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Ethanol production under endogenous crop prices: Theoretical analysis and application to barley

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ABSTRACT

We examine the social desirability of ethanol production from agricultural crops when the greenhouse gas balance, land competition and crop price determination are taken into account. We focus on the whole production chain and examine how the life cycle CO_2-equivalent (CO_2-eq) emissions and the endogenous crop prices impact social benefits from ethanol production. Ethanol production is desirable under current ethanol price only if the side products, grain residue for animal feed and the straw for energy, are produced. If either these cannot be produced or emissions from soil are high, social returns to ethanol production either vanish or become small.

1. Introduction

Climate policies, the European Union's Emission Trading Scheme (EU ETS) and the current renewable resource program have changed production incentives in favor of renewable energy production. The goal of renewable energy production is to reduce CO_2-eq emissions and promote the production and use of bioenergy and biofuels. However, the net greenhouse gas (GHG) impacts of alternative biofuel production pathways remain disputable. It is possible that instead of net CO_2-eq emission offsets, the production and use of biofuels creates more CO_2-eq emissions than the production and use of fossil fuels [1–3].

The determination of life cycle GHG profiles of biofuel and fossil fuel production chains requires life cycle assessment (LCA). Most LCA studies have focused on the energy and GHG balances of biofuels and fossil fuels. These studies have demonstrated that in comparison to conventional fuels, biofuel pathways may provide GHG emission reductions [2,3]. However, as von Blottnitz and Curran observed in their review of ethanol production pathways, GHG emission reductions provided by different biofuel chains may vary significantly [4]. This variation is mainly driven by differences in the treatment of co-products (protein meal from oilseed crops and feed from distiller grains) and how impacts are allocated to them. Also, the quantity and type of process energy used has a significant impact on the results [5]. Farrell et al. provide a meta-analysis of six studies on corn-based ethanol production and find that although the current corn ethanol technologies are less petroleum intensive than gasoline, they nevertheless entail as much greenhouse gas emissions as gasoline technologies. Also, the authors stress the importance of accounting for other environmental impacts of ethanol production [1]. Subsequent research has focused on a variety of

Abbreviations: DDGS, distillers' dried grains with solubles; GHG, greenhouse gas; LCA, life cycle assessment.

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environmental issues, in addition to energy balances and GHG emissions, of corn-based ethanol production. For instance, Delucchi examines water and land use, Groom et al. analyze biodiversity conservation, and Hill et al. health costs of air emissions from biofuels and gasoline [6–8]. Finally, Smith as well as Murhphy and Hall continue the analysis of improving energy and GHG efficiency of bioenergy crops [9,10].

Accounting for the direct greenhouse gas balance of the whole life cycle is not enough, however, to give a comprehensive assessment of ethanol production. Also changes in economic behavior must be accounted for, because these changes are reflected on the greenhouse gas balance as well. Promoting bioenergy and biofuel production leads to increased competition on agricultural land. Substituting biofuels for gasoline reduces direct GHG emissions and provides carbon benefits but using land for biofuel production can also create indirect carbon costs through land use change [11]. Diverting cropland from feed and food production in Europe and the U.S. could provide strong incentives for converting additional land into cultivation of feed and food crops in other parts of the world (such as Brazil, China and India). Consequently, this indirect land use change could result in additional emissions [11].

As Rajagopal and Zilberman suggest, changes in agricultural commodities prices depend on several regional factors, such as the intensity of bioenergy crop cultivation and the extent of trade in food-related commodities [5]. Furthermore, they point out that the food industry may be negatively affected by the resulting higher input costs [5]. The socially optimal amount of biofuel production does not only depend on the price of cereals and on the effects of rising prices on different industries, but also on the climate impacts from biofuel production. Thus, the social desirability of ethanol production should be analyzed under endogenous crop prices. The endogenized crop prices enable an analysis of trade-offs between climate benefits from bioenergy crop production (either for heat and electricity or biofuel) and consumers' valuation of food and feed production. The OECD and Mitchell assessed bioenergy production and its impact on agricultural commodity prices [12–15]. According to these studies, cereal prices may increase 5–15% due to increased biofuel and bioenergy production.

Besides corn, ethanol can be produced from barley or wheat using the existing cultivation methods. Barley and wheat are feasible cereals for cultivation in Northern agricultural areas, such as Scandinavia, where corn does not provide sufficient yields to become cultivated. Moreover, due to the small scale of agriculture in these countries, ethanol production in Northern marginal areas cannot be expected to cause large negative indirect global impacts. Therefore, it is interesting to examine, whether ethanol can be produced from barley or wheat in a sustainable fashion in the Northern areas. An equally interesting issue is to compare the energy efficiency and GHG impacts of these cereals to those of corn-based ethanol production in the U.S. [1]. These two issues constitute the research problem of this paper.

To endogenize the competition on land use, we employ a Ricardian model of heterogeneous land quality, where land is allocated to alternative crops on the basis of their relative profitability. This land-use model captures the fact that profits from crop cultivation depend on the land productivity and relative prices of alternative crops. The model comprises two land use types, bioenergy crop and conventional feed crop, and the effects on the GHG balance are explicitly taken into account. To endogenize the bioenergy crop price we assume that industry demands the crop for both ethanol and feed production, and thus, competes for the crop. We apply the theoretical framework to ethanol produced from barley in Finnish agricultural conditions.

There is currently no ethanol industry in Finland. However, there are plans to open one or two ethanol plants and this information is included in our empirical analysis. While this study provides an insight into the social desirability of ethanol production in Finland, the approach has a wider application. In addition to the general theoretical analysis, we suggest also a systematic economic and LCA treatment of the whole production chain to reveal the key variables impacting on ethanol production.

Our model integrates both the economic aspects as well as the climate impacts of agriculture and biofuel production. Integrating comprehensive GHG balances with consistent economic framework is vital in assessing the social desirability of biofuel production. Further, the model includes a detailed description of the associated agricultural production. This allows us to analyze the impacts of privately and socially optimal biofuel production on agriculture, a factor often ignored in macroeconomic models of biofuel production. We trace out the key parts of the life cycle chain and economics variables that impact on the desirability of biofuel production. Also, the use of the EBAMM model provides a useful comparison of the climate impacts of barley ethanol vis-à-vis corn-based ethanol.

The paper is organized as follows. In Section 2 we develop the theoretical framework and compare the privately and socially optimal solutions. Section 3 builds the parametric version of the model, presents the baseline results and examines key factors impacting the social returns to biofuel production. Concluding remarks and policy implications are provided in Section 4.

2. Ethanol production and commodity markets: a framework and market equilibrium

In this section we develop a framework to determine the private and social optimum for bioenergy crop production. We integrate the LCA aspects to conventional economic analysis. We assume that the bioenergy crop is used in the production of both biofuels and animal feed, resulting in competition for the bioenergy crop produced by farmers and that this competition will affect the endogenous price of the bioenergy and alternative crop.

2.1. *Privately optimal ethanol production*

2.1.1. *Ethanol and animal feed production*

Consider an ethanol firm that manufactures animal feed and ethanol. Ethanol is the primary product and it is produced from bioenergy crop grains. These grains initially go through the ethanol production process. Production technology defines a concave production function $g(\widehat{h}, e)$, where $\widehat{h}$ denotes bioenergy crop and e energy used in the production process, with