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Analysis

Integrating life-cycle assessment and choice analysis for alternative fuel valuation

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ABSTRACT

This study monetizes the environmental damage and human health risk externalities associated with the life-cycle production and use of ethanol biofuels from corn-based and cellulosic feedstocks. An integrated economic-environmental assessment framework couples the measured emission impacts from the fuels with individuals' preferences regarding each fuel's externalities. This framework allows the welfare values associated with gasoline and ethanol's externalities to be derived and compared. The results of the study reveal that the production and consumption of corn starch ethanol produce declines in environmental and health outcomes of $1.23 per gallon relative to gasoline for an 85% blend. Depending on the feedstock source, cellulosic based ethanol blends produce modest gains in environmental and health outcomes valued at between $0.04 and $0.06 per gallon relative to gasoline.

1. Introduction

Over the last two decades, the nonmarket impacts associated with the production and consumption of gasoline have gained increasing attention. This attention is due to a growing awareness that these impacts include serious health consequences for individuals, environmental destruction to ecosystems, as well as changes to the global climate (Murphy and Delucchi, 1998; Parry et al., 2007). Given that these damages are external to market transactions, they impose unaccounted for costs on society that lead to inefficient levels of production and consumption. Yet, gasoline consumption has continued to rise, increasing by over 30% since 1990 (BTS, 2008; FHWA, 2009). Subsequently, significant interest has been generated in finding alternative fuels that improve upon gasoline's environmental, health and resource outcomes.

Popular alternatives proposed as replacements include ethanol fuel blends. Ethanol can be created from a number of different types of feedstock. In this study, several of these are examined for their environmental and health performance including corn starch, corn stover, switchgrass, yellow poplar, newsprint and municipal solid waste. Each of these feedstocks results in a different set of environmental, health and resource outcomes over their life-cycle, but most are extolled as offering significant improvements in these areas relative to gasoline. In response, policy makers have offered generous incentives to aid in their development and production (Yano et al., 2010). Europe and the U.S. have gone further than incentives and have also mandated significant use of biofuels in-part for their perceived environmental benefits.

Yet evidence increasingly indicates that ethanol biofuel may actually result in worsening damages for many of the externalities its use is designed to improve upon. Analyses employing life-cycle impact assessment, in particular, have offered dissent about the positive outcomes generated by ethanol (Baral and Bakshi, 2010; Fargione et al., 2008; Hill et al., 2009; Kusiima and Powers, 2010; Melillo et al., 2009; Searchinger et al., 2008; Tilman et al., 2006). For example, Hill et al. (2009) quantify and monetize the climate change and health damages

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of greenhouse gases and particulate emissions over the life-cycle of gasoline and ethanol. They estimate total external costs to be 0.71¢ per gallon[1] for gasoline and between 0.47¢ and $1.45 per gallon for corn starch ethanol. The 47¢ per gallon estimate indicates that corn starch ethanol may offer improvements over gasoline if the energy used in refinement does not come from coal. They also estimate external costs to be between 0.19¢ and 0.25¢ per gallon for cellulosic ethanol blends, indicating that these blends could offer improvements. Their analysis does not include certain key environmental damages, which may be higher with ethanol use in place of gasoline. Such missing damages include hazardous air emissions (NO_x, SO_x, and VOC), acidification, eutrophication, and changes to habitat quality and quantity, all of which may alter the derived welfare estimates.

Kusiima and Powers (2010) build on this work by quantifying and monetizing a larger set of damages measured over the production life-cycle of ethanol created from different feedstocks. They estimate the average external cost of corn starch ethanol to be $2.17 per gallon. They also estimate corn stover's external costs at 0.77¢ per gallon and switchgrass damages at 0.37¢ per gallon. Their analysis does not include externalities created during the use phase of the life-cycle because only ethanol blends are compared and use phase emissions would be the same for each feedstock. Both of these studies utilized life-cycle inventory data to quantify damages and combined it with economic valuation to place a dollar value estimate on the externalities associated with fuels. They also both valued external impacts from the fuels individually and summed the resulting dollar values across all impacts to arrive at an estimate for the external cost of the fuel. But, this sort of valuation is known to overestimate total economic value (Randall, 1991).

In addition, neither of the previous analyses incorporated estimates on the damages that indirect land use change (ILUC) from biofuel production may create. ILUC may include biodiversity losses from cleared land, as well as lead to indirect releases of greenhouse gases which should be included in any welfare analysis (because releases everywhere are mixed and their warming effects are diffuse). ILUC impacts are caused by predictable responses of the world's production system to changes in fuel demand (Hertel et al., 2010). Loss of biodiversity and release of carbon dioxide occur when biofuel demand triggers a succession of land-use changes that cause ecosystems with high biodiversity and carbon stocks to be converted to agricultural cultivation.

Recent work in this area has shown that ILUC damages could be substantial. For example, Searchinger et al. (2008) find that corn starch ethanol nearly doubles the damages of greenhouse gas emissions, relative to gasoline, once ILUC emissions are taken into account. Hertel et al. (2010) similarly find that greenhouse gas emissions increase, but only by one-fourth the amount estimated by Searchinger et al. (2008) once market-mediated responses are included (still enough to negate any greenhouse gas benefits associated with biofuels). Melillo et al. (2009) also find increases in greenhouse gas emissions from corn starch and sugarcane ethanol. In addition, they find that biodiversity hot spots around the world are pressured as deforestation and land-clearing occur to bring more land into agricultural cultivation for biofuel production. These studies provide evidence of the importance of including ILUC damages in any welfare analysis involving biofuels, even though the exact nature of the changes induced by ILUC is still subject to a great deal of uncertainty.

This study contributes to the literature in four ways: First, the life-cycle inventory employed here contains measurements on a greater number of external damages created by gasoline and ethanol than in previous analyses, including indirect land use changes. Inclusion and comparison of the largest possible range of external damages are necessary to comprehensively assess the environmental and economic impacts of switching fuels. Second, it evaluates this larger set of damages over the entire life-cycle of each fuel from harvest or extraction through final consumption. Exclusion of any phase in the life-cycle may over or under state the relative impacts of gasoline and ethanol, leading to incorrect conclusions being drawn regarding the environmental performance of the fuels. Third, it utilizes an impact assessment framework to couple the life-cycle inventory to social preference weights regarding changes in the fuels' damages. This framework creates a link between the physical damages that fuels create on the outcomes individuals care about. And fourth, it monetizes the social preferences established for the different levels of damage associated with each fuel. This helps to inform policy decision-making and creates the opportunity to assess whether current and future fuel policies move society in a welfare increasing or decreasing direction.

The rest of the paper is structured as follows: the second section overviews the life-cycle inventory results and the life-cycle impact assessment framework, the third section explains the stated preference valuation study, the fourth section details the integration of the life-cycle impact assessment and valuation results, the fifth section derives the welfare estimates and the sixth section concludes.

2. Life-cycle Impact Assessment

The life-cycle inventory enumerates the resources consumed, energy inputs required and wastes generated throughout the life-cycle of a fuel. The analysis begins at extraction or harvest of raw materials and continues through final use of the fuel product (Vigon and Jensen, 1995). This sort of accounting is intended to identify opportunities for reductions in emissions and resource use that result in damages from a fuel's production and consumption. In this study, a life-cycle inventory on gasoline and ethanol (created from 6 different feedstocks) is utilized.[2]

The tiered hybrid life-cycle inventory for each fuel (corn starch, corn stover, switchgrass, yellow poplar, newsprint, and municipal solid waste ethanol, as well as gasoline) yields the physical quantities reported in Table 1. Each row in Table 1 is a set of impacts associated with damages to the environment and human health that result over the life-cycle of the corresponding fuel.[3] The functional unit of study in the inventory is a distance driven basis in a representative gasoline-powered vehicle. Thus, the emissions and resource consumption reported in Table 1 are expressed as impacts per mile traveled when consuming each fuel. The final category, ILUC, contains estimates of indirect land use changes that occur when biofuel production comes from corn starch, corn stover, and switchgrass feedstocks. These estimates were developed by the Environmental Protection Agency and augment the original life-cycle inventory (EPA, 2010). The remaining feedstocks come from waste products and are assumed to have no ILUC impacts. A total of ten emissions and two fossil fuel resources from the life-cycle inventory are used in the construction of life-cycle impact assessment (LCIA) damage indicators.

The construction of LCIA indicators is necessary to translate the physical impacts described in the life-cycle inventory into environmental and health damages individuals understand and value. Typically, an LCIA utilizes life-cycle inventory data to compare differences in the physical impacts created by the production, consumption and disposal of products, and then models the environmental and health damages these physical impacts create. The indicators can then be paired with economic valuation methods to monetize the damages associated with different products based on society's preferences.

LCIA frameworks, such as EPS (Steen, 1996), ExternE (EC, 1995), LIME (Itsubo et al., 2004) and Eco-Indicator 99 (Goedkoop and Spriensma, 1999), were initially created to aid in production decisions while also taking into account external damages to the environment

[1] All monetary values are denoted in 2009 United States dollars.

[2] For a detailed explanation of their methodology, assumptions, and result reference Baral and Bakshi (2010). For a good overview of LCIA reference (ISO, 2006).

[3] Each ethanol blend was calculated at both the 10% and 85% blend levels but only E85 results are reported here.