Energy Economics 37 (2013) 29–39

Contents lists available at SciVerse ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

A model for sustainable land use in biofuel production: An application to the state of Alabama

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ARTICLE INFO

Article history:
Received 6 January 2012
Received in revised form 1 November 2012
Accepted 8 January 2013
Available online 27 January 2013

Keywords:
Bioenergy
Econometric mathematical programming
Land-use change
Sustainable biofuels

ABSTRACT

The Renewable Fuel Standard aims to increase the production of biofuels to improve energy efficiency and decrease carbon dioxide emissions in the US. The effectiveness of this regulation is being debated by the scientific community regarding carbon emissions from direct and indirect land-use change. A valid alternative may be to design policies that stimulate sustainable land use in biofuel production. This article develops a model that simulates a voluntary program to increase the land use efficiency in production of biofuels. This stochastic dynamic model optimizes the sustainability of biofuels producible by including climate information and participatory decisions on land use. The model is parameterized using the Maximum Entropy econometric technique to present a simulation of the program in the State of Alabama. The results of this simulation show that participatory decisions on land-use may increase the net energy value of produced biofuel up to 215.68% and reduce the carbon emissions by 19.67% towards the state energy goals.
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> "*Use of [liquid transportation] fuels has given rise to energy security concerns, contributions to climate change and other environmental challenges.*" *National Biofuels Action Plan* (*Biomass Research and Development Board, 2008*).

1. Introduction

In 2008, the total US demand for transportation fuel accounted for 179% of the total oil produced in the country. The total consumption of fossil fuel was 22,606.7 trillion BTU. (Davis et al., 2010). The Renewable Fuel Standard (RFS), a key provision of the Energy Independence and Security Act of 2007 (EISA), aims to replace imported oil with 36 billion gallons of biofuels by 2022. According to RFS, these renewable fuels produced by modern biorefineries, will reduce the emissions of green house gasses (GHG) relative to the life cycle emissions from gasoline and diesel by at least 20%. As a consequence of the development of clean energy substitutes for fossil fuels, energy crops are becoming increasingly popular in the United States accounting for 12 billion gallons of corn ethanol and 0.60 billion gallon of soybean biodiesel production annually. The United States became the top world producer of bioethanol followed by Brazil (Renewable Fuel Association, 2011).

As energy crops gain importance, their efficiency and environmental impact are becoming an issue that is hotly debated by the scientific community. The RFS mandate may have a significant impact on land-use change. Searchinger et al. (2008) estimated that land-use change associated with corn-based ethanol production would double greenhouse gas (GHG) emissions over 30 years rather than reduce it by 20% as suggested by EISA.

Soils and plant biomass are the largest natural sources for carbon sequestration containing almost 2.7 times the carbon content of the atmosphere. Conversion of rainforests, peat lands, savannas and grasslands would release CO_2 as a result of microbiological processes resulting in decomposition of organic carbon naturally stored in plant biomass and soils. Consequently, a phenomenon called carbon emissions from indirect land-use change (ILUC) will occur. Fargione et al. (2008) defined the *carbon debt* of land conversion as the amount of CO_2 released during the first 50 years after conversion, from the decay processes of organic matter. Over time, the biofuel produced from converted land would repay the carbon debt; however, the authors estimated an increase of 420 times in GHG emissions in the atmosphere instead of a reduction as found by previous studies.

A GHG federal cap-and-trade program may benefit the US agricultural sector and may increase social welfare if the improvement in air and water quality and wildlife conservation derived from agricultural and forestry mitigation activities are considered (Baker et al., 2010). However, there may be some issues in the implementation of such a policy if the ILUC emissions are included in the regulation. Khanna et al. (2011) argue that the large variability of ILUC estimates within studies and between different studies may produce subjective policies rather than policies designed according to scientific evidence. Moreover, if such a policy would promote the production of biofuels with a lower ILUC factor, it will not guarantee global reductions in

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http://dx.doi.org/10.1016/j.eneco.2013.01.003

GHG emissions. Whether or not biofuels are a possible solution to climate change mitigation is strongly dependent on the type of biofuel or even the mix of biofuels considered. The authors conclude that an alternative policy approach would be "creating incentives for sustainable land management practices, such as land zoning regulations and payments to landowners for environmental protection" that may produce global reductions of GHG.

Based on their conclusion, an interesting research question would be whether or not participatory decisions on land management, made by landowners and institutions, would lead to sustainable production of biofuels. The objective of this study is to develop a multidisciplinary integrated model that can be used to test this hypothesis.

To the best of our knowledge, there is no other study that has attempted to examine our research question. This study is unique in the literature of biofuels and bioenergy for several reasons. First, the current research presents the first normative analysis that quantitatively assesses the potential environmental benefits deriving from a cooperative outcome in production of biofuels. Secondly, in this study the hypothesis is tested simulating a voluntary program that could promote a sustainable land use to produce biofuels. Thirdly, the simulation of the voluntary program in this study is performed using a new methodology that optimizes the sustainability of land use in biofuel production by including climate information and cooperative decisions. For this reason, our mathematical model differs from any other model used in the bioenergy and applied economics literature. Finally, we present an empirical application to the State of Alabama where the State Energy Program was awarded with \$55.57 million from the American Recovery and Reinvestment Act (2009) by the Department of Energy (DOE) to invest in public and private sectors aimed at building a sustainable energy economy and reducing GHG emissions in the state.

This article is organized as follows. Section two reviews previous research; section three presents the theoretical model; section four explains the source of data used for the empirical application; section five focuses on the econometric calibration of the model; and section six presents and discusses the results of the empirical analysis. Lastly, section seven gives some concluding remarks.

2. Review of previous research

In the past few years there is an increased interest in modeling the effects of biofuels expansion on land use. The models developed in the literature are essentially of two types: partial and general equilibrium models. Partial equilibrium models include the Forest and Agricultural Sector Optimization Model (FASOM) developed by Adams et al. (1996) for the United States Environmental Protection Agency (US-EPA). FASOM is a nonlinear (quadratic) deterministic dynamic model of the forest and agricultural sector of the United States. This model has been used by McCarl and Schneider (2001) to analyze the welfare and market implications derived from climate change policies. The objective of FASOM is to maximize the total welfare (Consumer plus Producer Surplus) of the agricultural and forestry sector subject to resources, market and policy constraints. The peculiarity of this model is that of having a price-endogenous specification of the inverse system of supply and demand for agricultural and forest products that compete in using land as a factor of production. This model is calibrated using the historical crop mixes in order to produce a crop land use pattern that deviates 10% from the observed historical land allocation (McCarl and Spreen, 1980; Önal and McCarl, 1991). FASOM employs 11 supply regions and a single national demand region providing the market price of agricultural and stumpage commodities as a model solution. Adams et al. (2008) extended FASOM including the net GHG emissions associated with the direct and indirect land use change for production of biofuels of first and second generations. FASOMGHG has been used to examine environmental and economic implications of carbon reduction policies and the impact of these policies on land use change (Baker et al., 2010; Birur et al., 2010).

Along the same theoretical line of FASOM, Chen et al. (2011) developed the Biofuel and Environmental Policy Analysis Model (BEPAM) which is a dynamic multimarket partial equilibrium price-endogenous model of the markets for fuel, biofuel, food, feed crops and livestock of 41 crop reporting districts of the United States that trade with the rest of the world. Compared to FASOM, BEPAM has a higher resolution and includes also the "vehicle kilometers traveled" as an additional endogenous variable. The calibration of this model is based on the use of synthetic (hypothetical) crop mixes in order to allow the possibility of planting new energy crops for what there is no historical data. The authors used this model to study the welfare and economic impact of the mandate for biofuels established by EISA.

The Food and Agricultural Policy Research Institute (FAPRI) modeling system is a static partial equilibrium model that relies on the econometric estimation of over 800 equations that capture biological, technological and economic relationship between the majority of the agricultural commodities of the United States. By linking the equations within a particular commodity sector, the equilibrium price is determined by imposing the market clearing conditions between supply and demand. In contrast to FASOM and BEPAM, market prices of energy crops are treated as exogenous; consequently an increase in price or quantity demanded of biofuels would shock the equilibrium conditions of the FAPRI model and a new equilibrium will be reached through an iterative computational procedure. Although the FAPRI model does not explicitly impose land constraints, US-EPA (2010) jointly used FAPRI and FASOM to estimate the ILUC emissions that may be induced by the EISA mandate. A different modeling approach on predicting the impact of the 2015 and 2022 EISA standards on land-use change was used by Dicks et al. (2009) who used the POLYSIS modeling system. POLYSIS is a partial equilibrium recursive model that uses a linear programming algorithm to simulate the planting decision at year t, followed by an econometric estimation of the demand at year $t+1$ to determine the crop price based on the supply predicted the previous year. In POLYSYS, an exogenous shock such as the EISA mandate alters the agricultural production activities from a baseline scenario projected by USDA. The interactive mechanism of supply and demand produces a scenario of crop land allocation at the clearing market conditions.

General equilibrium models such as the MIT Integrated Global System Model (IGSM), Global Trade Analysis Project (GTAP) and IFPRI-MIRAGE models are more geared towards studies on economy-wide effects of the biofuel expansion such as the impact of biofuel production on the equilibria of the fossil energy market (Bryant et al., 2010). These three models are calibrated in different base years using the same dataset provided by GTAP. However, IGSM was used by Melillo et al. (2009) in conjunction to a dynamic recursive terrestrial biogeochemistry model to study the impact of biofuels expansion programs on LUC/ILUC over the twenty-first century. GTAP is a static model of 18 agro-ecological zones of the world with a detailed world land use. Birur et al. (2010) linked the GTAP-BIO model, which includes the biofuels' component, to FASOMGHG through a static quadratic revenue function restricted to different crop price levels simulated with the latter model. This approach was used to simulate the effects of the global U.S. biofuels policies. IFPRI-MIRAGE is a dynamic general equilibrium model of the same resolution of GTAP and was used by the International Food Policy Research Institute (IFPRI) at request of the European Commission to make predictions on possible LUC/ILUC emissions connected with the European Biofuel mandate (Al-Riffai et al., 2010; Laborde, 2011).

The objective of the previous models is, in general, that of maximizing the total surplus, treating the policy variables as exogenous. Furthermore, they do not allow the stakeholders to take part in the decision process in a bottom-up fashion. We believe that these models are not well suited to analyze the specific research question that we would like to answer, i.e. whether participatory decisions

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