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Analysis

Biofuel policies and the environment: Do climate benefits warrant increased production from biofuel feedstocks?

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ABSTRACT

We examine whether climate benefits warrant policies promoting biofuel production from agricultural crops when other environmental impacts are accounted for. We develop a general economic–ecological modelling framework for integrated analysis of biofuel policies. An economic model of farmers' decision making is combined with a biophysical model predicting the effects of farming practices on crop yields and relevant environmental impacts. They include GHG emissions over the life cycle, nitrogen and phosphorus runoff, and the quality of wildlife habitats. We apply our model to crop production in Finland. We find that under current biofuel production technology the case for promotion of biofuels is not as evident as has been generally thought. Only reed canary grass for biodiesel is unambiguously desirable, whereas biodiesel from rape seed and ethanol production from wheat and barley cause in most cases negative net impacts on the environment. Suggested policies in the US and the EU tend to improve slightly the environmental performance of biofuel production.

1. Introduction

Bioenergy-related policy analyses have gradually shifted the focus from the mere output (biofuels and bioenergy) to a more comprehensive analysis that accounts for the climate impacts of the production chain (Farrell et al., 2006; Mäkinen et al., 2006; Edwards et al., 2006). The bulk of bioenergy and biofuels literature has focused on net energy balances and net greenhouse gas (GHG) emissions of alternative bioenergy and biofuels options, many extending their focus on the life cycle of the production chain. Accounting climate externalities in the biofuel production process allows one to make better decisions regarding biofuel policies.

However, one important step still remains to be taken in bioenergy policy studies. Bioenergy production has many kinds of environmental impacts, such as the effects on soil, water, biodiversity and the landscape. What is good for the climate may not be good for water ecosystems. Increasing bioenergy production affects biodiversity and the landscape, too. Thus, it is important to ask whether pursuing bioenergy policies for climate change entails important environmental trade-offs, for instance, with regard to water quality and biodiversity. Furthermore, if other environmental impacts exist, it is necessary to examine if there is a need to revise bioenergy policies to strike a better balance between all key environmental aspects.

Studies on multiple environmental effects of biofuel production are still rare. Two recent US biofuel studies focusing on water protection are alarming. Both examined environmental effects from land use change associated with corn-based ethanol production in the US. Donner and Kucharik (2008) analyse the effects of US ethanol targets on nitrogen runoff from farmland into the Gulf of Mexico. Their results show that meeting the US ethanol targets set out for 2022 will increase nitrogen loading by 10–34%. Using an integrated agronomic and economic model, Marshall (2007) shows that increased corn-based ethanol production will lead to a significant increase in total losses of nutrients from agriculture and an increased risk of erosion. From a slightly different angle, Evans and Cohen (2009) examine the competition of selected biofuel crops on land and water in the Southern States of the US, while de Fraiture et al. (2008) examine the land and water implications in China and India. Muller (2009) discusses the broad aspects of sustainable bioenergy crop production. Landis et al. (2008) analyse how increasing corn ethanol production reduces diversity of agricultural landscapes and decreases the value of biocontrol services to combat weeds and pests. Barney and DiTomaso (2008) assess the risk that recently favoured bioenergy crops become new invasive species in agricultural landscapes. Emphasizing both spatial and temporal aspects, Sala et al. (2009) provide a discussion on biodiversity, invasive and pollution aspects of biofuel crop production.

While all the above mentioned studies stress the complex ecological and biological problems associated with bioenergy crop production, they devote less attention to the economic aspects, the potential costs and benefits. There is clearly a need for a comprehensive monetary

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assessment of the climate and other impacts of bioenergy crop production. In this paper we examine whether the climate benefits warrant the current and suggested biofuel support policies when other environmental impacts are accounted for. We provide an integrated economic and ecological modelling approach: an economic model of farmers' decision making is combined with a biophysical model predicting the effects of biofuel support policies on farming practices, crop yields and the key environmental effects. They include GHG emissions over the life cycle, nitrogen and phosphorus runoff, and the quality of wildlife habitats.[1] To facilitate comparison of these diverse impacts, we express them in monetary terms (utilizing environmental valuation studies). Using monetary values as a common measure helps us to compare and contrast the value of other environmental impacts with the climate benefits of bioenergy production.

The baseline of the analysis consists of the current support programs that rely mostly on budgetary instruments, such as tax concessions and direct support, that are complemented with biofuel blending or use mandates and trade restrictions (mainly import tariffs). As regards policy analysis we scrutinize two types of biofuel support policy reforms. The first policy reform involves radical elimination of current support policy programs. The second policy reform is formulated in the spirit of two new large programs, the US Energy Act and the EU Bioenergy Directive. The US Energy Independence and Security Act (EISA) was enacted in December 2007, and the new EU Directive on Renewable Energy (DRE) is currently in the legislative process. While the former defines a Renewable Fuel Standard (RFS) calling for US biofuel use to grow to a minimum of 136 billion litres per year by 2022, the latter suggests biofuels will account for at least 10% of all transport fuel consumption.[2]

Bioenergy policies have profound impacts on commodity markets, land-use patterns and the environment. This requires a comprehensive approach. We follow here OECD (2008), which analysed the implications of biofuel support policies for biofuel supply and demand, as well as for agricultural commodity markets and land use by using the OECD Aglink simulation model complemented by the FAO-developed Cosimo model.[3] We adopt the new equilibrium EU crop prices taken from Aglink–Cosimo for our policy scenarios and incorporate them into our integrated economic and ecological model. Because comprehensive data on environmental impacts and their valuation for the EU is missing, we use Finnish agricultural and environmental data.

The rest of the paper is organized as follows. Section 2 develops a theoretical framework for the paper. The empirical application of the model is presented in Section 3. Finally, the results and discussion are presented in Section 4.

2. Theoretical Framework

We develop an integrated economic and ecological modelling approach to bioenergy policies. We first examine the market equilibrium of bioenergy crop production and use in biofuel production. We then link these decisions to a biophysical model predicting the effects of farming practices on the environmental effects. The analysed environmental effects include GHG emissions over the life cycle, nitrogen and phosphorus runoff, and the quality of wildlife habitats.

Consider a biofuel (ethanol or biodiesel) processing firm. It combines bioenergy crops (y) and energy (E) in the production process to manufacture biofuels. Let the production technology of the industry define a continuous and concave production function for biofuel (h): $h = g(y,E)$ with $g_y > 0, g_E > 0$ but $g_{yy} < 0, g_{EE} < 0$. Let η denote the price of biofuels, p the price of the bioenergy crop and v the price of energy. We describe the direct support as a subsidy (s) for the use of bioenergy crops, thus $(p - s)$ is the after-support price of bioenergy crops. As is well-known from other literature, a blending requirement (m) tends to increase the price of biofuel, so that we can express the biofuel price as $\eta = \eta(m)$, with $\eta' > 0$. An import tariff for biofuel will have a similar impact on the biofuel price: thus m can be used to describe both the impact of the blending requirement and the tariff. Equipped with this notation, the economic problem of the biofuel firm is to choose the use of inputs so as to maximize its profits, that is

$$\underset{y,E}{Max}\ \pi^b = \eta(m)g(y,E) - (p-s)y - vE. \tag{1}$$

The conventional first-order conditions

$$\pi_y^b = \eta(m)g_y - (p-s) = 0 \tag{2a}$$

$$\pi_E^b = \eta(m)g_E - v = 0 \tag{2b}$$

define the demand function for inputs. In particular, it holds for the demand for bioenergy crops, y^d, that $y^d = y^d(\eta(m),p,s,v)$. By differentiation we have that $y_m^d > 0$ and $y_s^d > 0$, so that biofuel policies increase demand for bioenergy crops. Furthermore, assuming the bioenergy crop and energy input are complements in the production process, we have $y_v^d < 0$. Hence, a higher price of energy decreases demand for bioenergy crops.

The amount of arable land, A, is allocated between bioenergy crops and food/feed crops. Land quality differs over parcels and we assume that it can be ranked by a scalar measure q, with the scale chosen so that minimal land quality is zero and maximal land quality is one, i.e., $0 \le q \le 1$. Let $A(q)$ denote the cumulative distribution of q (acreage having quality q at most), while $\alpha(q)$ is its density. It is further assumed that $\alpha(q)$ is continuous and differentiable. The total amount of land in the region is thus $A = \int_0^1 \alpha(q)dq$.

Suppose that the farmers can cultivate food/feed crops or bioenergy crops $i = 1,2$, where crop 1 refers to the food/feed crop and crop 2 denotes the bioenergy crop. Both crops are produced under constant returns to scale technologies. Output of each crop per unit of land area, y_i, is a function of land quality q and the fertilizer application rate (fertilizer per unit of land area) l_j, $y_i = f^i(l_i;q)$. The production function is increasing and concave in fertilizer and land quality, that is, $f_l^i(l_i;q) > 0$, $f_{ll}^i(l_i;q) < 0$, $f_q^i(l_i;q) > 0$, $f_{qq}^i(l_i;q) < 0$. Let p_i and c denote the respective prices of crops and fertilizer. Let $L_i(q)$ denote the share of land of quality q allocated to use i. The total amount of land allocated to each use is thus $H_i = \int_0^1 L_i(q)\alpha(q)dq$, $i = 1,2$. Let the per parcel profit be $\pi^i = pf^i(l_i(q),q) - cl_i(q) - M_i$, where M_i denotes other costs of cultivation except fertilizer. Then, we have the following constrained maximization problem to solve,

$$\underset{l_i,H_i}{max} \int_0^1 \sum_{i=1}^{2} \pi^i L^i \ \alpha(q)dq. \tag{3}$$

subject to $L_1(q) + L_2(q) \le 1 \forall q$.

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[1] As regards water, we focus on nutrient runoff only, because in Finland agriculture is rainfed, so that total water use is not a problem. There are many countries where water use matters, see for instance, Dominguez-Faus et al. (2009) and Chiu et al. (2009) for discussion.

[2] The revised statutory requirements for RFS establish new specific annual volume standards for cellulosic biofuel, biomass-based diesel, advanced biofuel, and total renewable fuel that must be used in transportation fuel. The revised statutory requirements also include new definitions and criteria for both renewable fuels and the feedstocks used to produce them, including new greenhouse gas emission (GHG) thresholds as determined by lifecycle analysis. The regulatory requirements for RFS will apply to domestic and foreign producers and importers of renewable fuel used in the US.

[3] Aglink–Cosimo-based analysis includes a sequence of scenarios aiming to shed light on a number of questions related to biofuel markets and biofuel support policies including: (i) the effects of existing policies analysed by simulating an elimination of biofuel support policies and (ii) analysing the impacts of two new programs (the US EISA and the EU DRE) on the supply of and demand for biofuels.