Monetized value of the environmental, health and resource externalities of soy biodiesel

By

Matthew Winden, Nathan Cruz,
Timothy Haab, Bhavik Bakshi

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University of Wisconsin – Whitewater
Department of Economics
4th Floor Hyland Hall
800 W. Main Street
Whitewater, WI 53190

Tel: (262) 472 - 1361

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Authors: Matthew Winden*, Nathan Cruze, Tim Haab, Bhavik Bakshi *Corresponding Author

ABSTRACT

This study monetizes the life cycle environmental damage, human health risk, and resource depletion externalities associated with the production and use of biodiesel fuels from soybean feedstock. Utilizing an integrated economic-environmental assessment framework that couples life cycle impacts and a conjoint choice experiment for social preference elicitation allows for a comprehensive comparison of petrodiesel and biodiesel's external impacts. The results of the study reveal the production and consumption of soybean based biodiesels produce net improvements in environmental, health and resource impacts of \$0.27 per gallon relative to petrodiesel for a 20% blend and \$3.14 per gallon for a 100% blend.

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Matthew Winden*
University of Wisconsin - Whitewater
Department of Economics
800 W. Main Street
Whitewater, WI 53190
windenm@uww.edu

Nathan Cruze
USDA-NASS
Research and Development Division
3251 Old Lee Highway
Fairfax, VA 22030
nathan.cruze@nass.usda.gov

Tim Haab
The Ohio State University
Department of AED Economics
2120 Fyffe Road
Columbus, OH 43210
haab.1@cfaes.osu.edu

Bhavik Bakshi
The Ohio State University
Dept. of Chem. and Biom. Engineering
140 West Nineteenth Avenue
Columbus, OH 43210
bakshi.2@osu.edu

Highlights

- Soy biodiesel offers benefits in environmental, health and resource outcomes over diesel
- Consumers' WTP for these benefits is $0.27/gallon for a 20% biodiesel blend
- Consumers' WTP for these benefits is $3.14/gallon for neat biodiesel
- Current policies encouraging biodiesel blends should likely be expanded.
- Integrated LCIA and valuation techniques can lead to more comprehensive fuel analysis

Introduction

The current transportation infrastructure in the United States is almost wholly dependent on petroleum based fossil fuels such as gasoline and diesel. Transportation consumes 30% of global energy, 99% of which is supplied by petroleum, and is expected to account for about ½ of the total projected increase in global oil use between 2003 and 2030 (EIA[a] 2013). Increasing prices and domestic and global demand for petroleum based energy have spurred interest in large-scale production of biofuels to address both domestic energy security, as well as global climate change issues (Soloman 2010). There seemed to exist no alternative that could compete widely in terms of cost and convenience for transportation applications, but today, biomass-based fuels like biodiesel are emerging as plausible alternatives (Rajagopol and Zilberman 2007).

Biodiesel is the product of organically derived oils (e.g. soy, canola, palm or animal fat) chemically reacting with an alcohol to produce a fatty acid alkyl ester, usually through the process of transesterification (Demirbas 2009; Wassell and Dittmer 2006). These biomass-derived esters can be blended with petroleum-based diesel fuel (petrodiesel) or be used on their own as a “neat” fuel. Due to their physical and chemical similarity, biodiesel is easily substituted in diesel engines and, while it is generally more expensive to produce, also significantly lowers many pollutant emissions compared with petrodiesel over its production and consumption life-cycle (Biodiesel Board 2013; DOE 2013).

The main contribution of these fuels is in providing energy that is renewable, less carbon intensive, easily adapted to current infrastructure, and can be produced domestically, which may increase farm income and improve national security (Demirbas 2009; Duffield 2007; Miyake et al. 2012; Rajagopol and Zilberman 2007; Soloman 2010). For all of these reasons, the share of biodiesel in the US automotive fuel market is expected to grow rapidly over the next decade and is expected to reach 1.4 billion gallons by 2019 (FAPRI 2005). But, expansion also raises a variety of concerns, such as the increase in food prices that follow and its impact on the poor (Janda, Kristoufek, and Zilberman 2012). Environmental impacts resulting from the expansion of agricultural land, the increase in use of pesticides, fertilizers and water, as well as the potential detrimental effects on soil carbon sequestration, soil quality maintenance, and the prevention of soil erosion are all of major concern as well (Delucchi 2010; Miyake et al. 2012; Soloman 2010; Ziolkowska and Simon 2011).

The consensus is that, compared to the GHG emissions from conventional petrodiesel, emissions from biodiesel are lower by 40-50%; air quality effects are mostly positive and reduce carbon monoxide emissions by 25-50%; particulate emissions are reduced by almost half and hydrocarbons by about two-thirds (DOE 2013). But nitrogen oxide emissions are higher in production and use, especially because of on-farm emissions from fertilizer usage. Water pollution and soil erosion outcomes are also worse. Substantial runoff of farm inputs such as chemical herbicides, insecticides and fertilizers, increases soil erosion, irrigation, salinization and wastewater generation, as well as reduces soil fertility and biological oxygen demand (Delucchi 2006; Demirbas 2009; Granda, Zhu and Holtzapple 2007). Thus, the environmental case for biodiesel is not entirely clear cut, since these fuels represent a trade-off among different environmental concerns. Given that government intervention is driving much of the growth in biodiesel and is advocated partly on the grounds of environmental improvements, it is important to quantify the costs and benefits associated with its production and consumption.

Wassell and Dittmer (2006) provide the only other attempt at monetizing the external impacts of biodiesel. Their analysis aims to determine whether biodiesel subsidies are efficient. They estimate the external benefits of combusting B100 in place of petrodiesel range from $0.32

to \$1.29/gallon (in 2009\$ \$0.40 to \$1.61/gallon). The analysis focused on the impacts associated with PM, NO_x, SO_2, VOC, and CO, but was limited by omission of some potentially significant impact categories. These include indirect land use change (iLUC) which can create substantial emission impacts (Hertel et al. 2010; Searchinger et al. 2008). Furthermore, the analysis used literature-based monetary unit values associated with each emission type and simply summed over the impacts to establish the total economic value of biodiesel's externalities. This is known to cause overestimation of economic value because it doesn't take in to account trade-off and substitution effects (Randall 1991). This approach to valuation also fails to include non-use values associated with emissions reductions, which can be substantial. Given the inherent emissions trade-offs in switching fuel types, characterizing the overall environmental impact of biodiesel is complex and challenging. Furthermore, a broader set of impacts must be considered in the assessment of the costs and benefits associated with promoting biodiesel.

This study builds on this previous work and contributes to the literature by 1) employing the most up-to-date and sophisticated life-cycle impact assessment methodology (ReCiPe) to best characterize biodiesel impact pathways, 2) analyzing a more comprehensive set of external fuel impacts than has been previously done including all of those in Wassell and Dittmer (2006) as well as, iLUC, P, CH_4, NO_2, CO_2, CFC's, and Natural Gas, 3) evaluating the entire "well-to-wheel" life cycle of petrodiesel and biodiesel through use of a tiered-hybrid life-cycle inventory, 4) allowing tradeoffs between fuel attributes and between fuel types to monetize both use and non-use external environmental, health and resource impacts, and 5) integrating the measured LCIA impacts with their estimated monetary values for biodiesel from soybean feedstock relative to petrodiesel to establish the external costs and benefits of switching fuel mixes.

The results indicate that, after accounting for all life-cycle costs, soybean-based biodiesel offers significant improvement in environmental, health and resource outcomes relative to more traditional petrodiesel. For policies with the intent of encouraging resource conservation and improving overall health risk and ecosystem quality, even first-generation crop-based biodiesel fuels have merit and continued governmental intervention is warranted. Overall, environmental damages, natural resource use, and human health risks decrease significantly relative to petrodiesel under implementation of either blended or neat biodiesel from soybean feedstock.

The rest of the paper is structured as follows: the first section overviews and reproduces the LCIA results, the second section explains the stated preference study, section three details the integration of the LCIA and conjoint choice experiment, section four derives the welfare results and the fifth section concludes.

1.) Life Cycle Impact Assessment

The most widely used technique for determination of the trade-offs between environmental aspects of biodiesel is a Life Cycle Assessment (LCA) approach. This technique aggregates the material (quantity of fuel, electricity, water, chemicals, pollutants, etc.) and the embodied energy flows associated with the production or consumption of a particular commodity (Delucchi 2010; Rajagopal and Zilberman 2007). In the case of fuels, LCA looks at the whole system of fuel production and consumption beginning with farming, followed by harvesting, processing, distribution, end use, and waste disposal (Delucchi 2006).

Soybean is the preferred feedstock to produce biodiesel in the U.S. despite its low oil content (20%), not only because of the large quantities that are produced, but also because of its unique ability to fix nitrogen (Granda, Zhu, and Holtzapple 2007). In this study, a previously developed life cycle inventory done by Baral and Bakshi (2010)[1] is utilized which enumerates the life cycle impacts associated with petrodiesel and biodiesel produced from soybean feedstock. Reproducing the tiered hybrid life-cycle inventory for each fuel they evaluated (petrodiesel, biodiesel 20 (B20) and biodiesel 100 (B100))[2] yields the quantities reported in Table 1. Each row of Table 1 is a vector of impacts corresponding to one of the three fuels.

The functional unit of study is a distance driven basis in a representative light duty truck. The emissions and resource consumption reported are expressed as impacts per mile travelled when utilizing ~~either~~ petrodiesel, B20 or B100. The final category, ILUC, contains estimates of indirect land use changes that occur from soybean based biodiesel production developed by the Environmental Protection Agency and augments the original inventory (EPA 2010).

Table 1: *Life Cycle Inventory Results*

The quantities in Table 1 were then used in the construction of LCIA ReCiPe categories representing aggregated environmental, resource and health impacts. Aggregation into ReCiPe endpoint indicators is possible from the completed hybrid inventory results in Table 1 combined with the necessary characterization factors expressed in Table 2. The coefficients are based on the characterization factors reported in a number of public references as well as contained in the software program SIMApro (Goedkoop et al. 2013; SimaPro 2013).

Table 2: *Characterization Factors for ReCiPe Endpoints*

Whereas the original inventory is expressed in terms of units of measurement particular to each pollutant or resource (e.g. tons of carbon dioxide or tons of methane), the impact assessment is expressed in terms of an appropriate common unit through application of the characterization factors. Although they may be subject to a higher degree of uncertainty,

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[1] For a detailed explanation of their methodology, assumptions, and results reference Baral and Bakshi (2010) and the associated supporting material. For a good overview of LCIA reference (ISO 2006).

[2] B20 refers to a 20% biodiesel, 80% petrodiesel fuel mixture. B100 refers to a 100% "neat" biodiesel fuel.

endpoint indicators offer a more concrete interpretation to panel respondents and are the type of indicators employed in the preference elicitation study (Goedkoop and Spriensma 1999; Itsubo et al. 2012). The ReCiPe framework aggregates into three endpoint indicators related directly to damages to human health (expressed in disability adjusted life years (DALY's), including years of life lost and/or lived disabled), ecosystem diversity (expressed as disappearance or extinction of species per area per year) and resource availability (expressed as dollar values of increased future extraction costs) associated with a product. Smaller numerical values in each of these categories are more desirable as they represent less damage in each indicator category.

Human health damages are modeled for infectious diseases, cardiovascular and respiratory diseases, cancer as a result of ionizing radiation, cancer and eye damages due to ozone layer depletion, and respiratory diseases and cancer due to toxic chemicals in air, drinking water, and food. Four steps are used to model these impacts: 1) Fate analysis, linking an emission (expressed as mass) to a temporary change in concentration; 2) Exposure analysis, linking this temporary concentration to a dose; 3) Effect analysis, linking the dose to associated health effects; and 4) Damage analysis, linking health effects to DALYs, using estimates of the number of Years Lived Disabled (YLD) and Years of Life Lost (YLL). Damage from emissions of certain heavy metals, endocrine disrupters, as well as health damages from allergic reactions, noise and odor are not yet able to be modeled in this framework (Goedkoop et al. 2013).

Ecosystem quality damages are modeled for toxic emissions and those that change acidity and nutrient levels in air and soil. The models go through the procedure of: 1) Fate analysis, linking emissions to concentrations; 2) Effect analysis, linking concentrations to toxic stress or increased nutrient or acidity levels; and 3) Damage analysis, linking these effects to the increased potentially disappeared fraction of plant species. Only damages to natural systems can be modeled and these damages are limited to airborne deposits and certain waterborne deposits (Goedkoop et al. 2013). So far the framework cannot model the effect of climate change on biodiversity and species loss, which could be large and important (Mellilo et al. 2009).

Resource depletion is defined as the additional net present costs that society has to pay as a result of an extraction. This cost can be calculated by multiplying the marginal cost increase of a resource by an amount that is extracted during a certain period. The models go through the procedure of calculating: 1) a marginal increase in yield (in $), caused by an extraction; 2) the relation between resource deposits and marginal cost; 3) the average weighted yield of the cost increase of all deposits that contribute to the production of the commodity (Goedkoop et al. 2013).

Table 3: *Life Cycle Impact Assessment Results*

The LCIA is complete for petrodiesel, B20 and B100 after combining the tiered hybrid inventory with the appropriate characterization factors. The results are summarized in Table 3. Although all of the indicator categories show marked improvement for both the B20 and B100 fuels over petrodiesel, it is necessary to determine how society values the magnitude of these improvements in order to monetize the benefits.

2.) Stated Preference Choice Analysis

To determine society's preferences over the LCIA impact categories derived in the previous section, a choice experiment was conducted to elicit society's relative willingness to trade off the impacts of changing the transportation fuel mix. Society's preference structure can be established as individuals make choices that force trade-offs regarding the price and associated external impacts of a fuel. To accomplish this, a representative sample of licensed drivers from the state of Ohio was obtained[3] and given information on how transportation fuels can affect ReCiPe-style index categories that scientists often use to summarize the production and consumption impacts of fuels. Table 4 details the socio-demographic characteristics of the sample and indicate they closely mirror Ohio, although sample mean age is slightly higher, more likely to be a homeowner, and more likely to have a valid driver's license. Given the eligibility requirements for survey participation, it must involve respondents who drive, consume the commodity, and pay for consumption (as such non-drivers are underrepresented in this sample).

Table 4: *Demographics of U.S., Ohio, and Sample*

The attributes were described[4] on a scale of 0 to 100, with 0 representing the most desirable outcome for each index: i.e. excellent health outcomes and little environmental damage and resource use. Similarly a level of 100 represents poor health outcomes and extensive environmental damage and resource use. The level of 50 is defined *a priori* as the status quo level of each attribute experienced by an individual under the current transportation fuel mix (gasoline and diesel).

A 'choice set' for a respondent consists of three fuel mixes: the status quo and two alternative fuel mixes. A fuel mix is fully described by a price per gallon of fuel and levels for each of the three indices. The status quo option consists of the respondents' self-reported price per gallon of gas last paid, and a value of 50 for each of the external impact index values. The self-reported price variable has a mean of $1.88, but ranges from as low as $0.90 to as high as $3.29[5]. The choice sets are then randomly assigned a price from one of five treatments: a 10% or

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[3] The sample was drawn from active members of Knowledge Networks internet survey panel: "KnowledgePanel"

[4] Figure 1 in the appendix details the prompt given to respondents and indicates the types of impacts contained within each ReCiPe-style index category.

[5] This mean value indicates good recall of last price paid as weekly Midwest regular conventional retail gasoline averaged per gallon prices of $1.908 the week of 03/09/09 and $1.849 the week of 03/16/09 (EIA[d] 2013). Retail diesel averaged per gallon prices of $1.98 and $1.96 over the same time-span. The price variability can be explained

5% decrease from the self-reported status quo, no change, and 5% or 10% increase from the self-reported status quo. The externality index levels for the two alternative fuel mixes are randomly assigned from five possible levels: 37.5, 45, 50, 55, and 62.5 on the scale, representing decreases of 25% and 10%, no change, and increases of 10% and 25% respectively from the status quo level of 50. Both the numerical value and percentage change were presented to respondents. An example choice scenario can be seen in Figure 2 of the appendix.

An orthogonal fractional-factorial, generic attribute experimental design optimally derived from the full factorial experimental design is utilized to present a total of 75 choice scenarios to respondents. In order to reduce the cognitive burden to manageable levels, the design was divided into 5 blocks, with each block containing 15 choice sets. Respondents were then randomly assigned to one of the five blocks. The choice sets were chosen to maintain design orthogonality and level balance between all attributes and first-order attribute interactions as best as possible. Some trade-offs were made between orthogonality and statistical efficiency in order to maximize the information obtained in each choice scenario and prevent duplicate or dominated alternatives from occurring. Inclusion of the "status quo" scenario allows individuals to have an "opt-out" or "no-change" option within the choice set and was necessary to maintain unbiased parameter estimates (Johnson et al. 2007). Assuming a common linear additive form of utility function underlies all respondents allows for estimation of society's preference structure regarding both main and first-order interaction effects for the impact categories.

Statistical analysis of the choice experiment proceeds by estimating the utility difference model using the random parameters logit estimator. Individuals' responses to the questions in the choice experiment yield the preference structure for the attributes and presume the choice

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by the use of coupons and discounts by some consumers, the timing of the consumer's last purchase, as well as natural differences in fuel pricing.

between fuel alternatives is driven by respondents' underlying utility. The utility function has two components (deterministic $\bar{V}(\boldsymbol{x_{ij}}, \boldsymbol{\beta})$ and stochastic ε_{ij}) and is therefore embedded in a random-utility framework[6] denoted by (1),

$$U_{ij} = \bar{V}(\boldsymbol{x_{ij}}, \boldsymbol{\beta}) + \varepsilon_{ij} \tag{1}$$

where subscript *i* denotes the individual, subscript *j* denotes the alternative, **x** is the vector of attributes that vary across alternatives and ε_{ij} is a stochastic error term capturing individual and alternative specific factors influencing utility unobservable by the researcher. The model is further formalized by assuming the deterministic portion of utility can be approximated as a linear function of attributes and can be represented by (2),

$$U_{ij} = \beta_0 + \boldsymbol{x}_{ij}\boldsymbol{\beta}_l + (M_i - p_{ij})\beta_M + \varepsilon_{ij} \tag{2}$$

where M_i is individual i's income and p_{ij} is the price faced by respondent i under alternative fuel profile j. The coefficient on residual income, β_M, is the marginal utility of income. The marginal price for a specific attribute is derived solely with respect to a change in that attribute. After estimating the common utility function, marginal price for attribute *l* is obtained by normalizing the marginal utility estimate of attribute *l* by the negative inverse of the marginal utility of income to yield,

$$\mathrm{MP}_l = -\frac{\hat{\boldsymbol{\beta}}_l}{\hat{\beta}_M} \tag{3}$$

where MP_l represents marginal price of attribute *l*, $\hat{\beta}_l$ is the estimated coefficient on *l*, and $\hat{\beta}_M$ is the estimated marginal utility of income.

The probability, P_{ij}, of a respondent, *i*, choosing an alternative, *j*, is given by $U_{ij} > U_{ik}$ and can be denoted as,

[6] For a more detailed discussion on the random-utility framework see Train (2009).

$$P_{ij} = Pr(\boldsymbol{V_{ij}} + \varepsilon_{ij} > \boldsymbol{V_{ik}} + \varepsilon_{ik}) = Pr(\varepsilon_{ij} - \varepsilon_{ik} > \boldsymbol{V_{ik}} - \boldsymbol{V_{ij}}) \quad (4)$$

The random parameter logit model assumes stochastic variation in the preference structure, so that each individual, i, has a unique β_i for each of the attributes (environmental damage, human health risk, and resource depletion) and these parameters are distributed in accordance with certain conditions in the population. When the generalized extreme value distribution is assumed to be the probability distribution of the error term, and f(β|θ) is the density function for a given distribution of β with parameter θ (i.e. means and distributions) the choice probability can be expressed as,

$$P_{ij} = \int \frac{\exp V_{ij}}{\sum \exp V_{ik}}(\beta)\ f(\beta|\theta)\ d\beta \quad (5)$$

A continuous distribution, such as the normal, is assumed for f(β). The selection probability becomes P^* using simulated maximum likelihood procedures. R represents the number of draws with β^r representing the r^{th} draw from the density function. This results in a simulated probability of,

$$P^*_{ij} = \frac{1}{R} \sum_r P_{ij}(\beta^r) \quad (6)$$

which is used to estimate the simulated log likelihood function (LL^*) and the parameter θ which defines the distribution that maximizes this function. Given d_{ij} is a dummy variable representing respondents' choices and is set to 1 when alternative j is chosen, the simulated log likelihood is estimated as,

$$LL^* = \sum_i \sum_j d_{ij} \ln(P^*_{ij}) \quad (7)$$

The distribution function which quantifies the variability in preferences found between respondents can be derived from these calculations (Train 2009).

For all four of the attributes comprising the fuel profiles, the parameters have well-defined expectations with respect to sign. Similar to price, increases in the levels of all attributes are welfare decreasing. Therefore, *ceteris paribus,* respondents are expected to prefer fuel profiles that offer lower levels of environmental damage, lower levels of natural resource use, lower levels of risk to human health, and lower prices. Table 5 contains the parameter estimates for the model. The signs for the attributes correspond with intuition and the parameter estimates are significant at the 99% confidence level. Increases in all attributes are negatively related to utility, showing increases in the levels of externalities are welfare decreasing for society.

Table 5: *Parameter and Marginal Price Estimates (N=7274)*

The analysis of the survey responses also yields marginal prices for the environmental damage, human health risk and resource depletion attributes, which are more intuitive. Calculated using equation (3), these estimates correspond to marginal changes for each attribute from the status quo level that individuals currently experience, holding other attributes constant. Rounding to the tenth-of-a-cent, a marginal price of 3.4¢, 2.9¢, and 2.2¢ per gallon for a unit reduction from status quo was estimated for the human health risk, environmental damage and natural resource use indices, respectively. All estimates are significant at the 99% level and are statistically significantly different from each other. The results follow previous findings in the area of social preference structure regarding these types of attributes, namely that health outcomes are preferred over environmental and resource use outcomes (Delucchi 2000; Goedkoop and Spriensma 1999; Itsubo et al. 2004).

3.) Integration

Goedkoop and Spriensma (1999), using the Eco-Indicator 99 framework, first demonstrated the application of combining a life cycle impact assessment (LCIA) method with economics-based stated preference valuation techniques. This study did not attempt to derive welfare estimates from changing product mixes, but instead aimed to establish social preference weights over the impact categories employed in the Eco-Indicator 99 framework so that impact categories could be aggregated into a single number. Itsubo et al. (2004) built upon this by demonstrating an LCIA method being coupled with stated preference valuation to establish monetary values for changes in the impact categories employed in the LIME framework. Their results show the feasibility of establishing weights across impact categories in an LCIA and generating reliable welfare results through the application of conjoint analysis as a means of establishing economic value in a Japanese context. Itsubo et al. (2012) expanded on the framework by employing the random parameters logit, as opposed to the simpler conditional logit originally used, to improve the econometric estimation of the preference parameters.

Integration of the LCIA ReCiPe values (Section 1, Table 3) and the estimated marginal prices for those impacts (Section 2, Table 5) yields specific WTP values for both B20 and B100. To integrate, the LCIA impacts must be represented in the choice analysis indices presented to respondents. This creates unique choice analysis index values for both B20 and B100 based on their measured LCIA impacts. This is accomplished by computing the percentage change in the values for B20 and B100 from petrodiesel in each of the environmental damage, natural resource use, and human health risk LCIA impact categories. The choice analysis index value for B20 and B100 can then be established by matching the appropriate percent change from the status quo value of 50 for each attribute. This yields the value of B20 and B100 in terms of their percentage change in impacts relative to petrodiesel in the choice analysis indices valued by respondents.

Once the percentage changes from petrodiesel are known for B20 and B100, the marginal willingness-to-pay for switching to that alternative fuel type is calculated. Thus, in the WTP analysis that follows, the $\boldsymbol{x}_j'$s are the values imputed from the integration for each alternative fuel and the $\boldsymbol{x}_0'$s are the status quo values of petrodiesel.

4.) Welfare Calculations

To establish the WTP for society to substitute either of the two biodiesel blends for petrodiesel, the indirect utility function described in (2) is calculated for each of the biodiesel blends and then equated to the indirect utility associated with the status quo option of petrodiesel and solved for WTP as denoted in (8).

$$\boldsymbol{x}_j\widehat{\boldsymbol{\beta}}_l + \left(M - WTP_j\right)\hat{\beta}_M = \boldsymbol{x}_0\widehat{\boldsymbol{\beta}}_l + (M)\hat{\beta}_M \tag{8}$$

Here, $\mathbf{x_j}$ represents the vector of attribute values describing either B20 or B100, $\widehat{\boldsymbol{\beta}}_l$ is the vector of estimated attribute parameters, and $\hat{\beta}_M$ is the estimated marginal utility of income. Solving for $\mathrm{WTP_j}$ yields (9), where $\boldsymbol{\Delta x}$ is the difference between the petrodiesel and biodiesel blend attribute levels.

$$\mathrm{WTP_j} = \frac{(\boldsymbol{\Delta x})\widehat{\boldsymbol{\beta}}_l}{\hat{\beta}_M} \tag{9}$$

The WTP in dollars per gallon for a change in attribute damages associated with substituting either a gallon of B20 or B100 in place of a gallon of petrodiesel are listed in Table 6.[7]

Table 6 *Marginal Willingness-To-Pay ($/Gallon)*

On average, individuals have a WTP of 0.27¢ to substitute a gallon of B20 in place of a gallon of petrodiesel, given the associated external benefits. Similarly, WTP for the benefits associated with burning one gallon of neat biodiesel in place of a gallon of petrodiesel are $3.14. This indicates the substantial aggregate improvements in health risk, environmental damage, and resource depletion outcomes that B100 can provide. Although trade-offs are made in the switch between fuels, the new array of human health risk, environmental damage and resource depletion outcomes are more valuable to society. Given the 2012 level of neat biodiesel production (969 million gallons) and assuming that without its use petrodiesel would be its replacement, the

[7] Several recent papers have also shown that U.S. consumers are willing to pay extra for biofuels, at least in the short term, to support its development (Petrolia et al. 2010; Soloman 2010)

United States gained over $3 billion dollars in gross benefits from biodiesel using the mean estimate in Table 6 (EIA[b] 2013; EIA[c] 2013; USDA-ERS 2013). Moreover, since current federal biodiesel supports total $1.00 per gallon for neat biodiesel, this analysis suggests current subsidies are not only well justified, but could be expanded (EIA[a] 2013).

Even with these estimated benefits, though, increasing biodiesel production and consumption above current levels will be difficult and may incur additional costs. For example, biodiesel production using the entire U.S. stock of vegetable oils and animal fats would only satisfy 13% of on-road petrodiesel demand at current yields (Wassell and Dittmer 2006). Replacing 10% of gasoline or petrodiesel fuel with biofuels from irrigated corn or soybeans would require roughly 100% of total U.S. freshwater consumption when water required to dilute pollution is included (Delucchi 2010). Production costs must also be considered. Feedstock cost is about 80% of the total cost of producing biodiesel, so increases in feedstock prices can increase costs significantly (Demirbas 2009; Duffield 2007; Wassell and Dittmer 2006)[8]. With these types of hurdles, a large-scale biofuels industry (ethanol and biodiesel) would unlikely be able to displace more than 20-30% of the petroleum-based transportation fuel market in the U.S. (Soloman 2010).

5.) Conclusion

Biodiesel production has increased in the U.S. and looks like it will continue to do so for the foreseeable future. However, the market share of biodiesel is still very small, accounting for less than 1% of the total transportation fuel market (EIA[c] 2013). As long as world energy demand continues to grow, oil prices are not likely to decrease, and as a result, the need for alternatives will continue to grow as well. Biodiesel offers a valuable improvement over

[8] This is a necessary factor to consider in terms of biodiesel's competitiveness in the marketplace with diesel, but is a separate consideration of the optimal subsidy (and size of external benefits generated by biodiesel).

petrodiesel in terms of external impacts and could therefore play an important role in the future energy economy (Rajagopol and Zilberman 2007).

The existence of market failure in the transportation energy market is indisputable and therefore governmental intervention in some cases can be justified. An efficient subsidy scheme will set the per gallon subsidy equal to the external benefits biodiesel produces. As shown in this analysis, consumers have a large, positive WTP to achieve the emissions benefits that biodiesel from soy can produce (over three times larger than current subsidy levels). Although the $1.00 per gallon biodiesel subsidy was removed temporarily in 2012, it was reinstituted as part of the "fiscal cliff" negotiations on January 1st, 2013. Based on this analysis, the $1.00 subsidy is a step in the right direction and should be continued, if not expanded. Maintaining or increasing biodiesel's subsidy will encourage substitution away from petrodiesel and thereby lead to valuable reductions in the total external emissions impacts associated with transportation fuel production and consumption.

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Table 1: *Life Cycle Inventory Results*

Fuel Type (kg/mi)	Inventory Pollutant (P) or Resource (R) *(Percentage Change from Petrodiesel)*												
	VOC (P)	CO (P)	NO_X (P)	PM10 (P)	SO_X (P)	CH_4 (P)	N_2O (P)	CO_2 (P)	P (P)	CFCS (P)	Crude Oil (R)	Nat. Gas (R)	ILUC (P)
Petro-diesel	2.20 E-04	4.09 E-04	5.60 E-04	4.85 E-05	1.51 E-04	9.83 E-04	4.50 E-08	4.72 E-01	0.00	6.39 E-12	1.59 E-01	5.49 E-03	0.00
B20	1.95 E-04	4.06 E-04	6.26 E-04	5.09 E-05	1.44 E-04	8.63 E-04	4.69 E-07	3.95 E-01	2.95 E-06	6.93 E-12	1.29 E-01	7.89 E-03	4.00 E-02
B100	1.60 E-04	4.24 E-04	8.97 E-04	6.19 E-05	1.17 E-04	3.71 E-04	2.21 E-06	7.69 E-02	3.45 E-05	9.13 E-12	7.52 E-03	1.78 E-02	2.05 E-01

LCIA is compiled assuming the use of resources and release of pollutants is linearly related to total outputs of the system. International (including domestic U.S. and global) changes in indirect land use change are denoted in the column titled ILUC and are denoted in C02 equivalent units.

Table 2: *Characterization Factors for ReCiPe Endpoints*

Inventory Item	Species.Yr/kg	MJ/kg	DALY/kg
VOC			3.90E-08
CO			1.78E-09
NO_x	1.01E-08		5.72E-05
PM10			2.60E-04
SO_x	1.42E-08		5.20E-05
CH_4 [a]	1.42E-07		2.67E-05
N_2O [a]	2.86E-06		5.37E-04
CO_2	1.87E-08		3.51E-06
P	4.44E08		6.61E-03
CFCs [a]			8.03E-03
Crude Oil		1.75E+01	
Natural Gas		1.16E+01	
ILUC[b]			2.10E-07

a) Characterization factors for CH_4, N_2O and CFCs are based on CO_2 equivalent releases. They are derived by multiplying CO_2 impacts by 23, 296 and 8500, respectively.
b) Indirect Land Use Change

Table 3: *Life Cycle Impact Assessment Results*

Fuel Type	Environmental Damage (Species.Yr/mi)	Resource Depletion ($/mi)	Human Health Risk (DALY/mi)
Petrodiesel	9.09E-09	2.9E+00	1.7E-06
B20	7.5E-09	2.4E+00	1.5E-06
B100	1.5E-09	3.4E-01	6.3E-07

LCIA results from sum-product of Tables 1 and 2.

Table 4: *Demographics of U.S., Ohio, and Sample*

	Mean or Percentage		
	United States[a]	**Ohio[b]**	**Sample**
HH Income ($/year)	52,175[c]	48,023[c]	52,290
Age (years)	36.7	37.9	48.3*
HH Members (#)	2.61	2.48	2.59
Married (%)	54.4	54.5	47.7
Female (%)	50.7	51.3	51.7
Homeowner (%)	67.1	69.6	78.4*
Bachelor's Degree or Higher (%)	27.4	23.8	21.8
White (%)	74.3	84.0	84.4
Metropolitan[d] (%)	80.3	71.4	75.8
Valid Driver's License (%)	88.0[e]	76.2	91.6*

A pretest of the survey was fielded to assess understanding and improve questionnaire design prior to implementing the main survey. Failing to provide either day-to-day vehicle mileage or the last price paid at the pump resulted in exclusion from the analysis. Field dates were in 2009 from March 13 to March 23 and had a 62.5% completion rate. *Denotes statistically significant difference between Sample and State Means at the 0.01 level. a) U.S. demographics obtained from U.S. Census Bureau's American Community Survey 2006-2008 estimates (http://www.census.gov) b) State of Ohio demographics obtained from U.S. Census Bureau and Ohio Bureau of Motor Vehicles (http://www.bmv.ohio.gov) c) median household income in 2008 inflation adjusted dollars d) Metropolitan indicates Urban or Suburban resident. e) 2005 Carter-Baker Commission Report

Table 5: *Parameter and Marginal Price Estimates (N=7274)*

Variables	**Mean** (Standard Error)	**Marginal Price**[c] (Standard Error)
ASC	**1.105** (0.069)	
Price ($/gal)	**-4.177** (0.267)	
Environmental Damage[a]	**-0.120** (0.005)	**0.029** (0.002)
Natural Resource Use[a]	**-0.092** (0.005)	**0.022** (0.002)
Human Health Risk[a]	**-0.141** (0.006)	**0.034** (0.003)
McFadden's Pseudo R^{2} [b]	**0.344**	
Log-Likelihood	**-5487.44**	

All parameter estimates were significant at the 1% level. a) Assumed parameter distribution is normal b) See Green 2012, page 537, for a detailed discussion. c) Delineated in dollars. Figures are estimates of marginal WTP for the listed attribute as calculated using equation (3). Estimates are for marginal 1% decrease from current, base levels. Estimated using Krinsky-Robb Simulation with 10,000 draws.

Table 6: *Marginal Willingness-To-Pay ($/Gallon)*

Fuel Type	MWTP (Standard Error)	1 % Lower Bound	99% Upper Bound
B20	**0.270** (0.021)	**0.224**	**0.326**
B100	**3.149** (0.248)	**2.619**	**3.804**

Figures are estimates of marginal willingness-to-pay for the listed fuel as calculated using equation (9). Estimates are for a change from petrodiesel to the listed alternative. They are estimated using Krinsky-Robb Simulation with 10,000 draws. Emissions vectors for B20 and B100 are increased by 10% per gallon to account for the decline in mileage experienced relative to petroleum; this is on the conservative end of mileage reductions (Demirbas 2009, Wassell and Dittmer 2006).

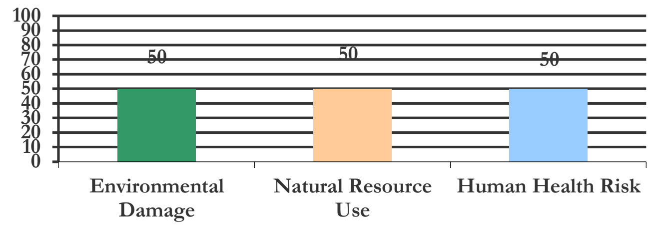
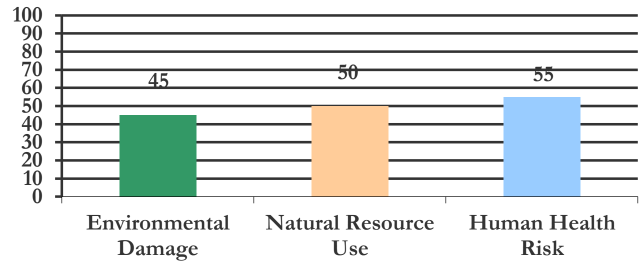
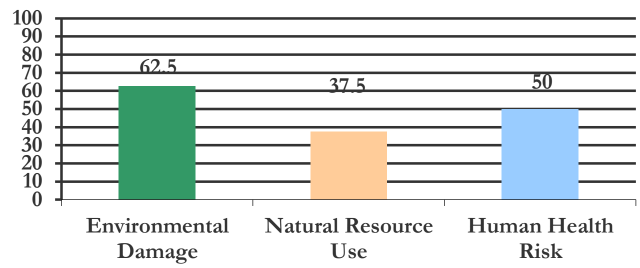
APPENDIX

Figure 1: *Index Descriptions*

The three index values for the Current Fuel Mix represent the impact that the current fuel mix has on the environment, natural resources, and human health
The Environmental Damage Index
An increase in the Environmental Damage Index means that there is more damage to the environment. Possible damages include: – Lower populations of various species including plants, worms, algae, amphibians, mollusks, crustaceans and fish. – Increased air, land, and water pollution creating a more toxic environment.
The Natural Resource Use Index
An increase in the Natural Resource Use Index means that there is increased strain on natural resources making it more difficult to extract minerals and fossil fuels, and that there are less available for future use. – Minerals, including lead, zinc, iron, copper, limestone and clay are used in countless consumer products. – Fossil Fuels, including oil, coal, and natural gas are used as energy sources for heating and cooling homes, electricity generation, and transportation.
The Human Health Risk Index
An increase in the Human Health Risk Index means that there is a higher risk of harmful effects on human health. Possible health effects include increased risk of: – Cancer, including thyroid, bone, breast, and lung cancers – Leukemia – Cardiovascular and respiratory diseases – Eye damage due to ozone layer depletion

Figure 2: Prompt, Stimulus, and Choice Question Format for Conjoint Experiment

[Q] Consider the following three fuel mixes. Each is characterized by different levels of the Environmental Damage, Natural Resource Use, and Human Health indices and a change in the fuel price per gallon.

Current Fuel Mix	$[**GASPRICE**] per gallon	
Fuel Mix A	$[**GASPRICE**] per gallon	
Fuel Mix B	$[**GASPRICE**] per gallon	

Assuming you are driving the same vehicle that you currently drive, and the expected fuel mileage does not change, which Fuel Mix would you prefer?

- ☐ I would prefer Current Fuel Mix
- ☐ I would prefer Fuel Mix A
- ☐ I would prefer Fuel Mix B

Note: **[GASPRICE]** refers to the respondents reported price paid per gallon multiplied by the experimentally determined price level