Bio-fuels, Food and Feed Tradeoffs Conference
St. Louis, Missouri, April 12-13, 2007

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

P. Wilner Jeanty and Fred Hitzhusen*
Department of Agricultural, Environmental, and Development Economics
The Ohio State University
2120 Fyffe Rd, Columbus, OH 43210

February 2007

Abstract

Using biodiesel fuel to reduce emissions from diesel engines is an area of increasing interest. Many environmental benefits associated with biodiesel are not traded in markets and their estimation requires economic valuation methods applied to non-market goods and services. This paper presents the results of a contingent valuation survey conducted in 2006 in two Ohio regions to estimate willingness to pay for air pollution reduction arising from using biodiesel fuel in diesel engines. The double bounded parametric formulation was used to estimate mean WTP ranging from $157 to $457. These results yield estimated aggregate benefits ranging from $123 to $429 million and can be used as a starting point for cost-benefit analysis.

Keywords: Biodiesel, diesel, air pollution, environmental benefits, contingent valuation, willingness to pay, double bounded model.

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

---

* P. Wilner Jeanty and Fred Hitzhusen are respectively post-doctoral researcher and Professor in the Department of Agricultural, Environmental, and Development Economics, The Ohio State University. Send comments and suggestions to jeanty.1@osu.edu. (614) 292-9519.

1. 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 EPA (2004), in 2002, the transportation sector (mobile on-road) accounted for 77% of carbon monoxide emissions (CO), 43.7% of volatile organic compound emissions (VOC) or Hydrocarbons (HCs), about 2.3% of PM2.5 (fine particulate matter) emissions, and 54.3% of nitrogen oxide emissions (NOx) 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 engine sales have grown over the last decade, so that now about a million new diesel engines are put to work in the U.S. every year. Diesels overwhelmingly dominate the bus and large truck markets and have been capturing a growing share of the light and heavy-duty vehicle market over the last decade. In the commercial and industrial applications, diesel is widely used. Diesel powers almost two-thirds of agricultural equipment, almost 100 percent of off-road construction equipment is diesel powered, as well as 94 percent of freight ton-miles such as rail, shipping and truck modes. It is also a fact that public transportation systems rely heavily upon diesel engines to provide transportation in and between cities.

In spite of their key role in the economy, diesel-powered vehicles and engines contribute to the health and welfare effects of ozone, PM, NOx, sulfur oxides (SOx), and volatile organic compounds (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 (EPA, 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.

Since the majority of air pollution is caused by vehicle exhaust, using cleaner burning fuels is one alternative that provides rather 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, 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 has 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% (EPA, 2002; DOE, 2001).

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) forcefully 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 willingness to pay (W?TP)? Is the range (15 to 30 cents) of price differential between diesel and biodiesel observed in the last few 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 and Myrick, 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.

The paper is structured as follows. The next section reviews the literature on valuation methods used to value air quality improvement. Section 3 briefly describes the survey methodology. Section 4 presents the empirical model and estimation procedures. The empirical results of the analysis are presented in section 5. Section 6 concludes the study.

2. 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[1] 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)".

---

[1] This approach is an attempt to reduce inconsistencies in WTP estimates yielded by the first and second questions.

3. Survey methodology

Between May and June 2006, 3500 surveys 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. 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)[2] 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 follow the procedures suggested in Dillman (2000) when implementing the survey.

The survey questionnaire contains four sections. The first section deals 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 contains the valuation scenario, which attempts 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) are followed as much as possible. To establish the institutional setting in which the good will be provided, the respondents were told that the Office of Energy Efficiency at the Ohio Department of Development was 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 is to be provided. For the contingent valuation study to be credible to

[2] The payment vehicle used was a one time lump sum contribution to a trust fund designed for the biodiesel project.

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).

Table 1: Environmental benefits of biodiesel

Benefits	**Indicators**		
		B100	B20
Reduction in Vehicle Emissions	**Emissions**		
	Carbon monoxide	-43.2%	-12.6%
	Hydrocarbons	-56.3%	-11.0%
	Particulates	-55.4%	-18.0%
	Nitrogen oxides	+5.8%	+1.2%
	Air toxics (Formaldehyde, benzene, …)	-60%-90%	-12%-20%
	Sulfur (SO2)	-100%	-20%
	Mutagenicity	-80%-90%	-20%
Reduction in CO2 emissions (the largest contributor to Global Warming)	Biodiesel adds no new CO2 added into the atmosphere, but CO2 uptake by plants,	Reduction by more than 75%	CO2 Reduction by 15%
		B100 recycles CO2	Reduces CO2 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, 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 Dept. of Energy, 2001; US EPA, 2002

The third part of the questionnaire focuses on economic and socio-demographic characteristics of the respondents. The final section concerns the evaluation of the survey. It checks 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 may 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.

4. 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 income. 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:

$$V(y\text{-}WTP, P, Z, Q1)=V(y, P, Z, Q_0), \qquad (1)$$

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, Shogren and White (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 1 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 μ_{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 to be equal across equations[3]. All models[4] were estimated using the maximum likelihood estimation technique. Also, data management and the empirical analysis were conducted using STATA 9.2.

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

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

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:

$$\hat{\sigma} = -1/\hat{\beta}_0 \tag{6}$$

5. Empirical results

5.1 Descriptive statistics

Out of 3500 questionnaires sent out, 309 surveys were returned 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 are concerned about air pollution in their areas; about 76% state that they are aware of the fact that lawmakers, agricultural groups, and clean air advocates have agreed on the use of

---

[3] Constrained models must be used for inferences if the data support the restrictions from a statistical standpoint.
[4] Explanatory variables included are based on previous studies.

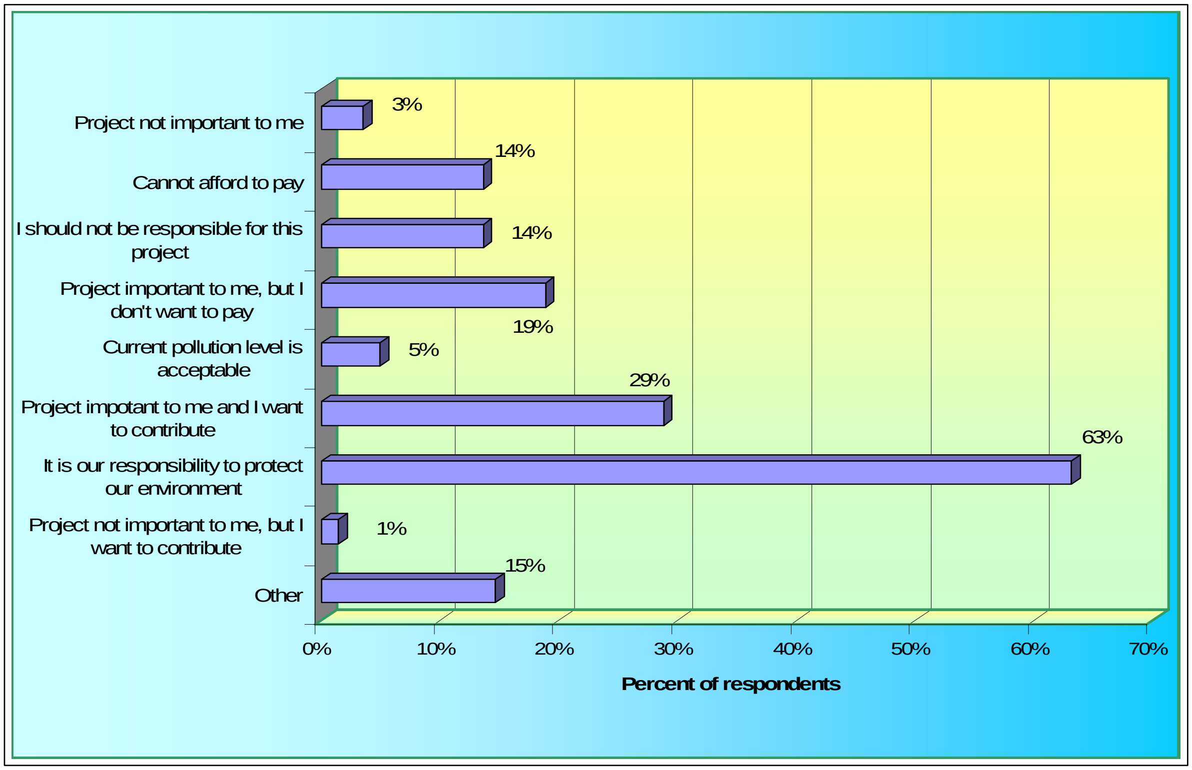
biodiesel as a way to reduce emissions from diesel powered vehicles. Most respondents are White, male represent 63%, and 67% are married or live with a partner.

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 causes of 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 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

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 scenario. Several statements were presented to the respondents 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 she just wants to participate in something good that is being undertaken. She 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 all statement do not sum to one hundred, because respondents were allowed to choose all statements that apply to them.

Figure 1: Reasons for Zero or Positive WTP



As can be seen, only 3% of the respondents felt that the project is not important. Fourteen percent indicate that they cannot afford to pay the proposed amount, indicating that the survey respondents were mindful of their income when stating their WTP. Another 14% thought that they are not the ones who should be paying. More than 90% of the respondents would vote yes simply because they want to contribute, and protecting the environment seems appealing to them. Only one percent of the respondents express their WTP because of pure or impure altruism. Fourteen percent of the respondents state 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.

5.2 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 for the plausibility of 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 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 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 indicate that bus services are not available in their cities. A dummy variable (*BUSSERV*) is used in lieu of inaccurately measured distance variables. The coefficients have a positive sign and are significant at the five percent significance level across models. This result indicates 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 increases in 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 understand the questionnaire and find the information provided useful are more likely to pay.

5.3 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 from the data using the conventional follow-up question. Model 2 and model 3 are double bounded models estimated from the data using the stochastic follow-up question. 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 in the study area. All the estimated mean WTP are significant at the one percent significance level. Ninety five percent confidence intervals given by the delta method and the Krinsky and Robb simulations 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 bee seen, aggregate benefits are estimated at \$123, \$429, and \$272 million respectively for the three models for a five-year period. The results can serve as a starting point for cost-benefit analysis of biofuel related policies.

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 (ODOT)[5], Ohio diesel consumption for the year 2005 was about 1.57 billion gallons. Based on population data[6], diesel consumption in the study area is estimated at 258 million gallons for 2005, yielding a premium for biodiesel estimated at nine, 31, and 20 cents for the three models respectively. Using efficiency as a criterion[7], model 3 would be the most appropriate, yielding a confidence interval of 14 to 26 cents. 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, 15 to 30 cents, observed in recent years.

---

[5] Source: Ohio Department of Transportation: Financial and Statistical Report, 2006

[6] According to the same ODOT report, fuel consumption in Ohio changes at the same rate as the Ohio population from 1970 to 2005.

[7] 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.

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

Table 4: Estimated mean/median 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

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

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

N.B.: 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

Conclusion remarks

The primary objective of this study was to estimate WTP for using more biodiesel 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 seem to provide evidence that the public would be willing to make 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. This premium is estimated at nine, 20, and 31 cents depending on the statistical model used. The results are consistent with the range of the price differential between diesel and biodiesel observed in the last few years.

However, one issue any policy to promote the production and use of biodiesel will have to face is the advent of the ultra-low sulfur diesel (ULSD) fuel on the market. A recent article published in the Economist suggests that the new cleaner burning diesel fuel might make up 10% of diesel consumption by 2025. As a result, diesel power vehicles will continue damaging the environment for some time in the absence of appropriate energy policies to prevent so. Another issue is that producing more biodiesel will have economic impacts on other sectors of the economy. One obvious implication is the food vs. feed trade off. 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, algae or rapeseed oil. These issues constitute arenas for further research.

References

Alberini, Anna and Alan Krupnick. "Valuing the Health Effects of Pollution." In Thomas Tietenberg and Henk Folmer (eds.), *The International Yearbook of Environmental and Resource Economics* 2002/2003. Northampton, MA: Edward Elgar, 2003.

Arrow, K.R., Solow, P.R., Portney, E.E., Leamer, R., Radner, R. and Schuman, H. "Report of the NOAA Panel on Contingent Valuation." *Federal Register*, 58(1993): 4601-4614.

Bateman, I.J. and K.G. Willis. *Valuing Environmental Preferences. Theory and Practice of the Contingent Valuation in the US, EU, and Developing Countries*, Oxford University Press, New York, (1999): 302-441.

Cameron, T. A. and J. Quiggin. "Estimation Using Contingent Valuation Data from a Dichotomous Choice with Follow-up Questionnaire." *Journal of Environmental Economics and Management* 27(1994): 218-34.

Carlsson, Fredrik and Olof Johansson-Stenman. "Willingness to Pay for Improved Air Quality in Sweden." *Applied Economics* 32 (2000): 661-69.

Carson, R. T., N.E. Flores, and N.F. Meade. "Contingent Valuation: Controversies and Evidence." *Environmental and Resources Economics* 19(2001): 173-210.

Carson, Richard T. "Contingent Valuation: A User's Guide." *Environmental Science and Technology* 34 (2000): 1413-1418.

Department of Energy (DOE). "Biodiesel Offers Fleets better Alternative to Petroleum Diesel. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy." *Technical Assistance Fact Sheet,* 2001.

Dillman, D. A. *Mail and Internet surveys: The Tailored Design Method*. 2nd ed. New York, NY: John Wiley & Sons, 2000.

Freeman III, A.M. "The Measurement of Environmental and Resource Values: Theory and Methods." *Resource for the Future*, Washington D.C., 2003.

Haab, Timothy C. and Kenneth E. McConnell. *Valuing Environmental Natural Resources*: *The Econometrics of Non-Market Valuation*. Northampton, MA: Edward Elgar Publishing, 2002.

Hanemann, W. M., J. Loomis, and B. J. Kanninen. "Statistical efficiency of double-bounded dichotomous choice contingent valuation." *American Journal of Agricultural Economics* 73 (1991): 1255-263.

Hanley, N., F.J. Shogren, and B. White. *Environmental Economics in Theory and Practice*, Macmillan Press Lt.d. U.K., 1997.

Huang, Ju-Chin and V.K. Smith. “Monte Carlo Benchmarks for Discrete Valuation Methods.” *Land Economics* 74(1998): 186-202.

Loureiro, Maria, A. Gracia, and R. M. Nayga. “Do Consumers Value Nutritional Labels?”. *European Journal of Agricultural Economics* 33(2006): 249-268.

McLeod, D. M. and O. Bergland. “Willingness-to-Pay Estimates Using the Double-Bounded Dichotomous-Choice Contingent Valuation Format: A Test for Validity and Precision in a Bayesian Framework.” *Land Economics* 75 (1999): 115-125.

Moran, Dominic and A.S. Moraes. “Contingent Valuation in Brazil: An Estimation of Pollution Damage in the Pantanal.” In *Natural Resources Valuation and Policy in Brazil: Methods and Cases,* eds Peter H May and Mary C. Paul, Columbia University Press, New York, 1999.

Randall, Alan. *Resource Economics: An Economics Approach to Natural Resource and Environmental Policy*, The Ohio State University, 1987.

The Economist. *Diesel in America: Second Coming*, November, 2006, p75.

U.S. Department of Energy (DOE). “Biodiesel Offers Fleets better Alternative to Petroleum Diesel. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy.” *Technical Assistance Fact Sheet,* 2001.

U. S. Environmental Protection Agency, National Emission Inventory Air Pollutant Emission Trends, 2004. Website: http://www.epa.gov/ttn/chief/trends.

U.S. Environmental Protection Agency, EPA. *A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions* (EPA-420-P-02-001), 2002.
http://www.epa.gov/otaq/models/biodsl.htm.

Vassanadumrongdee, Sjitra and Shunji Matsuoka. “Risk Perceptions and Value of a Statistical Life for Air Pollution and Traffic Accident: Evidence from Bangkok, Thailand.” *The Journal of Risk and Uncertainty* 30(2005): 261-287.

Yoo, Seung and Kyung-Suk Chae. “Measuring the Economic Benefits of the Ozone Pollution Control Policy in Seoul: Results of a Contingent Valuation Survey.” *Urban Studies* 38(2001): 49-60.