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

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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. Applying a framework that couples life cycle damage measurements with social preferences elicited from a conjoint choice experiment allows for comparison of petrodiesel and biodiesel's external damages. The results of the study reveal that production and consumption of soybean based biodiesels produce 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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1. 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, 93% of which was petroleum based in 2011, and is expected to account for over 60% of the total projected increase in global oil use between 2010 and 2040 (EIA, 2012; EIA, 2014). Increasing prices and 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 (Solomon, 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 (Rajagopal 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). 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 offers some significant benefits relative to petrodiesel over its production and consumption life-cycle.

Previous studies have found that the main advantages to biodiesel are 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; Rajagopal and Zilberman, 2007; Solomon, 2010). Other studies have also found positive emissions impacts. The consensus is that, compared to the carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) greenhouse gas (GHG) emissions from conventional petrodiesel, emissions from biodiesel are lower by 40–50% (DOE, 2013). In addition, air quality effects are mostly positive and reduce carbon monoxide (CO) emissions by 25–50%, sulfur oxide (SO_2) emissions by (8–30%), volatile organic compound (VOC) emissions by over 60%, particulate matter (PM) emissions by almost half and hydrocarbons (HC) by about two-thirds (Huo et al., 2008; Miller, 2008; Peng et al., 2012). For all of these reasons, the share of biodiesel in the U.S. automotive fuel market is expected to grow rapidly over the next decade, reaching 1.4 billion gallons by 2019 (FAPRI, 2005).

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But expansion also raises a variety of concerns. When the biofuel feedstock is a food source such as soybeans, expansion may increase food prices, which disproportionately impacts the poor and raises equity concerns (Janda et al., 2012). In addition, environmental damages resulting from the expansion of agricultural land due to market-mediated responses to feedstock price changes, known as indirect land use change (iLUC), have been shown to be substantial (Hertel et al., 2010; Searchinger et al., 2008). Increased water use for irrigation, the detrimental effects on soil carbon sequestration, soil quality maintenance, and the prevention of soil erosion are also of major concern (Delucchi, 2010; Miyake et al., 2012; Solomon, 2010; Ziolkowska and Simon, 2011). Other studies have additionally found that some emissions impacts are worse with biodiesel. For example, nitrogen oxide (NO_x) emissions are higher in production and use, while the substantial runoff of farm inputs such as chemical herbicides, insecticides and fertilizers worsens water pollution because of increased phosphorous (P) and nitrogen (N) loadings to waterways (Delucchi, 2006; Demirbas, 2009; Granda et al., 2007; Hu et al., 2008).

For these reasons, the environmental case for soy biodiesel is not entirely clear cut, since it creates trade-offs 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. This is a complex and challenging task given the broad set of externalities which must be considered.

In the European context, Vollebergh (1997) and De Nocker et al. (1998) examined biodiesel externalities from rapeseed feedstock. Vollebergh studied a 95% diesel, 5% biodiesel blend (B5) for France and found a reduction in external costs valued at \$0.714 per gallon relative to petrodiesel. De Nocker et al. studied a 100% biodiesel blend (B100) for Belgium, and found that it offered improvements in externalities valued at \$0.06 per gallon relative to petrodiesel. Both analyses included externalities caused by the emission of CO_2, N_2O, CH_4, CO, VOC, SO_2, NO_x (and PM for De Nocker et al.), but were limited by omission of other important impacts associated with P (or N) and chlorofluorocarbon (CFC) emissions, as well as iLUC. Furthermore, De Nocker et al. did not consider health externalities, which often account for the most damage and may have resulted in a downward biased estimate.

In the Asian context, Silalertruksa et al. (2012) and Le et al. (2013) examined Jatropha-based palm oil biodiesel blends in the context of Thailand and Vietnam respectively. Silalertruksa et al. estimated a B100 blend's benefits at \$0.06 per gallon relative to petrodiesel, while Le et al. found a B5 blend to have benefits around \$0.36 per gallon relative to petrodiesel. Both studies included externalities associated with CO_2, N_2O, CH_4, SO_2, NO_x and PM emissions. In addition, Silalertruksa et al. included VOC, CO emissions and some domestic land use impacts, while Le et al. included HC emissions. Both omitted impacts associated with P (or N), CFC and iLUC.

In Australia, Cuevas-Cubria (2009) looked at canola, tallow and waste cooking oil as feedstocks for a B5 blend and found improvements of \$1.43, \$1.58 and \$2.85 per gallon relative to petrodiesel respectively. The emissions included CO_2, N_2O, CH_4, CO, VOC, NO_x and PM, but omitted SO2, P (or N), CFC's and iLUC. In the U.S., Wassell and Dittmer (2006) estimated the external benefits of a B100 soy biodiesel fuel ranged from \$0.40 to \$1.61 per gallon relative to petrodiesel.[1] Damages associated with local air quality effects (i.e. CO, VOC, SO_2, NO_x and PM) were included, but damages associated with GHG's, CFC's and iLUC were not.

These previous analyses varied across country context, as well as emission and resource impacts considered. In addition, they used literature-based monetary unit values associated with each emission type, multiplied this monetary value per unit by the quantity of units emitted, and simply summed the resulting values to establish the total economic value of a fuel's externalities. This is known to cause overestimation of economic value because it does not take into 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.

This study builds on this previous work and contributes to the literature through the use of a stated preference conjoint choice experiment. This approach allows tradeoffs between fuel types and damages to monetize both use and non-use environmental, health and resource externalities and in-turn, allows the relative benefit of changing fuel mixes to be estimated. In addition, a larger number of external damages created by petrodiesel and soy biodiesel from CO_2, N_2O, CH_4, CO, VOC, SO_2, NO_x, CFC, P, PM, and iLUC are considered than in previous welfare analyses. The entire "well-to-wheel" life-cycle of petrodiesel and biodiesel from harvest or extraction through final use are included in the damage measurements. Exclusion of any damages or any phase of the life-cycle may over- or understate the relative environmental performance of the fuels and lead to biased welfare results. The damage estimates for each fuel are constructed from life cycle impact assessment, which models the physical emissions of fuels' in terms of environmental and economic damages. This creates a link between the physical emissions of fuels and the environmental and health damages individuals' experience. These damages are used as inputs in the conjoint choice experiment which establishes social preferences over each fuels' damages. The welfare estimates derived from these social preferences can then be used to help inform policy decision-making and provide the opportunity to assess whether current and future biodiesel policies move society in a welfare increasing or decreasing direction.

The rest of the paper is structured as follows: section two describes the methods employed including, the stated preference study, conjoint choice experiment, theoretical model, econometric analysis and the use of life cycle impact assessment damage measurements; section three derives the welfare estimates; the fourth section concludes.

2. Methods

2.1. Data collection

To determine whether switching from petrodiesel to soy biodiesel increases social welfare, a survey was conducted to elicit society's preferences regarding the damages these fuels create. Society's preference structure can be established as individuals make choices across different fuels which force trade-offs between the price and external damages of each fuel. To determine preferences, a representative sample of licensed Ohio drivers was drawn from active members of Knowledge Networks internet survey panel between March 13 and March 23, 2009. 532 out of 850 potential respondents completed the survey, yielding an effective response rate of 63%. After cleaning for non-response and unreported last fuel price paid (necessary information for the analysis), 491 respondents remained. Table 1 details the socio-demographic characteristics of the sample and indicates that they closely mirror Ohio, although sample mean age is 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 involved respondents who drive, consumed the commodity, and paid for consumption (as such non-drivers were underrepresented).

Respondents were presented information on how transportation fuels affect three indexes scientists use to summarize the production and consumption damages of fuels. These damage indexes represented the human health risk, environmental damage and resource depletion associated with different potential fuels. Fig. 1 details the prompt describing the types of damages contained within each index. The indexes were described on a scale of 0 to 100, with 0 representing the most

[1] All monetary values are denoted in 2009 United States dollars. All estimates from previous studies were converted from the original units and currency to 2009 United States dollars per gallon to facilitate comparison. Inflation adjustment from (http://www.bls.gov/data/inflation_calculator.htm). Currency conversion from (www.x-rate.com) and (http://www.ecb.europa.eu/press/pr/date/1998/html/pr980502.en.html).

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