1}{\gamma_1}\beta_1^{'}\mathbf{x}_i + \frac{1}{\gamma_2}\beta_2^{'}\mathbf{x}_i / r$$

$$= (\frac{1}{\gamma_2}\beta_2^{'} / r - \frac{1}{\gamma_1}\beta_1^{'})\,\mathbf{x}_i$$

For any covariate *k*, we can define the contribution to the difference as,

$$(\frac{\beta_{2k}}{r\gamma_2} - \frac{\beta_{1k}}{\gamma_1})x_{ik}$$

and test the hypothesis, for each *k* and conditional on *r*:

$$(5.12) \quad H_0\text{: } (\frac{\beta_{2k}}{r\gamma_2} - \frac{\beta_{1k}}{\gamma_1}) = 0$$

5.4 Empirical Results

5.4.1 The Data

A summary of the posted offers and frequencies of discrete responses is provided in Table 5.1. Of the 244 usable returned surveys, we consider 194 responses that provide a complete set of responses to the conditioning variables of interest (these are discussed further below). As evident from the table, the majority of respondents rejected both willingness to pay and the willingness to accept posted offers. Just under ten percent accepted one but not the other offer and only one percent accepted both. These results suggest that on balance the survey offers were likely set at too low or too high a level; nonetheless, the results below suggest there is sufficient variation to identify the valuation measures of interest.

Table 5.1: Descriptive Statistics: Posted Prices

Variable	Description	Mean	SD[a]	Min	Max
p_{1i}	Posted price, willingness to pay ($/AUM)	$10.37	$4.89	$1.50	$20.62
p_{2i}	Posted price, willingness to accept ($/AUM)	$91.11	$54.55	$5.00	$200.00
Y_1	Discrete response to willingness to pay question; Y_1=1, WTP amount posted	0.11			
Y_2	Discrete response to willingness to accept question; Y_2=1, WTA amount posted	0.08			
	Joint frequencies of discrete response:				
	Y_1=1 and Y_2=1	0.02			
	Y_1=1 and Y_2=0	0.09			
	Y_1=0 and Y_2=0	0.83			
	Y_1=0 and Y_2=1	0.07			
Total number of observations: 194					

[a]SD refers to standard deviation.

The survey asked respondents to provide a wide variety of information beyond their willingness to pay or accept the posted offer. Due to the nature of the estimation, however, we found it necessary to select a relatively small subset of the possible conditioning variables. We chose those that we thought most likely to have some information concerning the differences in welfare measures; these variables are described in Table 5.2. For purposes of later discussion, the variables are grouped into (i) financial factors, including income, and education, (ii) lifestyle or quality of life factors, and (iii) attitudes towards environment.

Table 5.2: Descriptive Statistics: Covariates[a]

Variable and Description	Mean	[b]SD/Freq[c]
Financial Factors and Education		
Income	3.974	[0.13, 0.18, 0.11, 0.11, 0.11, 0.36]
Categories 1-6, in $, 000s: [<30, 30-45, 45-60, 60-75, 75-90, >90]		
Acres owned, ’000s, continuous	10.244	32.185
Public Grazing, ’000 AUMs, continuous	5.655	10.336
Under financial stress, Likert scale [1, 5]	3.990	[0.03, 0.08, 0.13, 0.40, 0.36]
Education, Categories 1-8:	3.948	[0.02, 0.19, 0.36, 0.04, 0.23, 0.07, 0.05, 0.05]
1=grade school; 2=high school; 3=some college or technical school; 4=technical training in armed forces; 5=completed college; 6=completed college, some grad. classes; 7=completed Masters degree; 8=completed PhD.		
Lifestyle or Quality of Life Factors		
Work off ranch, categories 0-2: 0 = no; 1 = yes: part-time; 2 = yes: full-time.	0.907	[0.55, 0.00, 0.45]
Plan to pass ranch on to heir Indicator: yes = 1; no = 0	0.897	
Participant in community events Indicator: yes = 1; no = 0	0.479	
Attitude towards Environment		
Endangered wildlife are not threatened by grazing Likert scale [1, 5][a]	4.036	[0.07, 0.07, 0.10, 0.26, 0.49]
Total number of observations: 194		

[a] Likert scale [1, 5] range from 1 to 5 with 1 representing strongly disagree with the statement and 5 representing strongly agree.
[b] SD refers to standard deviation.
[c] Frequency is the proportion of each category in the total of 194 observations

In the first grouping, we have income by category, acres owned by the rancher, acres of public grazing currently used, an indicator of financial stress (Likert scale), and education by category.[42] For the second group, we are looking for variables that suggest a strong attachment to ranching and the local community as indicators of how important the ranching lifestyle is to the respondent. We conjecture that the greater the attachment the greater any endowment effect is likely to be. The variables we select for this are whether the rancher works off the ranch, whether the rancher intends to bequeath the ranch, and whether they are participants in community events such as local sports. Finally, the third grouping consists of an indicator of whether the rancher views grazing as a threat to endangered or threatened wildlife. As the issue of public grazing rights is closely linked to environmental concerns, this is a natural direction to explore.

Based on these variables, a typical ranch owner has a 10000 acre ranch using roughly 6000 AUMs of public forage, earns between $60-75000, considers herself to be under financial stress from the livestock business, has attended or completed college, plans to pass the ranch on to their heir(s), and does not believe that ranching threatens wildlife. Working part time appers not to be an option, with ranchers either working full time on the ranch or full time elsewhere. This latter characteristic suggests that just under half of the respondents are hobby ranchers (that is , 45% of ranchers work full time off the ranch). Finally, a slight majority of ranchers do not regularly participate in community events, such as local sporting events.[43]

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[42] Income is from all sources, not just from ranching.

[43] Details about the exact nature of the survey questions are available from the authors. See also van Kooten et al. (2005).

5.4.2 Probit Models

Empirical estimates of general unrestricted bivariate and univariate probit models are provided in Table 5.3; Table 5.4 presents more parsimonious versions of these models. In all cases, the models have as dependent variables the posted offers (p_{ji}, j = 1, 2) as well as the covariates, or a subset, discussed above. Note that we also include an interaction term for public grazing and private land ownership to model interdependencies between public and private land uses. Throughout, we restrict the set of covariates to be the same in both the willingness to accept and willingness to pay equations.

Table 5.3: Probit Estimation Results for WTP and WTA, General Models[a]

Explanatory Variable	Bivariate Probit Model		Univariate Probit Model	
	WTA	WTP	WTA	WTP
Constant	-2.369**	2.974***	-2.919***	3.156***
	(1.094)	(1.096)	(1.134)	(1.017)
Posted offer (p_{ji})	0.018***	-0.269***	0.018***	-0.271***
	(0.005)	(0.060)	(0.005)	(0.058)
Financial Factors and Education				
Income	-0.142*	0.013	-0.144	0.004
	(0.085)	(0.102)	(0.096)	(0.099)
Acres owned	-0.244***	0.003	-0.218***	0.003
	(0.064)	(0.005)	(0.059)	(0.005)
Public Grazing AUMs	0.183***	-0.024	0.178***	-0.011
	(0.052)	(0.034)	(0.054)	(0.035)
Acres owned x AUMs	0.002***	0.000	0.002***	0.000
	(0.001)	(0.000)	(0.001)	(0.000)
Under financial stress	-0.408**	-0.112	-0.408*	-0.137
	(0.188)	(0.146)	(0.218)	(0.148)
Education	0.071	-0.070	0.087	-0.092
	(0.104)	(0.077)	(0.103)	(0.077)
Lifestyle Factors				
Work off ranch	-0.050	0.120	-0.067	0.169
	(0.212)	(0.177)	(0.221)	(0.173)
Plan to pass ranch on to heir	-1.755***	-0.584	-1.737**	-0.682*
	(0.672)	(0.398)	(0.725)	(0.409)
Participant in community events	0.542*	-0.365	0.643	-0.450
	(0.326)	(0.341)	(0.358)	(0.321)
Attitudes towards Environment				
Endangered wildlife	0.432**	-0.261**	0.507*	-0.236*
are not threatened by grazing	(0.194)	(0.124)	(0.229)	(0.124)
ρ	0.748**		–	–
	(0.225)			
Log likelihood	–65.625		-29.429	-38.162
Pseudo-R^2	0.459		0.467	0.426

[a] Total number of observation is 194. Numbers are point estimates with heteroskedasticity robust standard erros provided in brackets. A *** denotes statistical significance at the 1% level; ** at the 5% level; * at the 10% level for a two-sided t-test using the standard normal distribution. The psuedo-R^2 is from McFadden (1974). See Tables 5.1 and 5.2 for variable definitions.

Table 5.4: Probit Estimation Results for WTP and WTA, Specific Models[a]

Explanatory Variable	Bivariate Probit Model		Univariate Probit Model	
	WTA	WTP	WTA	WTP
Constant	-2.125**	2.619***	-2.721**	2.749***
	(1.001)	(0.889)	(1.064)	(0.903)
Posted offer (p_{ji})	0.018***	-0.261***	0.018***	-0.262***
	(0.005)	(0.058)	(0.005)	(0.059)
Financial Factors and Education				
Income	-0.148*	0.026	-0.149*	0.024
	(0.079)	(0.094)	(0.087)	(0.092)
Acres owned	-0.240***	0.001	-0.210***	0.001
	(0.069)	(0.004)	(0.061)	(0.004)
Public Grazing AUMs	0.192***	-0.037	0.186***	-0.025
	(0.048)	(0.032)	(0.049)	(0.036)
Acres owned x AUMs	0.002**	0.000	0.002**	0.000
	(0.001)	(0.000)	(0.001)	(0.000)
Under financial stress	-0.408**	-0.085	-0.385*	-0.109
	(0.178)	(0.132)	(0.207)	(0.140)
Lifestyle Factors				
Plan to pass ranch on to heir	-1.760***	-0.488	-1.693**	-0.583
	(0.682)	(0.383)	(0.726)	(0.402)
Participant in community events	0.535*	-0.348	0.631*	-0.431
	(0.320)	(0.314)	(0.346)	(0.304)
Attitudes towards Environment				
Endangered wildlife	0.413**	-0.270**	0.483**	-0.247*
are not threatened by grazing	(0.167)	(0.125)	(0.216)	(0.127)
ρ	0.823** (0.200)		–	–
Log likelihood	–66.377		-29.719	-39.043
LR Test (p-value)[a]	0.826		0.415	0.748
Pseudo-R^2	0.453		0.462	0.413

[a] As for Table 5.3. LR Test reports the p-value for the χ^2 (q) distributed test of the restriction imposed in these models relative to the general models of Table 5.3. For the bivariate model, q=4; for the univariate models, q=2.

Some common features are immediately apparent from the two tables. First, in all cases the posted offers are statistically significant and correctly signed: for willingness to accept, as the offer rises the probability of acceptance increases; for willingness to pay, as the offer rises the probability of acceptance decreases. The magnitude of the coefficients across the two welfare measures differs but this is to be expected given that the willingness to accept question is phrased in terms of a one-off payment (a large current value number) while the willingness to pay is phrased in terms of a stream of smaller annual payments.

Second, in almost all instances the remaining covariates are statistically significant, if at all, only in the willingness to accept equations. The one exception is a variable concerning ranchers' attitudes toward the local environment. This is somewhat of a puzzle; even if there are good reasons to expect the two welfare measures to differ it is not obvious that they should differ in terms of conditioning variables to this extent. As this is not directly relevant to our main focus, we do not pursue this any further leaving it for further research.

Finally, the two estimation methods provide very similar results in terms of what variables are statistically significant and the coefficient magnitudes, suggesting that the results and any conclusions are robust to these different strategies. Since the correlation coefficient between the disturbances is statistically different from zero and relatively large, and because we wish to consider formal hypothesis tests across the two equations, we focus our discussion on the results of the bivariate probit model. This has the additional advantage of being a more efficient estimator given that $\rho \neq 0$.

The general models in Table 5.3 identify two variables that are statistically insignificant at the ten percent level, education and whether the respondent works off the ranch or not. The parsimonious models in Table 5.4 drop these two variables and the bivariate version of this model is our preferred specification. Setting aside for the moment the valuations implicit in the model, we first consider the covariates themselves and how they affect the likelihood of accepting the posted offers. With the exception of the environmental variable, we can confine the discussion to the willingness to accept equation since the other covariates are statistically insignificant in the willingness to pay equation.

Beginning with household income, we see that the higher a rancher's income category the less likely they are to accept an offer to forgo public grazing land. As this relates to income from all sources, it is not possible directly to link this to the success of the ranching operation.[44] One interpretation is that better off households, through a combination of ranch and outside income, are best placed to enjoy the benefits of ranching and hence less willing to give up ranching and the associated use of public grazing.

A closely related variable is the extent to which ranchers feel themselves to be under financial stress from the livestock business. The results indicate that the greater the financial stress, the less likely the posted offer is accepted. Plausibly, ranchers under financial stress view the public grazing system as a necessary subsidy to continue

[44] Fifty-four respondents indicated that at least one spouse worked off-farm part time, while in 51 households one worked full time. For these households, an average 75.6% of income was off farm. For all ranches, one-third of income came from off-farm work. Interestingly, there is essentially zero correlation between household income and extent of financial stress from the livestock business.

ranching and consequently are unwilling to forgo the subsidy. This suggests that the posted offers are not high enough to compensate for the implicit subsidy, a fact that is indirectly supported by the low number of offers accepted across the sample (see Table 5.1).

The scale of the ranch measured by acres owned also enters with a negative coefficient, indicating that those with larger ranches are less likely to accept an offer to forgo grazing rights. This suggests that the larger ranches are those more dependent upon public grazing. An implication from this is that private and public grazing lands are not simple substitutes but are somewhat complementary: while ranchers with large private holding are better able to operate without public forage, they also are more likely to have large grazing allotments (a large number of permits).

We next observe that ranchers with larger public grazing utilization are more likely to accept a posted offer, all else equal. That is, of two ranchers that are otherwise equal and offered the same price to forgo entirely public grazing, the one with a greater current utilization of public grazing land is more likely to accept the offer. This is a somewhat confusing result; a simple analysis of ranchers' valuations would suggest that those ranchers with larger allotments, all else equal, would have a larger surplus and so be less likely to accept a posted offer.[45] We offer the following possible explanations. First, it is possible that public grazing is not of uniform quality and that large allotments are systematically associated with lower quality grazing. In this case, it is possible for the

[45] Recall that the allotment of public grazing is determined by the public land management agencies and not by the ranchers themselves, so we treat the public grazing allotment as exogenous.

surplus value associated with large allotments to be less than those of small allotments. Of course, this does not explain why quantity of public grazing does not have similar implications for willingness to pay. Second, a rancher with a large allotment may be more willing to accept a buyout because the payment will be substantial, perhaps making it possible to get out of ranching entirely or to purchase enough private land so they are no longer dependent on public range. Finally, ranchers may believe that large allotments of public grazing are unlikely to persist given the pressures from government and environmental lobbies, while small allotments may be sustainable. In this case, those with large allotments may be more willing to accept an offer of at least a partial buyout as they view the loss of these grazing allotments as inevitable.

The cross-product term of public grazing and private land ownership is also positive and highly statistically significant. This indicates that, as the extent of privately-owned land (allotment of public forage) increases, the eagerness with which a rancher with a larger public grazing allotment (private holdings) accepts the offer of a buyout also increases. Large operators appear readier to be bought out, suggesting that, all else equal, lifestyle is more important than ranching per se. With a significant buyout and a large homestead, a rancher can maintain the ranch lifestyle, living off their private lands without the concerns about potentially losing public forage.

The lifestyle factors we consider are two: whether the ranch is intended to be bequeathed and whether the rancher is an active participant in community events. The former is negative and strongly significant, meaning that those intending to pass the ranch on to their heir(s) are less likely, all else equal, to accept a posted offer, a result we might expect. The community event variable, in contrast, is positive and only weakly significant (ten percent); clearly, it is not picking up a commitment to ranch lifestyle as we might expect.

Finally, we consider ranchers attitude regarding the effect of grazing on the local environment. Recall the question asks whether endangered wildlife species are unaffected by livestock grazing, with strongly disagree equal to one and strongly agree equal to five. The majority of respondents agreed with this statement, so there is little support from ranchers for these concerns. The regression results indicate that the less concern a rancher has about the environmental effect of livestock grazing, the more likely they are to accept the posted offer and the less likely they are to pay the posted price.

Neither of these results accords with our expectations. Ranchers who do not view grazing as environmentally costly necessarily have a larger surplus than those ranchers who do view grazing as costly, as long as the latter are internalizing these environmental costs. The larger surplus means these ranchers should be less likely to accept a particular offer, all else equal. Similarly, such ranchers should be more likely to agree to pay a posted price than ranchers with greater environmental concerns.

We offer several possible explanations. Suppose people's views on how grazing affects wildlife depends upon how they use their public grazing allotment, more or less intensively. Those using it more intensively are more likely to accept that grazing threatens wildlife than otherwise. Then we might reason that more intensive users of public grazing are those with greater benefits. As a consequence, less intensive users (those with a high value of the threaten species variable) have a smaller surplus and are more likely to accept an offer and less likely to agree to pay a price.

A second possibility is that the result may reflect the context of the survey questions, which motivate reductions in AUMs due to environmental concerns. Those who do not think livestock grazing has an adverse impact on endangered wildlife species may see no reason to pay more for the privilege of grazing cattle, and hence may be less likely to agree to a posted price. Indeed, they may even see livestock grazing as a benefit to wildlife (meaning they should be subsidized even more than currently). Nonetheless, they would be more likely to accept a posted offer to sell grazing permits because, if livestock do increase wildlife numbers, there will be even more pressure in the future to reduce access to public forage as there is more competition for habitat and forage between wildlife and livestock.

Finally, the result may reflect ranchers' views of the dependence of the future of public grazing on environmental concerns. Ranchers with a negative and pessimistic view of environmental concerns and issues may be more likely to agree that wildlife are not endangered by grazing, primarily as a statement against what they perceive to be growing support for land use policies dominated by environmental concerns. Consequently, these same ranchers may be pessimistic about the future of public grazing and so more willing to be bought out now. At the same time, they may be unwilling to pay more because the payment is considered an environmental payment.

Unfortunately, it is not possible to discriminate between these and other possible explanations given the data we have from the survey. Our results do suggest, however, that environmental concerns or attitudes may be influential in welfare valuation measures of the sort considered here and that there may well be an element of respondents using surveys for strategic purpose.

5.4.3 Statistical Tests of the Divergence between welfare measures

As discussed in the previous section, we can use the probit models to estimate valuations and to test for differences between the two measures. Table 5.5 reports mean willingness to accept and to pay for public grazing. To compare these payments, we consider discount rates of 2%, 4%, 7% and 11%.[46]

Table 5.5: Valuation Measure[a]

Valuations	Estimate	s.e.	p-value	
$\overline{WTA} = -\frac{1}{\hat{\gamma}_1}\hat{\beta}_1' \bar{x}$	262.65	26.78	0.000	
$\overline{WTP} = -\frac{1}{\hat{\gamma}_2}\hat{\beta}_2' \bar{x}$	2.21	1.04	0.033	
Test of Divergence				
Discount Rate	$\overline{WTA} - \overline{WTP}/r$	s.e.	p-value	$\overline{WTA}/(\overline{WTP}/r)$
2%	152.27	61.03	0.013	2.38
4%	207.46	39.40	0.000	4.75
7%	231.11	32.10	0.000	8.32
11%	242.58	29.43	0.000	13.07

[a] Reported Standard errors are based on a first order approximation of the valuation function conditional on the estimated mean, $\bar{x}$. p-values are for a two-sided test of the null-hypothesis that the valuations or functions of the valuations are statistically different from zero.

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[46] The choice of these discount rates is guided by the following. The real rate of return on investments by large U.S. companies over the period 1926-1990 was about seven percent, after taxes. Given a corporate income tax rate of about 35 percent, the pre-tax rate of return is thus about eleven percent. Since individuals in the U.S. pay up to 50 percent in income taxes, the rate of return to individuals as owners of companies is closer to four percent, which can then be considered the rate at which people trade off spending over time. The U.S. Office of Management and Budget requires the use of seven percent for valuing costs and benefits external to the government and 4 percent for internal costs and benefits (Newell and Pizer 2003). Finally, range economists argue an appropriate rate of return to livestock production is two percent.

The estimate of mean willingness to accept is \$262.65 per AUM while the estimate of mean willingness to pay is \$2.21; both are statistically significant. From Table 5.1, we know that the values of posted offers to accept range between \$5 and \$200, below the estimated mean willingness to accept reported in Table 5.5, which is consistent with the relatively small number of offers accepted in the sample. Similarly, the estimated of mean willingness to pay of \$2.21 is low relative to the range of posted payment offers (\$1.50 to\$20.62), consistent with the relatively small number of payment offers accepted in the sample. So the model seems to be doing a reasonable job: the predicted valuations are in line with observed behavior.

It is of some interest to compare the estimated willingness to pay valuation to the current fees for permit holders of public grazing allotments. In 2003, the fee charged was \$1.35 per AUM, below but not statistically significantly different from our estimate of \$2.21 per AUM (*p*-value of 0.282). If we simply focus on the point estimate, then current permit holders are willing to pay quite a bit more than the current grazing fee. In contrast, our valuation estimate is well below the \$4.90 per AUM that is charged those without permits in Nevada (BLM 2003).

As discussed in the previous section, it is possible to estimate each individual's mean willingness to accept and willingness to pay, $-\frac{1}{\gamma_1}\beta_1^{'}\mathbf{x}_i$ and $-\frac{1}{\gamma_2}\beta_2^{'}\mathbf{x}_i$. As our first indication of how closely related are the willingness to pay and to accept valuations, we can consider the Pearson correlation coefficient; this is 0.60 for our sample, higher than that reported by Borges and Knetsch (1998) but below that one would expect if individuals' WTP valuations are closely tied to their WTA valuations.

The last part of Table 5.5 looks at this issue more formally by testing whether the mean willingness to accept is significantly different from the mean willingness to pay measure adjusted by the discount rates identified above. For all discount rates considered, the willingness to accept valuation exceeds the adjusted willingness to pay valuation by a large amount and, despite the uncertainty surrounding our estimates, the differences are statistically significant. The differences we observe are consistent with others in the literature. With a discount rate of four percent, the results suggest that willingness to sell a grazing permit exceeds willingness to pay for current access to public forage by a factor of about 5 while for a discount rate of eleven percent the ratio is about 13. These are well within the 'reasonable' range of divergence found by Horowitz and McConnell (2002) for public and non-market goods (e.g., hunting permits), health and safety, and even some private goods.

5.4.4 Factors Contributing to the Divergence between WTA and WTP

We now examine divergence in the factors contributing to the difference between the two welfare measures in the manner laid out in the previous section. We continue to focus on the parsimonious bivariate probit model presented in Table 5.4. The results are presented in Table 5.6. The numbers can be interpreted as dollar values with positive numbers making a positive contribution to the valuation of interest. In the instance of a dichotomous variable such as the bequest motive, the coefficients have a very simple interpretation: the desire to pass the ranch on to your heir raises the willingness to accept valuation by nearly $100 per AUM.

Table 5.6: Contributions to Divergence of Valuation Measures[a]

Explanatory Variable	WTA $(-\hat{\beta}_{1k}/\hat{\gamma}_1)$	WTP $(-\hat{\beta}_{2k}/\hat{\gamma}_2 \times 1/r)$			
		Discount Rate			
		2%	4%	7%	11%
Financial Factors					
Income	8.066	5.009	2.504	1.431	0.911
		(0.875)	(0.605)	(0.361)	(0.212)
Acres owned	13.096	0.204	0.102	0.058	0.037
		(0.000)	(0.000)	(0.000)	(0.000)
Public Grazing AUMs	-10.482	-7.013	-3.507	-2.003	-1.275
		(0.613)	(0.070)	(0.002)	(0.000)
Acres owned x AUMs	-0.117	0.062	0.031	0.018	0.011
		(0.011)	(0.006)	(0.006)	(0.007)
Under financial stress	22.291	-16.400	-8.200	-4.686	-2.982
		(0.166)	(0.054)	(0.015)	(0.006)
Lifestyle Factors					
Plan to pass ranch on heir	96.158	-93.689	-46.794	-26.741	-17.016
		(0.039)	(0.012)	(0.004)	(0.002)
Participant in community events	-29.219	-66.817	-33.408	-19.090	-12.148
		(0.597)	(0.917)	(0.725)	(0.482)
Attitudes towards Environment					
Endangered wildlife are not threatened by grazing	-22.582	-51.871	-25.935	-14.820	-9.431
		(0.288)	(0.840)	(0.541)	(0.240)

[a] Numbers in labeled rows are coefficient ratios; numbers below are marginal significance levels for the hypothesis test that the WTA component and the adjusted WTP component are equal; that is, $(-\hat{\beta}_{2k}/\hat{\gamma}_2) = (-\hat{\beta}_{1k}/\hat{\gamma}_1 \times 1/r)$. Inference is based upon first order approximations.

The following variables make statistically significant contributions to the difference between the two valuations measures; acres owned, public grazing, financial stress, and bequest motive. The other lifestyle factor, participation in community events, and the environmental variable do not make a statistically significant contribution. These conclusions are unchanged across different discount factors.

In the case of acres owned, or size of the ranch, there is a positive contribution to both the willingness to accept valuation and the willingness to pay valuation, but the effect is much larger for the former. Previously, we argued the positive contribution to willingness to accept might be explained by the dependence of larger ranches on public grazing, so that the two types of grazing are complementary. This is consistent with the positive effect it has on willingness to pay as well (though recall this variable is not statistically significant in the probit model itself). Viewed from this perspective, the fact that the effect is larger for WTA is consistent with the theoretical divergence in the two valuation measures arising from lack of close substitutes for the good being valued, Hanemann (1991). We can provide a rough guide to the magnitude of the contribution as well; the mean value of acres owned is approximately 10, so the contribution to the difference of $207 (using a 4% discount rate) is approximately $130, almost half.

Public grazing has the opposite effect, reducing both valuation measures (again, though, this variable is not statistically significant in the WTP probit equation). The relative magnitude of the two effects, however, is such that it brings the two valuation measures closer together. In general terms, the divergence of the valuation measures for the good (public grazing) is smaller the greater the allocation of the good. If we interpret the discrepancy as arising from an endowment effect, this implies that the effect is stronger for smaller quantities of the good (public grazing), a somewhat surprising result. As indicated previously, however, it may well be that small ranches as opposed to large ones, are all that is needed to maintain the ‘ranch lifestyle’. If there is sufficient off-ranch income or a large enough buyout, ranchers appear content to continue on a reduced scale.

Financial stress also makes a significant contribution to the discrepancy between the two valuation measures, raising the willingness to accept and lowering the willingness to pay. Financial stress tends to raise the willingness to accept valuation, as discussed previously, while at the same time reducing the willingness to pay valuation. While the former is somewhat difficult to explain, the latter would seem to be a straightforward prediction. As a general conjecture, it seems that the overall financial situation, including financial constraints, may bear on the divergence between the welfare measures. Notably, these sorts of issues are very unlikely to arise in standard experimental settings examining welfare measures.

Finally, we see a large contribution from the bequest motive. As noted previously, the desire to pass the ranch on to an heir raises the minimum willingness to accept by nearly $100; similarly, it lowers the maximum (adjusted) willingness to pay by roughly $50 (for a discount factor of four percent). If we view the bequest motive as evidence of a long-term commitment to ranching, both as an occupation as well as a lifestyle, then we might conclude that lifestyle— broadly defined — is important for explaining the discrepancy between valuations.

5.5 Conclusions

The relationship between an individual's maximum willingness to pay and minimum willingness to accept compensation for the same change in a good or service has been the topic of considerable inquiry. The repeated findings from numerous survey-based contingent valuation field studies, which have now been replicated in various experimental and market settings, is that WTA and WTP diverge, with WTA typically much higher than WTP. The persistence of such disparities across numerous settings has defied any single explanation, with researchers having offered a number of competing interpretations. The novelty of this paper is to evaluate the disparities and examine the contributions from different socioeconomic characteristics.

The study uses the results of the 2002 Nevada Ranch Survey, which provides a rich set of information about rancher characteristics as well as responses concerning willingness to pay for access to public grazing and willingness to accept payment for permanently giving up access to public grazing. The joint contingent valuation responses allow us to model the two valuations simultaneously using a bivariate probit model; this has the added advantage of allowing us to pursue inferences regarding the contribution of different factors to disparities in welfare measures.

The principal conclusions are easily summarized and have implications both for public grazing policies as well as research generally concerned with discrepancies in welfare measures. First, larger ranches are associated with greater discrepancies in valuations. We conjecture this may reflect the lack of viable substitutes for public grazing lands for larger ranches. Second, the size of allocation of public grazing is inversely related to the discrepancy in valuations, a result which we find surprising and which warrants further investigation. Third, financial stress contributes to the discrepancy; it would seem to be of some interest as to whether this result is more general. Finally, long term commitment to ranching, either as an occupation or lifestyle, contributes substantially to the discrepancy.

It is useful to consider these results in terms of land use polices for grazing. Range economists have always argued that the public land agencies should promote trading of grazing rights. Where this has been done, however, trades have been remarkably few. One possible reason for the thin market is the persistence of a difference between WTA and WTP; sellers require greater compensation than buyers are willing to pay. Our results provide support for this explanation of low trading. If successful markets in public grazing rights are desirable, then our results suggest a number of directions worth exploring. First, it might be useful to focus attention on markets tailored to smaller ranches where valuations are more closely aligned. These are likely to be more successful, perhaps providing a starting point for more general markets to develop. Second, in ways that we do not properly understand, existing allocations seem to matter. As this factor is under the direct control of the land use agencies, a better understanding of this result might shed very useful information on improvements to the public grazing system. A further aspect of our results that may bear on land use polices concerns the evidence of lifestyle factors affecting welfare measures. The results suggest that ranchers with large public AUMs are more willing to be bought out, retreating to their owned acres. This is reinforced by our finding that WTA-WTP divergence is greater for small ranchers. Both are suggestive of lifestyle (and perhaps an endowment effect). While further investigation is needed, it does suggest that surplus is not the driving factor, but lifestyle appears to be the main driver as suggested by ranch economists. If this is the case, the public agencies need to re-think the issuance of large grazing allotments that also provide large subsidies.

5.6 Appendix

WTA Question: The Grand Canyon Trust has retired 750,000 acres of public land by providing one-time payments of $75 per AUM to retire grazing leases. Some ranchers have donated grazing leases in exchange for tax deductions to create parks. Environmental groups want the federal government to buyout all permit holders on public lands. Would you be willing to accept a one-time payment of $y per AUM to retire all of your grazing leases? (Circle) Yes No

WTP Question: "According to *The Economist* (a global news magazine), 'grazing represents the last bastion of government-subsidized extraction of commodities from public lands'. Suppose that, as a result of such views and environmental lobbying, the costs of grazing on public lands will be increased dramatically. Would you be willing to pay $x per AUM to graze your livestock in the future?" (Circle) Yes No

5.7 References

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Chapter 6

Discussion

The research reported in this dissertation contributes to both policy and the method of non-market valuation. On the policy side, the study employed two original surveys to examine the economics of (1) creating carbon sinks by converting agricultural land to forestry and (2) purchasing rights to public forage in Nevada to protect environmental amenities. On the empirical method side, this study fills a gap in the preference uncertainty literature by comparing emerging approaches for addressing preference uncertainty in a contingent valuation framework. It further purposes a promising approach, the fuzzy random utility maximization method, to take into consideration preference uncertainty. Moreover, the study provides further empirical support of a divergence between willingness to accept and willingness to pay. The major findings in regards to the above aspects have been summarized in each of the separate chapters. Therefore, in this chapter we focus on potential future research on the themes of preference uncertainty in contingent valuation and the divergence between WTA and WTP. Future research in non-market valuation is also discussed more generally.

6.1 Preference uncertainty in contingent valuation

In this thesis, a fuzzy random utility maximization (FRUM) model is proposed to incorporate preference uncertainty in contingent valuation. Results indicate that FRUM ‘performs’ as well or better than traditional methods of non-market valuation. Given human’s lack of cognitive ability in making choices, especially in the case of non-market valuation, fuzzy logic appears to be especially appropriate. The application of fuzzy logic in non-market valuation can be further developed at least from the following aspects.

First, full development of fuzzy choice theory is needed. Classical choice theory has done a good job in dealing with the issue of making a rational choice from a crisp preference relation. Arguing that human preferences are inherently imprecise and vague, a lot of work has been done in the area of choice-making behavior using fuzzy preferences. Such research has made some progress in helping us understand fuzzy preferences, fuzzy choice functions and fuzzy utility functions. However, a solid theory of fuzzy choices is still missing, and it will be the key to further application of fuzzy logic in economics.

Second, the current research has utilized the fuzzy cluster approach to form a fuzzy random utility function. This approach can be further developed to consider not only preference uncertainty, but also heterogeneous preferences. The fuzzy c-means clustering algorithm in Chapter 4 can be extended to address heterogeneous preferences in a way that provides an alternative approach to that suggested by Boxall and Adamowicz (2002), although this needs to be determined more formally. The sample observations can be clustered according to the certainty confidence variable as well as other variables, such as age, education and income to consider heterogeneity among different age, education and income groups. The computational burden with the fuzzy modeling will increase with this extension, but it may not be an issue because it increases at the same rate as in the case of multiple linear regressions as additional explanatory variables are added to the model (Giles 2003).

Besides the fuzzy cluster approach, a fuzzy random utility function can also be derived directly by assuming each individual's utility is a fuzzy number with a fuzzy distribution function. In the conventional statistical regression model, the deviation between the actual values and the estimated values are supposed to be due to measurement errors. However, in an approach like this, these deviations can be regarded as the fuzziness of the parameters. That is, the deviations between the actual values and the estimated values come from the non-specificity of the system structure.

Finally, as noted by Evans, Flores and Boyle (2003), the application of fuzzy set theory to non-market valuation would seem especially appropriate given that the valuation of environmental amenities and public goods is likely best done using verbal language. This idea of using verbal language could be applied to both the valuation question and attitudinal variables in CVM. Currently, likert scales are widely applied to describe attitudinal variables. The problem of likert scales is that this assumes the distance between each level of attitude is the same, which is not reasonable. Instead of using likert numbers, Lein (2002) translated the normal language into fuzzy numbers. He employs normal language to describe attitudes such as 'very important', 'important', 'neutral', 'not important', and 'completely unimportant'. Then a linguistic perception measure might be elicited in the survey (e.g., an individual's measure of 'very important' may be from 78 to 92 on a hundred percent scale, while 'important' may be 68-82).[47] The normal language can be translated into fuzzy numbers using this perception measure.

6.2 Divergence between WTA and WTP

Empirical studies in a variety of contexts have found a great disparity between WTA and WTP. This study provides further support of the divergence of WTA and WTP

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[47] Notice the overlap of the membership functions— a normal situation is seen in Figure 4.1 for the case of fuzzy indifference curves.

in the context of a Nevada ranch survey using a simultaneous equation system. Various reasons for the WTA-WTP divergence have been offered from both standard economic theory and prospect theory (endowment effect), but none are very satisfying and further exploration is obviously needed. Indeed, if the WTA-WTP divergence is the result of an endowment effect (Knetsch 2005), then utility functions are no longer continuous as assumed in consumer demand theory. If this is the case, then much of the foundation upon which economic policy analysis is built is in jeopardy, including cost-benefit analysis. Yet, whatever the reason, such a disparity may have significant policy implications. Two recent papers by Guria (2005) and Knetsch (2005) aim to focus attention on the possible policy implications. These implications should not be ignored.

6.3 Research on non-market valuation generally

Future research on non-market valuation, especially the stated preference method, needs to better combine psychology and economics. One criticism of CVM is that it seeks to elicit values for natural resources from respondents who may lack the cognitive ability to make such assessments. Psychologists consider four possibilities in regards to human preferences (van Kooten and Bulte 2000, p.138):

1. Preferences exist and are stable, well-defined and easily measured.
2. Preferences exist and are stable, but are not easily measured because some of the resulting measures are biased.
3. Preferences exist and are stable, but all measurements are biased.
4. Preferences may not exist in some situations or, if they do exist, they are not stable or well formed.

Clearly, if the latter possibility is true, then traditional theory needs to be reexamined and possibly modified. The findings that people usually use language to describe preferences, and often treat gains and losses asymmetrically, provide some evidence that preferences may not be stable or well formed. Human preferences in some cases can be described as ambiguous or fuzzy, and reference based.

Practitioners of the stated preference, or contingent valuation, method have sought to address issues related vague, ill-formed, unstable or non-existent preferences by refining the technique. Much day-to-day research on non-market valuation has focused on improving survey design and statistical modeling, including the use of valuation follow-up questions or other questions that directly attempt to elicit respondent or preference uncertainty, and carefully applying validity assessments. Cummings et al. (1986), and Bateman and Turner (1993), have provided guidelines concerning the implementation of CVM, while the U.S. National Oceanic and Atmospheric Administration (NOAA) had commissioned a blue-ribbon Panel to review CVM (Arrow et al. 1993). The Panel provided support for the contingent valuation method, including recommendations and an ad hoc rule (use ½ of WTP answer) that created controversy. Bishop (2003) focused on the three Cs of validity assessment – content, construct, and criterion validity.[48] While these studies and many others provide tools to guide CVM practices, it is important to keep in mind that CVM and good survey design can never resolve the problem posed by ill-formed, vague, unstable or non-existent preferences (point 4 above). Indeed, it would be difficult for any CVM study to satisfy fully all of the

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[48] Research by Adamowicz et al. (1997), Haener et al. (2001) and Whitehead (2005) using joint revealed and stated preferences indicates that predictive validity is increased, but this does not imply that jointly estimated revealed and stated behavior models will always perform better and make accurate forecasts of future behavior.

criteria related to instrument design – to implement the perfect survey. In practice, surveys employ guidelines to varying degrees depending on the situation.

Finally, non-market valuation has come to a long way since it emerged in 1960s. It filled a significant gap in cost-benefit analysis related to the assessment of environmental and resource projects/programs. Although various non-market valuation methods have been used by governments in cost-benefit analysis and in the determination of environmental damages, the technique continues to stir up controversy in economics and outside, particularly among those economists less familiar with environmental economics and non-economists who object to the assignment of monetary values to environmental amenities or people on ethical grounds. Yet, whenever decisions are made that involve tradeoffs related to the environment (or the loss of life), a value is placed on the environmental amenity (a person's statistical life), at least implicitly. If environmental amenities are to compete with other goods and services for society's attention it can be done either by protest (an irrational and inefficient means of allocating resources) or by demonstrating the value of the resource or environmental amenity to society. The job of economists is to demonstrate that non-market valuation contributes to the latter – to the rational and efficient allocation of scarce environmental and other resources. However, as Manski (2000) points out, valuation methods will likely need further refining if economics is to make progress in bringing non-market values to the table of rational decision making. This dissertation can be viewed as a contribution to the further development of non-market valuation, both theoretically and empirically. The hope is that this dissertation is a step towards better consideration of ill-defined, unstable or non-existent preferences, or uncertain preferences, in environmental valuation.

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