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Using Stated Preferences to Estimate Environmental Benefits of Biodiesel Fuel in Diesel Engines

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Introduction

Most people recognize that clean air is vital for a healthy environment. However, our economy is dependent on many sectors whose activities are associated with air pollutant emissions; leading to environmental degradation and global warming. Instances include the transportation and the industrial sectors. In fact, road transportation is responsible for a significant share of gaseous emissions. According to US Environmental Protection Agency (2004), in 2002, the transportation sector (mobile on-road) accounted for 77% of carbon monoxide (CO) emissions, 43.7% of volatile organic compound (VOC) emissions or hydrocarbons (HCs), about 2.3% of PM2.5 (fine particulate matter) emissions and 54.3% of nitrogen oxide (NOx) emissions which react with VOCs and sunlight to form ozone and smog in the atmosphere. Mobile sources (on-road and non-road) produce several other important air pollutants such as air toxics and greenhouse gases. Greenhouse gas emissions such as carbon dioxide (CO_2) are known to trap heat in the Earth's atmosphere, contributing to global climate change.

Within mobile sources, diesel engines contribute considerable pollution to the nation's continuing air quality problems. Diesel emissions lead to a failure to meet federal air quality standards in many US counties. While federal standards have begun to address emissions in newly manufactured engines since 2007, existing diesel vehicles will continue to cause health and environmental problems for decades, unless actions are taken to prevent them. Diesel engine sales have grown over the last decade, so that now about a million new diesel engines are put to work in the United States every year. Diesels overwhelmingly dominate the bus and large truck markets and have captured a growing share of the light and heavy-duty vehicle market over the last decade. In commercial and industrial applications, diesel is widely used. Diesel engines power almost two thirds of agricultural equipment, almost 100% of off-road construction equipment, as well as 94% of freight ton-miles such as rail, shipping and truck modes (Diesel Forum Technology, 2003). It is also a fact that public transportation systems rely heavily upon diesel engines to provide transportation in and between cities.

While playing a vital part in economic growth, diesel-powered vehicles contribute to the negative health effects associated with ozone, PM, NOx, sulfur oxides (SOx) and VOCs, including toxic compounds such as formaldehyde. Indeed, from the emissions contributed by the transportation sector, diesel-powered engines account for 46.1% of NOx, 55.3% of PM-10 and 4.6% of VOCs (US Environmental Protection Agency, 2004). Nitrogen and sulfur oxides are important constituents of acid rain, which degrades rivers and lakes, diminishes crop yields, deteriorates buildings and damages trees and forests.[2]

Since the majority of air pollution is caused by vehicle exhaust, using cleaner burning fuels is one alternative that could provide immediate results. Thus, using pure biodiesel or blended diesel fuel in diesel engines has received considerable attention from the government and consumers in the United States. The use of biodiesel does not give rise to any net CO_2 emissions on combustion, and its direct sulfur emissions from combustion are normally measured as between 0% (for B100, pure biodiesel) and 20% (for B20, a diesel blend with 20% biodiesel) those of diesel. The tail pipe particulate emissions are often measured as between a third and half those from fossil diesel, provided the engine timing is adjusted. Biodiesel provides other environmental benefits such as low toxicity and high bio-degradability that make it particularly suitable for use in environmentally sensitive areas, which warrant special protection. Specifically, in a full lifecycle assessment, using B100 would reduce emissions of CO_2 by 75%, PM by 47%, sulfur by 100% and VOC by 56.3% (US Environmental Protection Agency, 2002; US Department of Energy, 2001).

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[2] When the new low sulfur diesel engines saturate the market PM and NOx will be reduced significantly.

This case study focuses on the valuation of these environmental benefits, which is crucial to conducting a full cost-benefit analysis for energy policies involving biofuels. As Carson (2000) argues, such analysis is seriously defective when neglecting the monetary values for environmental amenities and services associated with the proposed action. We address the issue as to whether citizen consumers would be willing to bear the cost of putting to use more biodiesel in order to reduce diesel-powered vehicle exhaust. If so, how much would they be willing to pay and what are the determinants of their willingness to pay (WTP)? Is the range ($0.15 to $0.30/gallon (gal)) of price differential between diesel and biodiesel observed in recent years reasonable? To the best of our knowledge, answers to these questions, which are crucial for energy policy decision-making, have not been determined.

Since the aforementioned environmental benefits are not traded in markets, our approach is rooted in economic valuation methods applied to non-market goods and services (Freeman, 2003; Haab and McConnell, 2002). Following Arrow *et al.* (1993), we use the dichotomous choice question or referendum rather than the open-ended format. As suggested by Hanemann *et al.* (1991), to improve the statistical efficiency of WTP estimates, a follow-up question to the dichotomous choice question – thus the double bounded formulation – was used.

Methods for Valuing Benefits from Air Pollution Reduction

In the literature, two general methods have been used to value environmental benefits arising from air pollution reduction: the hedonic pricing method (HPM) and the contingent valuation method (CVM). The basic premise of the HPM is that the price of a particular characteristic of a good is embedded in the price of the good. On the other hand, the CVM asks individuals to state their willingness to pay for environmental improvement directly using a survey questionnaire to acquire information. Central to this method is the construction of a hypothetical allocation procedure for the public good under consideration.

Because HPM cannot be used to measure non-use values, CVM has evolved as a more flexible approach to estimating non-market benefits of air pollution reduction. CVM has been used in different formats. However, most recent applications use the double bounded dichotomous choice question, which has been proven to improve statistical efficiency. The double bounded formulation entails asking the respondents a first bid question then increasing (respectively decreasing) the bid if the respondents answer yes (respectively no) to the first bid.

A study by Vassanadumrongdee and Matsuoka (2005) employed the double bounded model to measure individuals' WTP to reduce mortality risk arising from air pollution and from traffic accidents in Bangkok, Thailand. Yoo and Chae (2001) utilized the double bounded format to assess the economic benefits of an ozone pollution control policy in Seoul. Another study by McLeod and Bergland (1999) put forward the double bounded method in a Bayesian framework to estimate WTP for a 25% reduction in US air and water pollution.

While the studies cited above concern air quality improvement, none of them has focused on measuring the environmental benefits arising from using biodiesel fuel in diesel engines. Another improvement over the current literature is that this study applies a new follow-up approach, referred to as stochastic follow-up, wherein the second question in the double bounded format is formulated in a probabilistic format. Unlike the conventional follow-up format which requires a yes/no answer from the respondent, the stochastic follow-up approach[3] calls for an answer from five answer choices which are "definitely no (DN)," "probably no (PN)," "not sure (NS)," "probably yes (PY)," and "definitely yes (DY)."

Survey Methodology

Between May and June 2006, 3500 survey questionnaires were mailed out to a random sample of residents age 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. 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)[4] 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." To minimize non-response bias, we followed the 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

[3] This approach is an attempt to reduce inconsistencies in WTP estimates yielded by the first and second questions.
[4] The payment vehicle used was a one time lump sum contribution to a trust fund designed for the biodiesel project.

Table 1: Environmental Benefits of Biodiesel.

Benefits	Indicators		
		B100	B20
Reduction in vehicle emissions	**Emissions**		
	Carbon monoxide (CO)	-43.2%	-12.6%
	Hydrocarbons (HCs)	-56.3%	-11.0%
	Particulates (PM)	-55.4%	-18.0%
	Nitrogen oxides (NOx)	+5.8%	+1.2%
	Air toxics (Formaldehyde, benzene, ...)	-60%-90%	-12%-20%
	Sulfur (SO_2)	-100%	-20%
	Mutagenicity	-80%-90%	-20%
Reduction in CO_2 emissions (the largest contributor to global warming)	Biodiesel adds no new CO_2 added into the atmosphere, but CO_2 uptake by plants.	Reduction by more than 75%	CO2 Reduction by 15%
		B100 recycles CO_2	Reduces CO_2 significantly in the atmosphere
Better smell	No sulfur, fewer aromatic hydrocarbons	Odors reduced by over 50%. Benzofluoranthene: 56% reduction; Benzopyrenes: 71% reduction	Odors reduced sufficiently with B20 to smell much more pleasant to human noses.
Biodegradability and non-toxicity	Four times faster than conventional diesel, therefore much less risk in case of spills in marine or other sensitive environments. More degradable than sugar and less toxic than table salt.	B100 is 100% degradable.	B20 improves biodegradability significantly.

Sources: US Department of Energy, 2001; US Environmental Protection Agency, 2002.

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. For the contingent valuation study to be credible to policy makers, it suffices that the respondents or prospective consumers understand what they are being asked to value, how it will be provided and how it will be paid for (Carson *et al.*, 2001). The respondents were told that they might want to vote for the project because of the environmental benefits listed in the last column of Table 1 (See the valuation scenario in Appendix).

The third part of the questionnaire focused on economic and socio-demographic characteristics of the respondents. The final section concerned the 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.

Strategic behavior such as free-riding problems is known to cause respondents to state non-positive willingness to pay (even though they value the good), knowing that if the good is provided they cannot be excluded from its consumption due to the non-divisibility and non-rivalness characteristics of the good. To deal with free-riding, the respondents were notified that the good will not be provided unless everyone contributes.

Theoretical Framework and Estimation Procedures

The theoretical underpinning of the contingent valuation method is a well developed area. Individuals or households are assumed to maximize utility subject to their income constraint. As a result, the indirect utility function and minimum expenditure function provide the theoretical basis for welfare estimation. For stated preferences, welfare change is measured by a change in these functions. Thus, CVM can be viewed as a direct measure of welfare change. WTP is the amount of income that compensates an individual for a welfare change. In principal, an individual's WTP for air pollution reduction is the amount that must be taken away from the individual's income while keeping his or her utility unchanged:

$$V(y\text{-}WTP, P, Z, Q_1) = V(y, P, Z, Q_0), \qquad (1)$$

where V is the indirect utility function, y income, P is a price vector, Z is a vector of socio-economic variables and

Q_0 and Q_1 are the environmental quality at status quo and improved levels, respectively.

Solving for WTP yields:

$$WTP = F(Y, P, Z, Q_0, Q_1). \quad (2)$$

Equation 2 underlies the estimation of a valuation function that depicts the monetary value of a change in economic welfare that occurs for any change in environmental quality. More on theoretical foundation of assessing welfare change using a contingent valuation framework can be found, for example, in Freeman (2003); Bateman and Willis (1999); Hanley *et al.* (1997); and in Randall (1987).

Denoting the willingness to pay determinants as a vector, *X*, then for each respondent $j=1, ..., N$ in the sample, the latent variable, WTP*, can be written as in Equation 1 for a single bounded model:

$$WTP^* = X_j'\beta + \varepsilon_j, \quad (3)$$

where β is a vector of parameters to be estimated. To obtain insight regarding the validity of the contingent valuation, Equation 3 was estimated using different distributional and functional form assumptions. Responses to the first question in both sub-samples are pooled together to carry out these regressions.

To improve the precision of mean/median WTP estimates, double bounded models were estimated. While such models can be estimated using answers to the two yes/no questions in the conventional follow-up, the five answer choices in the stochastic format will need to be recoded in yes/no answers. Econometrically modeling data generated by the double bounded question format relies on the formulation given by:

$$WTP_{ij} = \mu_i + \varepsilon_{ij}, \quad (4)$$

where WTP_{ij} represents the j^{th} respondent's willingness to pay and i=1, 2 denotes 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. Assuming a normal bivariate distribution $NBD(\mu_1, \mu_2, \sigma_1, \sigma_2, \rho)$, this general specification yields the double bounded bivariate probit model (Cameron and Quiggin, 1994). When ρ, 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 equations.[5] All models[6] were estimated using the maximum likelihood estimation technique. Also, data management and the empirical analysis were conducted using Stata 9.2.

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

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

Assuming a linear function form, mean/median WTP is given as in Huang and Smith (1998) for each question or equation:

$$\hat{\mu} = -(\hat{\alpha} + \overline{X}\hat{\beta}')/\hat{\beta}_0, \quad (5)$$

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

$$\hat{\sigma} = -1/\hat{\beta}. \quad (6)$$

Empirical Results

Descriptive Statistics

Out of 3500 questionnaires sent out, 309 surveys 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 are usable. Descriptive statistics are shown in Table 2. 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; males represented 63%; and 67% were married or lived with a partner.

At the end of the valuation section, the respondents were asked an attitudinal question to establish the reasons underlying their willingness or unwillingness to contribute to the hypothetical biodiesel project. Several statements were presented to them and they were to choose all options that fit them best based on how they felt when they valued the project. They were also given the possibility to write their own statements. One statement offered was to identify respondents who would express WTP solely on the basis of altruistic motives (pure or impure). For example, if a respondent chooses the option stating: "*The project is not important to me, but I want to contribute to a good cause,*" this would imply that he or she just wants to participate in something good that is being undertaken. The respondent may also think that other people will derive some benefits once the good is provided. The results are displayed in Figure 1. Note that the percentages associated to the statements do not sum up to one hundred, because respondents were allowed to choose all statements that applied to them.

As can be seen, only 3% of the respondents felt that the project were not important. Fourteen percent indicated that they could not afford to pay the proposed amount, meaning that the survey respondents were mindful of their income when stating their WTP. Another 14% thought that they should not be responsible for the project. More than 90% of the respondents would vote yes simply because they wanted to contribute, and protecting the environment seemed appeal-

Table 2: 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 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

ing to them. Only one percent of the respondents expressed their WTP because of pure or impure altruism. Fifteen percent of the respondents stated other reasons for their unwillingness or willingness to pay. Among these reasons are the following:

- I doubt the government's ability to carry this through.
- Let the economic forces of the market place operate.
- I would be willing to pay even for those who cannot pay.
- We made the mess and fixing it costs money.
- Take the money from my taxes.
- This is more than important, let us see more of it.

WTP Determinants

Table 3 summarizes the results 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, the respondents would be less likely to pay, providing credence to the WTP responses.

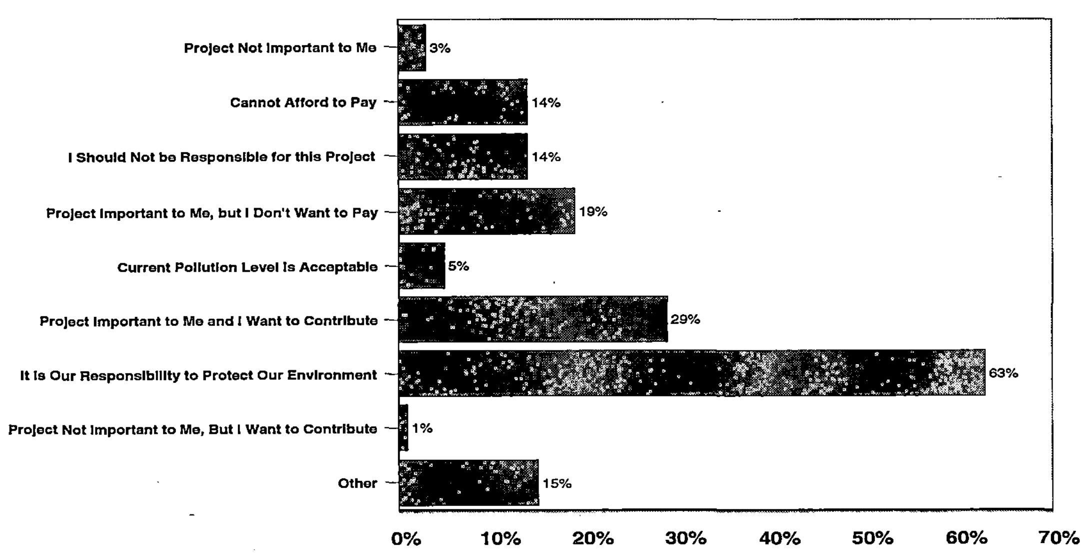

Figure 1: Reasons for Zero or Positive WTP.

Table 3: 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 the 5%; *** Significant at the 1%. Standard errors, which are in parenthesis, are adjusted for intra-county correlation.

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. Another explanation has to do with property right. The pollution-knowledgeable respondents may think that they have the right to a clean environment and that, knowing the

Table 4: Estimated Mean/median Willingness to Pay (WTP) ($).

Statistics	Conventional DC-DB	Stochastic DC-DB[b]	
	Model 1	Model 2	Model 3
Mean WTP*	157	547	347
σ	384	896	637
ρ	0.56	0.58	0.88
Delta Method[a]	119 – 195	390 - 705	234 - 461
Krinsky-Robb[a]	117 – 194	431 - 783	245 - 463
LogL	-380.82	-355.36	-340.00
N	323	313	313

Note: All mean WTP estimates are significant at the one percent significance level.
[a] 95% confidence interval.
[b] Mean and variance of WTP are constrained to be the same for both questions.

source of air pollution, they should not be paying. 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 statistically 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 are 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 likely to pay.

Mean and Aggregate WTP

To compute mean/median WTP several bivariate probit models were estimated. Drawing upon Moran and Moraes (1999), only the bid price and income are used as covariates. Results are reported in Table 4 for three models based on a statistical efficiency criterion. Model 1 is a double bounded model estimated using data from the conventional follow-up approach. Model 2 and Model 3 are double bounded models estimated using data from the stochastic follow-up method. Model 2 is obtained by recoding DN and PN as "no;" and NS, PY and DY as "yes." For Model 3, the recoding method is the same as in Model 2 except that NS is recoded as "yes" only for the respondents who answered yes to the first WTP question.

For a period of five years, mean/median WTP is estimated at $157, $547 and $347, respectively, for the three models. In computing mean/median WTP, median income from Census data for the study area is used rather than the average or median income from the survey data, adjusting for the fact that the survey respondents' median income is much higher than the median income of the population in the study area. All the mean WTP estimates are significant at the one percent significance level. Ninety five percent confidence intervals given by the delta method and the Krinsky and Robb simulation procedures are fairly similar.

Aggregate estimates are obtained based on estimated mean/median WTP and the total number of households in the study area. The results are displayed in Table 5. As can be seen, aggregate benefits are estimated at $123, $429 and $272 million, respectively, for the three models for a five-year period. These figures can serve as a starting point for cost-benefit analysis of biofuel related policies.

Table 5: Aggregate Benefits (10^6).

	Conventional follow-up	Stochastic follow-up	
	Model 1	Model 2	Model 3
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

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

Table 6: Estimated biodiesel price premium.

Annual benefits per gallon of diesel ($)						
	Conventional follow-up		Stochastic follow-up			
	Model 1		Model 2		Model 3	
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

The aggregate benefits are translated into annual benefits or WTP per gallon of diesel, which can be viewed as a premium for biodiesel. According to the Ohio Department of Transportation (2006), Ohio diesel consumption for the year 2005 was about 1.57 billion gal. Based on population data,[7] diesel consumption in the study area is estimated at 258 million gal for 2005, yielding a premium for biodiesel estimated at $0.09, $0.31 and $0.20 for the three models, respectively. Using efficiency as a criterion,[8] Model 3 would be the most appropriate, yielding a confidence interval of $0.14 to $0.26. These results, which are shown in Table 6, suggest that if a policy aiming at promoting biodiesel production and use requires charging a premium within the above range, consumers would be willing to pay it. 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, $0.15 to $0.30, observed in recent years (*The Economist*, 2005).

Concluding Remarks

The primary objective of this study was to estimate environmental benefits of using B20 in diesel engines in a 16 county airshed in Central and South Eastern Ohio. Single bounded models 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.

The double bounded parametric formulation was used to estimate mean and aggregate WTP. The results provide evidence 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. Based on a statistical efficiency criterion, this premium is estimated at $0.14 to $0.26, which is consistent with the range of the price differential between diesel and biodiesel observed in recent years. The study demonstrates how the contingent valuation method can be used to estimate environmental benefits of biodiesel in diesel engines.

However, producing more biodiesel to reduce diesel emissions is fraught with issues, one of which is the advent of the Ultra Low Sulfur Diesel (ULSD) on the market. A legitimate question is whether biodiesel will hold its environmental and other advantages in the near future. An October 2006 article published in The Economist suggests that the new cleaner burning diesel fuel might make up 10% of diesel consumption by 2025. Or, at least, the ULSD will dominate the market when EPA regulations require all highway and off-road diesel fuel to be ULSD. As a result, diesel-powered vehicles will continue damaging the environment for some time in the absence of appropriate energy policies to reduce diesel emissions. In addition, unpredictable prices and low fuel performance are two important concerns of the users awaiting ULSD. Early evaluations on ULSD foresee deficiencies in lubricity, conductivity, clod flow and increases in peroxide formation, which result from the sulfur removal process to meet the US Environmental Protection Agency standards (BEN, 2006). The uncertainty around the market conditions and expected poor performance of the ultra-low sulfur diesel may make biodiesel still attractive. Further, a study conducted by Clark *et al.* (2007) and commissioned by the Federal Transit Administration (FTA), a

[7] According to the same Ohio Department of Transportation report, fuel consumption in Ohio changes at the same rate as the Ohio population from 1970 to 2005.

[8] The ratio of the confidence interval to the mean/median WTP is used as a relative measure of efficiency or precision of WTP estimates (*i.e.*, CI/mean = (Upper bound - lower bound)/mean WTP). Also, the Krinsky and Robb method is more appropriate than the delta method since WTP measures are non-linear combinations of parameter estimates.

unit of the US Department of Transportation, analyzes transit bus life cycle cost (LCC), projected transit bus emissions and fuel economy for four 2007 model year buses: diesel buses using ULSD, diesel buses using B20 biodiesel (20% biodiesel and 80% ULSD), compressed natural gases (CNG) buses and hybrid diesel-electric buses. From a global perspective, B20 diesel buses were found to be the second best bus technology (after the hybrid technology) for well to wheels GHG emissions.[9] Ultimately, biodiesel could play a double role of lubricity additive and/or cetane booster for ULSD and of reducing particulates and unburned hydrocarbons.

Another issue has to do with producing biodiesel at a lower cost. This entails using feedstocks other than soybean oils. One solution would be to develop a variant of soybeans that generates proportionally more oil or to use other biomass resources such as used cooking oil, animal fats, algae or rapeseed oil. If soybeans oil is to be used at least for the moment, there will be implications for the livestock sector and other sectors of the economy. These issues constitute arenas for further research.

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[9] Recent studies comparing B20 and ULSD show that B20 biodiesel buses emit lower tailpipe PM and non-methane hydrocarbons (NMHC) than the ULSD fueled conventional buses. However, B20 buses emit slightly higher tailpipe NOx and CO_2 emissions than buses on the ULSD (Clark *et al.*, 2007). Increase in NOx can be eliminated using NOx control technologies such as catalytic converters which are common NOx reducing devices in Europe (Kotrba, 2005). Besides, a NREL's study, "NOx solutions for biodiesel," finds that di-tertiary butyl peroxide and ethylhexylnitrate, which are both cetane improvers, effectively reduce NOx without a PM trade-off (McCormick *et al*, 2003).

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Appendix: Valuation Scenario and Questions with Both Conventional and Stochastic Follow-up Valuation Scenario

We would now like to know what using more biodiesel in Ohio is worth to your household. Consider the following information:

Vehicles powered with petroleum diesel contribute to air pollution. Petroleum diesel exhaust contains components that have been linked to health and environmental impacts. Below we provide a list of diesel exhaust components and their related health and environmental impacts.

List of diesel exhaust components	**List of Impacts**	
	Health	**Environment**
❖ Air Toxics ❖ Carbon monoxides (CO) ❖ Hydrocarbons (HC) ❖ Nitrogen oxides (NOx) ❖ Particulate matter (PM) ❖ Sulfur oxides ❖ Ozone (Sunlight + HC + NOx)	❖ Cancer ❖ Chronic bronchitis ❖ Aggravated asthma and allergy symptoms ❖ Premature death ❖ Aggravated respiratory and cardiovascular disease	❖ Eutrophication of waterways ❖ Climate change ❖ Smog ❖ Acid rain ❖ Crop and forest damage

Emissions related to petroleum diesel fail to meet federal air standards which will begin to address these emissions in newly manufactured vehicles beginning in 2007. However, existing vehicles will continue to create emissions that affect air quality, unless actions are taken to prevent them.

To reduce emissions from diesel engines, the Ohio Department of Development's Office of Energy Efficiency (OEE) is considering a project to increase the production and use of biodiesel in Ohio. This project would encourage the fuel B20 (a blend of 20% pure biodiesel and 80% petroleum diesel) in all school and university buses, trains, trucks, tractors, transit buses and public fleets in your county. B20 reduces exposure to diesel exhaust by the communities including bused children, asthmatics, occupationally exposed workers, people with existing respiratory problems and elderly.

For this project to be implemented, it has to go on the ballot. We are doing this survey so that when we know the exact cost we can determine whether enough people would support it before putting it on the ballot. If the project does go on the ballot and passes, then everyone will contribute an equal amount to a trust fund devoted specifically to the project.

Currently, biodiesel production and use is sustained by a modest government tax incentive program. Therefore, any funds generated through contributions would be for the Ohio government to 1) organize, monitor, manage and promote the production of biodiesel since in Ohio, as of March 2006, only two biodiesel facilities exist and one facility is proposed to be built, 2) provide training on handling and use of biodiesel, 3) continue funding and possibly expand the tax credit incentive program, 4) and fund research on how to produce biodiesel at lower cost.

You may want to vote for the project for the following reasons:

- ❖ Results of a complete evaluation of emissions and potential health and environmental effects of biodiesel as an alternative fuel has been submitted to the US Environmental Protection Agency (EPA) under the Clean Air Act Section 211(b).
- ❖ Biodiesel is able to decompose naturally and is non-toxic.

- As indicated in studies conducted and reviewed by US EPA and US Department of Energy (DOE), using B20 will reduce tailpipe and engine compartment emissions from diesel-powered vehicles as follows, given the current technology available:
  - Regulated pollutants
    - Total unburned hydrocarbons by 20%
    - Carbon monoxide by 12%
    - Particulate matter by 12-18%
  - Unregulated pollutants
    - Sulfates by 20%
    - Polycyclic Aromatic hydrocarbon (PAH) by 13%
    - Nitrated PAH's (nPHA) by 50%
    - Ozone potential of speciated HC by 10%
- Reduction of greenhouse gases which cause global climate change.

However, you may prefer spending money on other things including other environmental goods such as protection of endangered species. In addition, depending on whether additives are used or not with B20, nitrogen oxides may increase by 2%, which may have some health effects such as respiratory infections.

Please answer the following questions: (Valuation questions with conventional follow-up)

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)

18. Based on how you would vote on this project, please tell us how you feel about it. From the list below, please circle the numbers indicating all statements below that apply to you.
    1. This project is not important to me
    2. I cannot afford to pay the proposed amount
    3. I do not think that I should be responsible for this project.
    4. The project is important to me, but I don't want to pay for it
    5. I think the current pollution level is acceptable
    6. I feel this project is very important to me and I want to contribute

Appendix (continued)

7. I think it is our responsibility to protect our environment.
8. This project is not important to me, but I want to contribute to a good cause.
9. Other____

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