Willingness to Pay for Biodiesel in Diesel Engines: A Stochastic Double Bounded Contingent Valuation Survey

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The double bounded dichotomous choice format has been proven to improve efficiency in contingent valuation models. However, this format has been criticized due to lack of behavioral and statistical consistencies between the first and the second responses. In this study a split sampling methodology was used to determine whether allowing respondents to express uncertainty in the follow-up question would alleviate such inconsistencies. Results indicate that allowing respondents to express uncertainty in the follow-up question was effective at reducing both types of inconsistencies while efficiency gain is maintained.

Keywords: Biodiesel, diesel, environmental benefits, contingent valuation, willingness to pay, double bounded model, and statistical and behavioral inconsistencies.

JEL Classification: I18, L91, Q42, Q51, Q53

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In order to elicit individuals' willingness to pay (WTP) for a non-market good, the National Oceanic Atmospheric Administration (NOAA) recommends using the dichotomous choice format in contingent valuation surveys (Arrow et al., 1993). This approach consists of asking respondents whether they would be willing to pay a particular price for the good. The prominent advantage of this approach is that it mimics the decision task that individuals face in everyday life: whether you buy it or not (Carlsson and Johansson-Stenman, 2000). A significant drawback inherent in this approach, however, is its relatively poor efficiency due to limited information obtained from each respondent, necessitating the use of fairly large samples in order to attain a reasonable degree of accuracy in welfare estimates. The double bounded dichotomous choice (DB-DC) format has emerged as a means to improve statistical efficiency in contingent valuation applications. Recent work includes Loureiro et al., (2006), Yoo and Chae (2001), Calia and Strezzera (2000), and McLeod and Bergland (1999). The double bounded approach, first developed by Hanemann et al. (1991), entails asking the respondent two yes/no WTP questions where the bid price in the second or follow-up question is higher (respectively lower) if the answer to first question is positive (respectively negative). However, this approach has been criticized due to statistical and behavioral inconsistencies observed between the first and the second responses. (Bateman et al., 2001; Harrison and Kristöm, 1995).

Despite this potential for bias, the use of the double bounded question format seems to be justified since it leads to lower mean squared error (Alberini, 1995) or yields a more conservative WTP estimate (Banzhaf et al., 2004) by narrowing down the confidence interval around WTP measures. One way to avert strategic behavior associated with the double bounded format while gaining efficiency is to adopt a "one and one half" bound model suggested by Cooper, Hanemann, and Signorelli (2002). However, Bateman et al. (2006) show that this model fails crucial tests of procedural invariance and induces strategic behavior among responses as in the double bounded model. In this current study, focusing on the follow-up question, we seek to determine whether allowing respondents to express uncertainty in the double bounded dichotomous choice format has an effect in reducing the strategic behavior (downward mean shift) and statistical inconsistency (imperfect correlation) while efficiency gain is maintained.

In a contingent valuation survey to estimate WTP for using more biodiesel fuel in diesel engines in a 16 county airshed in Central and South Eastern Ohio, a split sampling methodology was used wherein the first half respondents received questionnaires with the conventional DB-DC format and the second half respondents received questionnaires in which the follow-up question is in a stochastic format. Unlike the conventional follow-up question which requires a yes/no answer from a respondent, the stochastic follow-up question asks the respondent for the probability or likelihood of paying a higher (respectively lower) bid amount if he/she answers "yes" (respectively "no") to the first WTP question. Answer choices for the stochastic follow-up question include "Definitely no", "Probably no", "Not sure", "Probably yes", and "Definitely yes". Numeric answers ranging from 0 to 100 were also offered to support the verbal answer choices. From a methodological standpoint, this study distinguishes from previous research by being the first to implement a double bounded contingent valuation survey with a stochastic follow-up question.

To compare the dichotomous choice format with the conventional follow-up question to a dichotomous choice format with the proposed stochastic follow-up question, uncertain response choices were recoded in yes/no answers, allowing estimation of several bivariate probit models. Results indicate that the stochastic follow-up approach performs better than the conventional follow-up format in terms of efficiency. The estimated error correlation coefficients in models using the stochastic follow-up data are higher, reducing statistical inconsistency between the first and second responses. The stochastic double bounded format yields models for which mean WTP in both questions are not only the same but more efficient than those in the single bounded format.

This article is organized as follows. The next section reviews the literature on uncertainty in contingent valuation models and explains the rationale behind the stochastic format. Section 3 briefly describes the survey methodology. Section 4 outlines the model specification and estimation procedures. The empirical results of the analysis are presented in section 5. Section 6 concludes the study and presents areas for further research.

Uncertainty in Contingent Survey and the Stochastic Double Bounded Approach

The notion of preference uncertainty from the perspective of the respondents has been investigated by a number of studies. According to Li and Mattsson (1995), under preference uncertainty, it is possible for some individuals to answer yes even if their true valuation is less than the bid or no even if their true valuation is greater than the bid. Consequently, Li and Masson (1995) model the individual's yes/no choice as a specific realization of some underlying probabilistic mechanism. In addition to the discrete choice question on whether to pay a given bid for the resource, a post-decisional confidence measure was elicited using a follow-up debriefing question in which they design a graphical scale from 0 to 100% with 5% intervals. These measures are then interpreted as subjective probabilities that the individual's valuation is greater (for a yes answer) or less (for a no answer) than the bid.

Similar to Li and Mattsson, Loomis and Ekstrand (1998) use a debriefing question after the dichotomous choice question. The question wording is as follows:

> *On a scale of 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 certain and 10=very certain.*

It was found that 45 percent of the respondents giving "no" responses were very certain of their answers, while only 30 percent of those giving "yes" responses were equally certain.

Welsh and Poe (1998) develop a multiple bounded question format with uncertain response options. The difference between the single and double bounded formats and the multiple bounded format is that the latter lists a number of bids and respondents are asked whether they would pay each bid amount. Alberini et al. (2003) expand on Welsh and Poe to devise a conceptual model supporting the use of uncertainty response options. However, these studies yield divergent results, indicating that more needs to be done in terms of framing of the questions and response formats. This need gives motivation for an attempt to incorporate uncertainty in the double bounded question format by focusing on the follow-up question, which bears the brunt of the double bounded model's criticism.

A more recent study by Vassanadumrongdee and Matsuoka (2005) has attempted to take into account uncertainty in a contingent valuation with a follow-up question. Their study focused on measuring individuals' willingness to pay (WTP) to reduce mortality risk arising from air pollution and traffic accidents in Bangkok, Thailand. In the final section of their questionnaire, two debriefing questions were asked, the first of which was to capture the degree of certainty about the WTP responses. The respondents were asked how confident they were about their answers to both the first and second WTP questions. Only 28 percent in the air pollution sample and 24 percent in the traffic accident sample reported that they were very confident about their WTP answers.

In this current study, a different methodology is used to incorporate uncertainty in CVM. Unlike these studies mentioned above, the focus is on double bounded dichotomous choice approach. We argue that the inconsistency observed between the first and the second responses may be due to uncertainty created when the second question is introduced. Therefore, allowing respondents to express uncertainty in the second responses may help alleviate this inconsistency problem.

The first dichotomous choice question is more market-like and often considered more similar to every day consumption decisions, i.e. you either buy or do not buy the good at a certain price (Carlsson and Johansson-Stenman, 2000). Before the second question arrives, it is possible that respondents know their valuation with certainty under certain conditions such as some prior knowledge of the good or service. However, the follow-up question may result in creating uncertainties about the nature and the quality of the good or service. Respondents may follow decision rules not reflecting their true valuation, since neither a 'yes' nor a "no" could accurately convey their true preferences. Since confining and restrictive, it renders the respondents' task difficult.

An elicitation format designed to ease the respondents' burden is presented as an alternative to the current DB-DC format. After the first question, the stochastic double bounded format asks respondents the likelihood that they would vote for the project regardless of their decision on the first dichotomous choice question. Since this alternative approach calls for an answer in a likelihood format in the second round, it is referred to as the stochastic or random double-bounded format.

Survey methodology

Between May and June 2006, 3500 survey questionnaires were mailed out to a random sample of residents aged 18 years or older in two Ohio regions: Southeastern and Central Ohio. One half of the respondents received questionnaires with a conventional follow-up question and to the other half, questionnaires with a stochastic follow-up question were sent (See both follow-up formats in the Appendix). However, inherent in the stochastic follow-up were two important issues. First, different people would give divergent interpretations to the verbal answer choices. Thus, numeric answers ranging from 0 to 100 were offered to support the verbal answer choices. Second, order effects may arise depending on whether the subjective probabilities are presented in ascending or descending order. An example of order effect is primacy effect, which is a tendency of a respondent to choose items that appear first in a list. In order to test for order effect, the second half of the survey sample was subdivided. One portion of respondents received questionnaires wherein the order of the response choices was “Definitely no”, “Probably no”, “Not sure”, “Probably yes”, and “Definitely yes”. The order was reversed for the other portion.

Based on results of a pre-test, the sets of bids used in the study were: (50, 25, 100), (75, 40, 150), (100, 50, 200), and (250, 125, 500) where the first element of each set represents the first bid, the second element corresponds to the lower bid if the respondent answers “no” to the first bid, and the third element corresponds to the higher bid if the response to the first bid is a “yes”. The payment vehicle used was a one time lump sum contribution to a trust fund designed for a biodiesel project. To minimize non-response bias, we followed procedures suggested in Dillman (2000) when implementing the survey.

The survey questionnaire was split into four sections. The first section dealt with the respondents' background on air pollution in general and on global environmental changes and with their attitude toward diesel, biodiesel, and the environment. The second section contained the valuation scenario, which attempted to provide as much information as possible about the hypothetical market. Guidelines for a valid contingent valuation analysis suggested by Carson (2000), Carson et al. (2001), and Arrow et al. (1993) were followed as much as possible. To establish the institutional setting in which the good would be provided, the respondents were told that the Office of Energy Efficiency at the Ohio Department of Development is considering a project to reduce air pollution emissions in their county using B20, a blend of 20% pure biodiesel and 80% pure diesel. However, consistent with previous studies (Loureiro et al., 2006), they were not explicitly told whether the results of the study will affect these considerations. Providing this information to the respondents could have affected their decisions, given the context in which the good would be provided.

The third part of the questionnaire focused on economic and socio-demographic characteristics of the respondents. The final section concerned evaluation of the survey. It checked whether the respondents fully understood what they were asked to value and whether the information provided in the survey was useful for and relevant to them.

Model Specification and Estimation Procedures

In order to assess the internal validity of the contingent valuation, we first estimate four single bounded probit and logit models using linear and exponential functional forms. These models are described in Haab and McConnell (2002). That part of the analysis focuses on the first dichotomous choice question, and all appropriate covariates are used. Data from the two follow-up approaches are pooled together. Second, for each follow-up approach, a dichotomous choice (DC) single bounded model and DC double bounded bivariate probit models are estimated for efficiency and follow-up approach comparison. As in Moran and Moraes (1999), only the bid price and income are used as covariates. Note that simply allowing respondents to express uncertainty in the follow up question has nothing to do with efficiency. However, the central tendency may be affected. Efficiency gain would occur only if the stochastic follow-up format leads to higher correlation between the first and the second questions.

We employ bivariate probit for the double bounded models because the bivariate normal density function is appealing to statisticians in the sense that it allows for non-zero correlation, while the logistic distribution does not. In addition, constraining the parameters in the bivariate probit model yields other models such as the interval data model and the random effects probit model (Cameron and Quiggin, 1994; Haab, 1997). Specifically, when the correlation coefficient between the error terms of the two questions is relatively high, more efficient welfare measures can be obtained by constraining the means and the variances to be equal across questions[1].

Econometrically modeling data generated by the double bounded question format relies on the formulation given by:

$$WTP_{ij} = \mu_i + \varepsilon_{ij} \qquad (1)$$

where WTP_{ij} represents the j^{th} respondent's willingness to pay and i=1,2 denoting the first and the second question. μ_1 and μ_2 are the means for the first and the second responses. Setting $\mu_{ij} = X'_{ij}\beta_i$ allows the means to be dependent upon the characteristics of the respondents.

Following Haab and McConnell (2002), the j^{th} contribution to the likelihood function is given as:

$$L_j(\mu / t) = Pr(\mu_1 + \varepsilon_{1j} \geq t_1, \mu_2 + \varepsilon_{2j} < t_2)^{YN} * Pr(\mu_1 + \varepsilon_{1j} > t_1, \mu_2 + \varepsilon_{2j} \geq t_2)^{YY} *$$

$$Pr(\mu_1 + \varepsilon_{1j} < t_1, \mu_2 + \varepsilon_{2j} < t_2)^{NN} * Pr(\mu_1 + \varepsilon_{1j} < t_1, \mu_2 + \varepsilon_{2j} \geq t_2)^{NY} \quad (2)$$

where YY = 1 for a yes-yes answer, 0 otherwise, NY =1 for a no-yes answer, 0 otherwise, and so on. This is the bivariate discrete choice model. Assuming normally distributed error terms with mean zero and respective variances σ_1 and σ_2, then WTP_{1j} and WTP_{2j} have a bivariate normal distribution with means μ_1 and μ_2, variances σ_1 and σ_2, and correlation coefficient ρ. As a result, the j^{th} contribution to the bivariate probit likelihood function becomes:

$$L_j(\mu / t) = \Phi_{\varepsilon 1 \varepsilon 2}(d_{1j}((t_1 - \mu_1)/\sigma_1), d_{2j}((t_2 - \mu_2)/\sigma_2), d_{1j}d_{2j}\rho), \quad (3)$$

where

$\Phi_{\varepsilon 1 \varepsilon 2}$= Standardized bivariate normal distribution function with zero means
$d_{1j}=2y_{1j}-1$, and $d_{2j}= 2y_{2j}-1$
y_{1j}=1 if the response to the first question is yes, and 0 otherwise
y_{2j}=1 if the response to the second question is yes, 0 otherwise
ρ = correlation coefficient
σ = standard deviation of the errors

While double bounded models can be estimated using answers to the two yes/no questions in the conventional follow-up, the five uncertain answer choices in the stochastic format need to be recoded in certain (yes or no) answers. Previous studies suggest that when respondents are forced to give either a firm "yes" or a firm "no" and they are leaning toward answering "yes" ("definitely" or "probably yes"), they will answer yes (Alberini et al., 2003). However, results obtained by Welsh and Poe (1998) indicate that people who are uncertain but not leaning toward answering "no" will answer "yes". In addition, findings by Carson et al. (1998) imply that all uncertain responses should be no responses in a binary yes/no response choice. Based on these divergent results, the following recoding methods are used. First, “definitely” and “probably yes” are recoded as “yes” and all other response choices are recoded as “no”. Second, “definitely yes”, “probably yes”, and “not sure” are recoded as “yes” and all others as “no”. A third recoding method, which is in line with the results by Welsh and Poe (1998), is suggested by the response pattern in the second sub-sample. Figure 1 indicates that respondents who answered “no” to the first WTP question seem to lean toward answering “no” to the follow-up question. As a result, if they are “not sure” they will be less likely to answer “yes”. This reasoning yields the third recoding method, which is the same as the second method except that “not sure” responses are recoded as “yes” only for those respondents who answered “yes” to the first WTP question. All models[2] were estimated using the maximum likelihood estimation technique. Also, data management and the empirical analysis were conducted using STATA 9.2.

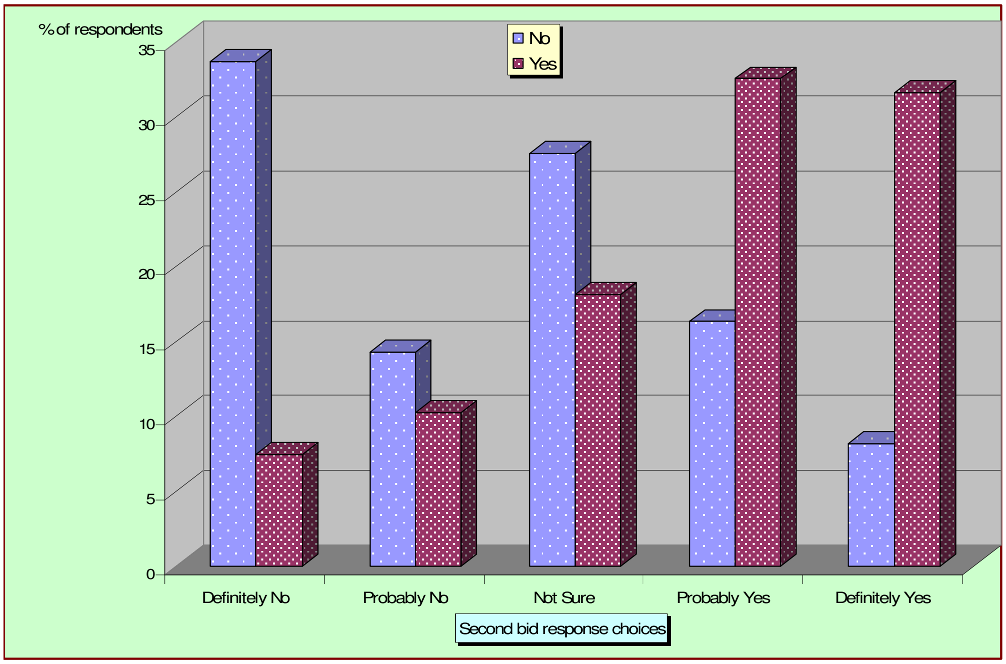
Using a linear function form, mean[3] WTP is given as in Huang and Smith (1998) for each question or equation:

$$\hat{\mu} = -(\hat{\alpha} + \overline{X}\hat{\beta}^{'}) / \hat{\beta}_0 , \tag{4}$$

where $\hat{\beta}_0$ is the coefficient on the bid amount, which is a point estimate of 1/σ. As a result, an estimate for the dispersion parameter or standard deviation of WTP is given by:

$$\hat{\sigma} = -1 \big/ \hat{\beta}_0 \tag{5}$$

Figure 1: Distribution of first and second responses in the stochastic format



Empirical Results

Descriptive statistics and results from the single bounded analysis

Out of 3500 questionnaires sent out, 309 were returned unfilled due to undeliverable addresses and deceased respondents. For the two versions of the survey, 658 questionnaires were returned completed, yielding a response rate about 21%. From the 658 questionnaires, 636 were usable. Descriptive statistics are shown in Table 1. For instance, it can be seen that 78% of the respondents were concerned about air pollution in their areas; about 76% stated that they were aware of the fact that lawmakers, agricultural groups, and clean air advocates had agreed on the use of biodiesel as a way to reduce emissions from diesel-powered vehicles. Most respondents were White, male represented 63%, and 67% were married or lived with a partner. For more details on the survey results, refer to Jeanty (2006).

Table 1: Descriptive statistics

Variables	Definition	N	Mean	Std
bid	Bid price	636	115.17	77.11
knowpol	1 if know about air pollution, 0 otherwise	636	0.51	0.5
poldis	1 if know about air pollution as one of the causes of many lung diseases, 0 otherwise	636	0.47	0.5
diespol	1 if know diesel-powered vehicles cause air pollution, 0 otherwise	635	0.43	0.5
pollcon	1 if concerned about air pollution in living area	636	0.78	0.42
member	1 if member of at least one environmental group, 0 otherwise	636	0.06	0.25
bioaware	1 if aware of biodiesel support, 0 otherwise	636	0.76	0.43
busserv	1 if bus service exists, 0 otherwise	636	0.91	0.29
male	1 if male, 0 otherwise	636	0.63	0.48
white	1 if White, 0 otherwise	636	0.91	0.29
age	Age in years	636	53.17	14.19
education	Education in years	636	15.00	2.37
marital	1 if married or living together, 0 otherwise	636	0.67	0.47
income	Income in $1000	636	57.47	31.77
comfortable	1 if comfortable with the survey, 0 otherwise	635	0.95	0.21
useful	1 if information in survey useful, 0 otherwise	635	0.89	0.31

Table 2 summarizes the results obtained for single bounded probit and logit models using both the linear and exponential functional forms. The values of the log likelihood functions at the bottom of the Table indicate that the four models fit the data nearly the same, implying that the results are not sensitive to distributional and functional form assumptions. The following observations are worthy of note.

First, as anticipated, the probability of saying "yes" to the WTP question is significantly related to the bid amount in all specifications. The negative sign indicates that as the bid amount increases, respondents would be less likely to pay, providing credence to the WTP responses.

Second, the coefficients on knowledge about air pollution (*KNOWPOL*) are statistically significant across models. The negative sign on these coefficients suggests that respondents who know more about air pollution would be less inclined to pay. This counter-intuitive result is similar to findings by Carlsson and Johansson-Stenman (2000), and Vassanadumrongdee and Matsuoka (2005). One would expect that air pollution knowledgeable respondents would be more disposed to pay than those learning of the problems for the first time. A possible explanation is that these respondents may view the problems less saliently as opposed to less informed respondents. Alternatively, the coefficients on the variable *POLDIS* are significant at the five percent significance level and have a positive sign in all models. This variable takes on the value of one if respondents state that they know about air pollution as one of the leading causes of many lung diseases, and zero otherwise. This result suggests that those who hold this view tend to express higher willingness to pay.

Third, in all specifications, the coefficients on *POLLCON* are statically related to the likelihood of saying "yes" to the first WTP question. The positive sign implies that respondents expressing concern about air pollution in their areas would be more likely to contribute to the project. This result is consistent with the view of Vassanadumrongdee and Matsuoka (2005) that respondents who ranked air pollution as their greatest concern would be more likely to pay.

Fourth, the respondents were asked to provide an approximation about how far they live from a major highway, a bus stop or route, and a railroad. About half of the respondents provided incomplete responses to these questions. Some respondents stated that they do not know or wrote responses with a question mark. Others indicated that bus services are not available in their cities. We use a dummy variable (*BUSSERV*) in lieu of inaccurately measured distance variables. The coefficients have a positive sign and are significant at the five percent significance level across models, implying that respondents living in areas serviced by a bus system would be more likely to pay.

Fifth, for all models, the coefficients on the education, marital status, and income variables are positive and highly significant, as expected. The probability of a "yes" increases with the respondents' education and income, and when the respondents are married or living together. The positive and significant effects of income, education and marital status convey additional evidence of the internal validity of the contingent valuation experiment (Alberini and Krupnick, 2003; Carson et al., 2001).

Finally, the coefficients on both the *COMFORTABLE* and *USEFUL* variables are positive and highly significant, implying that respondents who understood the questionnaire and found the information provided useful are more inclined to pay.

Results from the bivariate probit regressions

To compare the performance of the two dichotomous choice follow-up approaches, 6 models are estimated. Models 1 and 3 are single bounded probit regressions using the conventional and stochastic double bounded data respectively. Models 2, 4, 5, and 6 are double bounded bivariate probit regressions. While Model 2 is estimated using data from the conventional follow-up approach, Models 4, 5, and 6 are estimated using data from the stochastic follow-up approach based on the three recoding methods. Table 3 displays descriptive statistics and summarizes the joint frequencies of discrete responses for the two follow-up procedures. Using T-tests, the null hypothesis of equality of means for the first and second bid amounts and income across follow-up approaches cannot be rejected (P-values are 0.135, 0.482, and 0.600 respectively).

Table 2: Results from single bounded probit and logit regressions

Variable	Probit models		Logit models	
	Linear	Exponential	Linear	Exponential
bid	-0.0024***		-0.0042***	
	(0.0004)		(0.0007)	
log bid		-0.3186***		-0.5575***
		(0.0571)		(0.0973)
knowpol	-0.2752***	-0.2688	-0.4874***	-0.4765***
	(0.1001)	(0.0989)	(0.171)	(0.1682)
poldis	0.2873**	0.2882**	0.4975**	0.4998**
	(0.1397)	(0.1375)	(0.2442)	(0.2413)
diespol	-0.0327	-0.0344	-0.0517	-0.0564
	(0.1509)	(0.1508)	(0.2578)	(0.2572)
pollcon	0.4318***	0.4312***	0.7575***	0.756***
	(0.0993)	(0.0998)	(0.1679)	(0.169)
member	0.2456	0.2432	0.425	0.4227
	(0.1542)	(0.1516)	(0.2749)	(0.2704)
bioaware	-0.0474	-0.0515	-0.0728	-0.0818
	(0.1344)	(0.1329)	(0.2207)	(0.2179)
busserv	0.3644**	0.3586**	0.608**	0.6001**
	(0.1716)	(0.17)	(0.3005)	(0.2983)
male	-0.0512	-0.0485	-0.0558	-0.0541
	(0.1001)	(0.102)	(0.1902)	(0.193)
white	0.1613	0.1598	0.2362	0.2354
	(0.1197)	(0.1218)	(0.2238)	(0.2287)
age	-0.0051*	-0.0051*	-0.0085**	-0.0085**
	(0.0026)	(0.0026)	(0.0042)	(0.0042)
education	0.0279**	0.0282**	0.0542**	0.0547***
	(0.012)	(0.0117)	(0.0216)	(0.0209)
marital	0.1556**	0.1568**	0.2648**	0.2676***
	(0.0626)	(0.0627)	(0.1031)	(0.1033)
income	0.0086***	0.0086***	0.0152***	0.0151***
	(0.0026)	(0.0026)	(0.0046)	(0.0046)
comfortable	0.9583***	0.9591***	1.6583***	1.6558***
	(0.2347)	(0.2278)	(0.427)	(0.4098)
useful	0.6716***	0.6739***	1.1716***	1.1757***
	(0.1569)	(0.1567)	(0.2737)	(0.2747)
intercept	-2.1034***	-0.9299***	-3.7678***	-1.7088***
	(0.505)	(0.5718)	(0.9068)	(1.0157)
N	634	634	634	634
LogL	-324.571	-324.48	-323.772	-323.636
Pseudo R^2	0.1521	0.1523	0.1542	0.1545

Legend: *: significant at the 10%; **: Significant at 5%; ***: Significant at 1%
Standard errors, which are in parentheses, are adjusted for intra-county correlation

While *Y1* measures the responses to the first question for both sub-samples, *Y2c* is a variable for the responses to the second question in the conventional follow-up approach. *Ys1*, *Ys2*, and *Ys3* are three variables used for the recoded yes/no answers using the three recoding procedures. Results from several non-parametric tests indicate a failure to reject the null hypothesis of no order effects, implying that the order in which the response choices were presented to the respondents has no influence in their choices. As a result, there is no need to account for order effects when estimating the stochastic double bounded models.

Table 3: Descriptive statistics and summary of responses

Variables	Conventional DC-DB			Stochastic DC-DB		
	Obs	Mean	Std	Obs	Mean	Std
Y1	323	0.72	0.45	313	0.69	0.46
Y2c	322	0.52	0.50			
Ys1				313	0.52	0.50
Ys2				313	0.73	0.45
Ys3				313	0.64	0.48
Threshold 1*	323	110.68	73.05	313	119.81	80.95
Threshold 2*	323	169.47	136.99	313	177.56	152.54
Income ($1000)*	323	56.80	31.34	313	58.16294	32.23169

Variables	Y1				Total
	Yes - Yes	Yes - No	No - Yes	No - No	
Y2c	138	95	31	58	322
	43%	29%	10%	18%	100%
Ys1	138	77	24	74	313
	44%	24%	8%	24%	100%
Ys2	177	38	51	47	313
	57%	12%	16%	15%	100%
Ys3	177	38	24	74	313
	56%	12%	8%	24%	100%

Y1: Discrete responses to the first question for both follow-up approaches
Y2c: Discrete responses to the second question (conventional DC-DB)
Ys1: DY and PY = yes, and NS, PN, DN = no
Ys2: DY, PY, and NS = yes, and PN, DN = no
Ys3: Same as Ys2 except that NS = yes only for those who answered yes to the first threshold

*: Test results fail to reject the null hypothesis that the means of these variables are equal for the two sub-samples (P-value are 0.135, 0.482, and 0.600 respectively).

Table 4 reports the mean WTP estimates, the dispersion parameters for the first and the second equations, the error correlation coefficients, confidence intervals using the delta method and the Krinsky and Robb procedures[4], the values of the likelihood functions, and the number of observations used in each estimation. Confidence intervals calculated using Krinsky and Robb procedures are obtained using a set of 1000 draws, which is sufficient to generate a sufficiently accurate empirical distribution (Krinsky and Robb, 1986; Park et al., 1991). In computing mean WTP, median income obtained from the Census Bureau for the study area is used rather than the average or median income obtained from the survey, adjusting for the fact that the survey respondents' median income was much higher than the median income in the study area.

Results obtained for the conventional follow-up protocol indicate that the estimated mean WTP is lower when the second question is introduced. This is a typical result of the double bounded modeling. The variation in the binary responses conveys information about the error in each equation, since the bid amounts vary across individuals. The dispersion parameters for the double bounded model are lower ($422 and $384) than that of the single bounded model ($509). However, unlike previous studies (Cameron and Quiggin 1994), the standard error of the second equation is lower than that of the first equation. The error correlation is significant at the one percent level and estimated at 0.56, justifying the use of the bivariate probit model. An interesting result is that confidence intervals around the double bounded WTP estimates are tighter than the one around the single bounded WTP estimate, justifying the use of the double bounded questions.

Now consider the results from the stochastic follow-up approach. The first observation is that the correlation coefficients are higher as compared to the conventional approach, indicating a potential for efficiency gain even if the estimated mean WTP estimates for the two questions are different. Second, the gap between the single bounded and the double bounded mean WTP estimates is slightly lower as compared to the results in the conventional follow-up approach and in previous studies. Now as in previous studies, the dispersion parameters in the second question are higher than in the first question. Responses to the second WTP question seem to contain more statistical noise than responses to the first question. Also, responses to the second question in the stochastic follow-up are noisier than those in the conventional follow-up. When “not sure” is recoded as “yes”, the second question yields higher mean WTP estimates than the first question.

It can be seen that confidence intervals around the stochastic double bounded WTP estimates (models 3, 4, 5, and 6) are tighter those around the conventional double bounded WTP estimates (models 1 and 2). However, among the stochastic double bounded models only model 4 yields a more efficient WTP estimate than the single bounded model (model 3), which appears slightly more efficient than model 6. Since the correlation coefficients are considerably higher than 0.5, efficiency gain can be obtained by constraining the means and the dispersion parameters to be the same across equations or questions. However, the data need to respond in kind.

Results from restricted bivariate probit regressions

Models 2, 4, 5, and 6 were re-estimated, constraining the means and the dispersion parameters to be identical for both questions[5]. Table 5 reports the results from the restricted bivariate probit regressions (models 2’, 4’, 5’ and 6’). Again, compared to the single bounded model, the mean WTP estimate decreases more sharply in the conventional follow-up than in the stochastic follow-up models when the second question is taken into account. For models

5' and 6', mean WTP actually increases in the second equation. That mean WTP tends to shift downward when the second question is introduced is often attributed by researchers to the respondent's strategic behavior on the follow-up question (Haab and McConnell, 2002). These results seem to provide empirical evidence that allowing respondents to express uncertainty would alleviate this behavioral disadvantage of the follow-up question. One possible side effect of the stochastic follow-up approach is that it may increase statistical noise in the second response.

Table 4: Comparison between conventional DC-DB and stochastic DC-DB models

Statistics	Conventional Follow-up		Stochastic follow-up[a]			
	DC-SB (1)	DC-DB (2)	DC-SB (3)	DC-DB1 (4)	DC-DB2 (5)	DC-DB3 (6)
Mean WTP 1*	353	311	323	291	320	289
Mean WTP 2*		157		121	552	356
σ1	509	422	545	460	473	452
σ2		384		818	760	700
ρ		0.56		0.66	0.61	0.88
Delta Method	67 - 639	73 - 549	167 - 478	154 - 428	139 - 500	148 - 430
		119- 195		-6 - 248	428 - 678	251 - 462
Krinsky-Robb	180 -1803	172 - 1450	206 - 580	189 - 526	197 - 694	184 - 529
		117- 194		-120 - 215	461 - 742	257 - 469
LogL	-177.72	-380.82	-186.38	-336.29	-352.29	-338.12
N	323	323	313	313	313	313

*: All mean WTP estimates are significant at the one percent significance level.
a: A dummy variable used to account for the order in which the uncertain response choices were presented was not significant as expected. As a result, it was dropped from the analysis.

Likelihood ratio tests were implemented to determine whether the restrictions applied to models 2, 4, 5, and 6 are valid, i.e. supported by the data (See bottom of the Table 5). As illustrated, while the restrictions are rejected at the one percent significance level for models 2 and 4, they cannot be rejected for models 5 and 6 (P-values are 0.105 and 0.413).

Table 5: Results from restricted bivariate probit regressions

Statistics	Conventional DC-DB	Stochastic DC-DB		
	DC-DB (2')	DC-DB1 (4')	DC-DB2 (5')	DC-DB3 (6')
Mean WTP*	204	221	547	347
σ	312	520	896	637
ρ	0.55	0.67	0.58	0.88
Delta Method	164 - 245	140 -301	390 - 705	234 - 461
Krinsky-Robb	168 - 245	138 - 295	431 - 783	245 - 463
LogL	-393.20	-388.50	-355.36	-340.00
LR test ($\chi^2(3)$, P-value)	(24.77, 0.000)	(23.40, 0.000)	(6.13, 0.105)	(2.86, 0.413)
N	323	313	313	313

*: All mean WTP estimates are significant at the one percent significance level.

Relative efficiency comparison

Drawing upon Loomis and Ekstrand (1998), the ratio of the confidence interval to the mean WTP is used as a relative measure of efficiency or precision of WTP estimates (i.e., CI/mean = (Upper bound – lower bound)/meanWTP) for the first equation/question. The lower the ratio, the higher is the efficiency. Table 6 shows that the more efficient models are the restricted ones. Because the restrictions are rejected for models 2' and 4' but hold for models 5' and 6', the appropriate double bounded models are models 2, 4, 5', and 6'. As a result, model 1 should be compared with model 2 in the conventional follow-up approach and model 3 should be compared with models 4, 5' and 6' in the stochastic follow-up approach.

As can be seen, the double bounded model 2 yields a more efficient WTP estimate than the single bounded model 1 and the three stochastic double bounded models 4, 5', and 6' are more efficient than the single bounded model 3. Between models 5' and 6', the more efficient model depends on the procedures used to compute the confidence intervals. While the delta method portrays model 5' as more efficient, model 6' appears more efficient when considering the Krinsky and Robb procedures. Because the WTP measure yielded by model 5' is noisier, one may prefer model 6'. In addition, since WTP measures are non-linear combinations of the parameter estimates, they are less likely to be normally distributed and thus non-symmetric around the means. Percentile non-symmetric confidence intervals given by the Krinsky and Robb (KR) method would be more appropriate. Note the larger efficiency gain provided by model 2' as compared with all other estimated models. However, this efficiency gain comes at the cost of biasness since the restrictions are rejected at the one percent significant level.

Previous studies have attempted to correct behavioral inconsistencies between the first and second responses. These studies suggest that the efficiency gain may be lost by doing so. Speaking of the single bounded model, Alberini et al., (2003) advance that there is no reason to believe that allowing uncertain responses will affect the efficiency of welfare estimates. However, this may not be the case for the double bounded model. If the process allows for more correlation between the first and the second questions, efficiency gain may arise. Results in this study seem to provide empirical evidence that a follow-up approach which allows respondents to express uncertainty when answering the second question may not only yield more efficient WTP estimates than the conventional follow-up approach but also the resulting double bounded models may be more efficient than the single bounded model. Further, behavioral and statistical inconsistencies observed in previous studies may be alleviated as well, since the restrictions constraining the means and variances across equations are not rejected by the data and error correlation coefficients become higher.

Table 6: Efficiency comparison

Models		CI/Mean	
		Delta method	Krinsky and Robb procedures
Conventional follow-up	Model (1)	1.59	4.60
	Model (2)[a]	1.53	4.10
	Model (2')	0.40	0.38
Stochastic follow-up	Model (3)	0.96	1.16
	Model (4)[a]	0.94	1.15
	Model (4')	0.73	0.71
	Model (5)	1.13	1.15
	Model (5')[a]	0.58	0.64
	Model (6)	0.98	1.19
	Model (6')[a]	0.65	0.63

a: Appropriate double bounded models

Aggregation of benefits

Mitchell and Carson (1989) pinpoint four issues to consider regarding sampling design and execution in order to have a valid aggregation of benefits: population choice bias, sampling frame bias, sample non-response bias and sample selection bias. To select the respondents, random sampling was used in the study. Consistent with Carlsson and Johansson-Stenman (2000), protest and zero responses were not excluded from the analysis. As a result, these biases are not expected to affect the aggregate benefits.

Based on the number of households in the study area and mean WTP given by the restricted stochastic double bounded models and the second equation in the unconstrained conventional double bounded model, aggregate benefits are estimated at $429, $272, and $123. These benefits can be translated in terms of annual benefits or WTP per gallon of diesel, which can be viewed as a premium for biodiesel price compared to petroleum diesel price. According to the Ohio Department of Transportation (2006), Ohio diesel consumption for the year 2005 was about 1.57 billion gallons, and fuel consumption in Ohio changed at the same rate as the Ohio population from 1970 to 2005. Relying on population data, diesel consumption in the study area is estimated at 257.84 million gallons for 2005, yielding a premium for biodiesel price estimated at nine, 31, and 20 cents for the three models respectively.

Since model 6' is the most efficient, the appropriate premium lies in the confidence interval of 14 to 26 cents, as shown in Table 8. These results suggest that if a policy aiming at promoting biodiesel production and use entails charging a premium within the above range, consumers would be willing to pay it because of the environmental benefits they will reap. Put differently, a price differential between pure diesel and blended or pure biodiesel would be justified from the perspective of the consumers. It is worth noting that the estimated premium range is consistent with the price differential range, 15 to 30 cents, observed in recent years.

Table 7: Aggregate benefits and their confidence intervals

	Conventional follow-up	Stochastic follow-up	
	Model 2 ($\$10^6$)	Model 5' ($\$10^6$)	Model 6'($\$10^6$)
Benefits	123.05	428.70	271.95
Delta	93.26 - 152.83	305.66 - 552.53	183.39 - 360.52
Krinsky-Robb	91.70 - 152.04	337.79 - 613.66	192.01 - 362.87

N.B.: For annual benefits, these numbers need to be divided by 5.

Table 8: Annual WTP per gallon of diesel

Annual benefits per gallon of diesel ($)						
	Conventional follow-up		Stochastic follow-up			
	Model 2		Model 5'		Model 6'	
Benefits	0.089		0.311		0.197	
Delta*	0.068	0.111	0.222	0.401	0.133	0.261
Krinsky-Robb*	0.066	0.110	0.245	0.445	0.139	0.263

*: 95% Confidence interval

Concluding remarks

The double bounded dichotomous choice has emerged as a means to improve statistical efficiency in contingent valuation applications. However, this approach has been criticized. The second question is an incentive for strategic behavior. Respondents answering “yes” to first question tend to answer “no” to the second question regardless of the second bid amount, leading mean WTP to shift downward when the second question is introduced. We then asked the question as to whether allowing respondents to express uncertainty in the follow-up question has an effect in reducing inconsistencies between the first and the second responses while efficiency gain is maintained over the single bounded model.

A split sampling methodology was used wherein the first half respondents received the conventional double bounded questionnaire and the second half respondents received a questionnaire in which the follow-up question is in a stochastic format to allow respondents to provide uncertain responses. The stochastic format asks the respondents the probability or likelihood of paying a higher (respectively lower) bid if he/she answers “yes” (respectively “no”) to the first bid.

Single bounded models using pooled data from the first question in both sub-samples were estimated to assess the internal validity of the contingent valuation and to identify determinants of WTP. The results confirm the validity of the contingent valuation and are consistent with findings in most contingent valuation studies.

Comparing the two follow-up approaches results indicate that the stochastic format yields more efficient WTP estimates than the regular or conventional follow-up approach by increasing the correlation between the first and the second responses. Since the error correlation coefficients are considerably above 0.5, efficiency gain can be obtained by constraining both means and variances to be the same across questions. Four restricted models were then estimated: one conventional double bounded model and three stochastic double bounded models. Whereas the restrictions were rejected for the conventional double bounded model, they hold for two of the stochastic double bounded models. Since the restricted stochastic double bounded models are valid and more efficient than the single bounded model, allowing respondents to express uncertainty in the follow-up question seems to reduce the strategic behavior while maintaining efficiency gain. Statistical inconsistencies seem to be alleviated also since the error correlation coefficients increase in the stochastic double bounded models.

The restricted conventional double bounded model is more efficient than the restricted stochastic double bounded models, but the data did not support the restrictions. Thus, the efficiency gain comes at the cost of biasness. Since less noisy, the WTP estimate for the second equation in the unrestricted version of the conventional double bounded model is used to estimate aggregate benefits at \$123 million. Aggregate benefits using the valid restricted stochastic double bounded models are estimated at \$429 million and \$272 million for a five-year period. Energy policy implications of these results are that that the public would be willing to make money contributions to protect the environment. If the cost of producing and using more biodiesel entails charging a premium, consumers would be willing to pay it, due to the resulting environmental benefits.

Our hope is that this study will be followed by other applications of the dichotomous choice format with a stochastic follow-up question. Future research may try implementing a scope test. The test can be done using both the regular and the stochastic follow-up formats to determine whether both follow-up versions pass the test. In addition, the recoding methods used to convert responses from uncertain to certain can be an issue. Results may vary depending on how uncertain response choices are recoded. Here, we draw upon previous studies and the pattern of the data to choose the recoding methods. The results in this study indicate that the recoding procedure relying on the pattern of the data yields the most efficient and appropriate model. To avoid the issue of recoding, future research using the stochastic follow-up can attempt to parameterize the likelihood function in a way to incorporate the uncertain response options directly. One condition that needs to be satisfied is that respondents must switch from “definitely yes” to more uncertain response categories (“probably yes”, “not sure” and “probably no”) and to “definitely no” as the magnitude of the bid increases. In this study, such a behavior was not observed. When such a behavior is observed then thresholds that further bound WTP can be estimated.

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Appendix: Valuation Questions with both Conventional and Stochastic Follow-up Formats

Valuation questions with conventional follow-up format

Please answer the following questions:

14. If fundings were available, would you favor a cleaner environment? Please circle one of the following:
    1. Yes
    2. No

When answering the following questions, please think of your income and what producing and using more biodiesel in Ohio are worth to your household.

15. Suppose this project could be completed in 5 years and is estimated to cost your household a lump sum payment of $***X*** to the trust fund. Suppose further that payment arrangement allows you to spread out your payment over one year. If an election were held today, would you vote for the project?
    1. Yes
    2. No

If you said *Yes*, please continue to question 16

If you said *No*, please Skip to question 17

16. Suppose instead the project would cost your household a lump sum payment of $***Y (>X)***, would you still vote for it? Please circle one of the following:
    1. Yes
    2. No

Now skip to question 18

17. Suppose instead the project would cost your household a lump sum payment of $***Z (<X)***, would you now vote for it? Please circle one of the following:
    1. Yes
    2. No

(Continue to question 18)

Valuation questions with stochastic follow-up

Please answer the following questions:

14. If fundings were available, would you favor a cleaner environment? Please circle one of the following:
    1. Yes
    2. No

When answering the following questions, please think of your income and what producing and using more biodiesel in Ohio are worth to your household.

15. Suppose this project could be completed in 5 years and is estimated to cost your household a lump sum payment of **$*X*** to the trust fund. Suppose further that payment arrangement allows you to spread out your payment over one year. If an election were held today, would you vote for the project?
    1. Yes
    2. No

If you said *Yes*, please continue to question 16

If you said *No*, please Skip to question 17

16. Suppose instead the project would cost your household a lump sum payment of $***Y* (>*X*),** how likely would it be for you to vote for it? Please mark a box with an x to indicate how you would vote. For example, “Definitely Yes” means that you would definitely vote for the project. The numbers indicate the probability that you would vote for the project. For example, 1.0 indicates a 100 percent probability that you would vote for the project.

	Definitely Yes			Probably Yes		Not sure	Probably No		Definitely No		
	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0
→											

Now Skip to question 18

17. Suppose instead the project would cost your household a lump sum payment of $***Z (<X),*** how likely would it be for you to vote for it? Please mark a box with an x to indicate how you would vote. For example, “Definitely Yes” means that you would definitely vote for the project. The numbers indicate the probability that you would vote for the project.

	Definitely Yes			Probably Yes		Not sure	Probably No		Definitely No		
	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0
→											

Continue to question 18

Endnotes

[1] Constrained models must be used for inferences if the data support the restrictions from a statistical standpoint.

[2] Explanatory variables included are based on previous studies.

[3] For the linear model, mean and median WTP are equivalent

[4] The bootstrapping method, although not appropriate here, was attempted. It is very computationally intensive and thus very unattractive in bivariate probit models.

[5] While these models are referred to as random effects probit, we did not use random effects probit routines. The models are estimated by bivariate probit procedures while applying the restrictions. Interval data models were also estimated; however, the data did not support the restrictions imposed by the interval data models. Applying restrictions rejected by the data would entail imposing one’s will on the data.

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