Biofuels production versus forestry in the presence of lobbies and technological change

Johanna Jussila Hammes*

Swedish National Road and Transport Research Institute, VTI

Box 55685; SE-10215 Stockholm

Tel: +46 8 555 77 035; E-mail: johanna.jussila.hammes@vti.se

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Abstract

We study the political determination of a hypothetical land tax, which internalises a negative environmental externality from biofuels. The tax allocates land from biofuels towards forestry. Lobbying affects the tax rate, so that the sector with the lower elasticity of land demand determines the direction in which the tax deviaties from the social optimum. Lobbying by the sector with higher elasticity of land demand cancels partly out the other sector's lobbying. The politically optimal tax rate is "self-enhancing" in that the tax lowers the elasticity of land demand in the sector which initially had a lower elasticity,

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and raises it in the other sector. This can dwarf the government's other attempts to support the production of biofuels. Finally, technological progress in biofuels serves to strengthen that sector by lowering its elasticity of land demand, and weakens the forestry sector by raising its elasticity of land demand. Depending on the initial tax rate, this can be welfare enhancing or lowering. Furthermore, it can lead to excessive deforestation.

Keywords: Biofuels, forestry, land use, political economy, technological change

"This paper has not been submitted elsewhere in identical or similar form, nor will it be during the first three months after its submission to the Publisher."

1 Introduction

Production and use of biofuels, both for electricity and heat generation and for transportation, has grown over the past years. There are many reasons for this, among other climate change, energy security, high fossil fuel prices and rural development goals. Production of most types of biofuels requires land, however, thus competing for land both with agriculture and with forestry.[1] For instance, Hyytiäinen et al. (2008) find for Finland that the production of biofuels (reed canary grass) is the most profitable use of arable land (compared to growing oats or pine trees), although only in the proximity of (at most 40 km from) a thermal power station. Lankoski and Ollikainen (2008) in turn find that production of reed canary grass in Finland, when the alternative is oats, is socially optimal even 100 km away from the power plant. In the tropics, not only fallow or unused agricultural land is used for biofuel production but also rainforest land has been converted, for instance, to palm oil plantations.[2] This development is largely driven by policy measures, for instance, by the European Union's (EU) 20-20-20 target (a reduction of at least 20% in greenhouse gas emissions, and a 20% share of renewable energies in the EU's energy consumption by 2020), set by the European Council in March 2007.

Biofuel production may, however, lead to negative side effects. According to (WWF, 2008, 3),

> depending on which crops are produced, where and how, bioenergy developments can cause significant negative environmental and social impacts, including deforestation, biodiversity loss, soil

> erosion, excessive water use, conflicts over land rights and land use, food shortages and staple food crop price spikes.

It is further conceivable that biofuel production that replaces forestry increases the use of fertilizers, pesticides and herbicides, thus increasing the run-off of these to the surrounding nature and waterways.

It is thus possible that land use change towards the production of biofuels, especially if biofuel production replaces forests, creates a negative external effect compared to land use for forestry. Although several different external effects are present, the common thread is the change in land use. Therefore, if a government wanted to internalise the externality using only one policy instrument, taxing land use for biofuel production would be a first-best policy instrument. It is, however, possible that lobbying by the sectors involved affects the setting of such a tax rate.

The aim of this paper is to contribute to our understanding of the process of land use change between forests and biofuels, how it is regulated, and how the political economics behind this process work. We do this by examining three factors that can influence such a process. We start by assuming that the government imposes a land use tax on the biofuels producing sector, in order to internalise the negative externalities that it produces.[3] However, lobbying, and government susceptibility to lobbying, have an impact on the level of this policy instrument. This in turn affects the allocation of land between the two sectors. It is futher possible that government policies change the strength of the two lobby groups, the biofuels and the forestry lobby, respectively. We examine both how a land tax on biofuels and an (exogenous) biofuels target or other such policy which aims to boost the production of biofuels affect the lobby groups' strength.

Finally, we study the effect of an (exogenous) improvement in the technology of growing biofuels, and how this affects the two lobby groups' strength, and the optimal land use. The cause of technological progress is unspecified and can take the form of better varieties of crops, increased fertilizer, pesticide or herbicide use or other changes. If a small country is able to export at a given price, then an improvement in the technology, by increasing the productivity of land in biofuel production, increases demand for land for biofuels and thereby leads to deforestation. What we add is a description of how lobbying affects this land reallocation.

The present paper touches several different branches of economic inquiry. Thus, studies of optimal land allocation between two sectors have mainly concentrated on studying land allocation between agriculture and forestry, and the mechanisms behind deforestation. The question has mainly been seen as a dynamic resource use problem. Among others, Ehui and Hertel (1989) and Ehui et al. (1990) calculate the optimal steady-state forest stock, and examine also the effect of other factors, such as technology, fertilizer use or social discount rates. Barbier et al. (2005) study the cumulative level of resource conversion and examine how trade policy influences the distortions created by political corruption. Their empirical findings suggest that increased corruption and resource dependency promote land conversion, whereas rising terms of trade reduce conversion of forestland to agriculture.

While the literature on biofuels is rather young, it is growing fast. It has mainly concentrated on examining the efficiency of various policy instruments in supporting the expansion of biofuels production,[4] and more recently, the implications of biofuels production on the environment,[5] and the food supply.[6]

Land taxes have been studied extensively in the past, although the research has concentrated on the effect of land taxation on economic growth.[7] Land taxes as an instrument for environmental policy is largely missing from the literature. This might be partly due to the fact that land taxes rarely exist in reality (Lindholm (1979)). Plausible explanations as to why this is so are (to our knowledge) missing from the literature.

By way of including lobby groups that attempt to influence the government's policy, this article offers an explanation to the rarity of land taxation, and even to the fact that land use for e.g., agriculture is often subsidised rather than taxed. The motive for land taxation here differs from that in the traditional literature, however, where it is seen as a tool to raise revenue and to encourage economic growth. Thus, we formulate a political economy model of a land tax aimed at internalising a negative environmental externality arising from land use by the biofuels sector in a setting where two sectors, biofuels and forestry, use land in production. Unlike in the "traditional" land tax literature, there is no revenue motive for taxation. Furthermore, it is possible that lobbying turns the "tax" into a subsidy. The model is based on Bernheim and Whinston (1986) principal-agent model with menu auctions, which Grossman and Helpman (1994) extend to trade policy formation.

Grossman and Helpman's model has by now spawned a large literature examining environmental policy determination.[8] The contribution of the present paper to this literature is twofold. Firstly, we introduce a general equilibrium effect arising from competition for, and a change in a factor use arising from the introduction of the policy instrument. Thus, both the biofuels and the forestry sectors use land in production and compete for it, and land use by neither sector is fixed.[9] This innovation allows us to study endogenous change in lobby group strength and to adjust factor use endogenously.[10]

We further examine the effect of land augmenting technological change in the biofuels sector, and its consequences for lobby group strength and welfare. Technological chage raises the productivity of land thereby leading to an increase in its value, given constant output prices, and resulting in land reallocation from the less towards the more productive sector. This corresponds for instance to Ehui and Hertel (1989), who show that technological progress in agriculture lowers the optimal steady-state forest stock. In the present article, we show how technological change also works to strengthen the (technologically) improving sector's lobby group vis-á-vis the government compared to the stagnant sector, and how this leads to increased pressure to lower the land tax rate and the allocation of land between the sectors.

The paper is organized as follows: In Section 2 we present the formal model and discuss changes in land use due to land taxation. Section 3 discusses the tax rate, and 4 analyses the lobby groups' strength and strategies. In Section 5 we study the effect of technological change on the lobby groups and on land allocation. The final section concludes.

2 The Model

Consider a small open economy where the output prices of goods are treated as exogenous. In other words, we assume the existense of a world market both for biofuels and for wood, which sets the world market price for these goods and that the world market prices also apply domestically. The economy is assumed to consist of N individuals with identical, additively separable preferences. We normalize $N = 1$ without loss of generality. Each individual maximizes a utility function of the form $U^h = x_O + \sum_{i=B,\ F} u_i(x_i) - \phi(T_B)$, where x_O denotes consumption of a numeraire good O and x_i consumption of biofuel and logs, which will be indexed by $i,\ j \in \{B,\ F\}$, $i \neq j$. The sub-utility functions $u_i(x_i)$ are differentiable, increasing and strictly concave. The net damages from land use for biofuels production, $\phi(T_B)$, where T_B is land use by the biofuels sector, are differentiable, increasing and strictly convex. Land use in the forestry sector F, T_F, is assumed not to cause any (net) externalities.

The numeraire good O has a domestic and world market price equal to one. The domestic and world market price of biofuels and logs equals p_i. With these preferences each consumer demands $d_i(p_i)$ units of good i, where $d_i(p_i)$ is the inverse of the marginal utility function $u_i'(x_i)$. The remainder of a consumer's income E is devoted to the numeraire good. The consumer thus attains indirect utility given by $v(\mathbf{p},\ E) = E + S(\mathbf{p}) - \phi(T_B)$, where $\mathbf{p} \equiv (p_B,\ p_F)$ is the vector of output prices of the non-numeraire goods and $S(\mathbf{p}) = \sum_{i\in\{B,\ F\}} u_i[d_i(p_i)] - \sum_{i\in\{B,\ F\}} p_i d_i(p_i)$ is the consumer surplus from goods B and F. Consumption of the numeraire good produces no consumer surplus.

The numeraire good O is produced using labor alone, with constant returns to scale and an input-output coefficient equal to one. We assume that the aggregate labor supply, l, is sufficiently large to ensure a positive output of this good. It is then possible to choose units so that we can set the wage rate to one ($w = 1$). Goods B and F are produced using labor and land, also with constant returns to scale. The aggregate rent accruing to land in sector $i = \{B,\ F\}$ is denoted by $\Pi_i\left(p_i,\ z_i,\ H_i\right)$, where H_i is a technology parameter on land use (Romer, 2001, 9) and z_i is the cost of land.[11] Hotelling's lemma gives the industry's land demand curve $\frac{\partial \Pi_i}{\partial z_i} = -T_i$. Because a change in land price, and consequently, land demand, also affects sector j, we further obtain a general equilibrium effect on that sector's land demand: $\frac{\partial \Pi_j}{\partial z_i} = -T_j \frac{\partial z_j}{\partial z_i}$.

Allocation of land between the sectors is not fixed but land demand T_i is a function $T_i\left(p_i,\ z_i,\ H_i\right)$. For simplicity, we assume land demand to be falling but linear in land price, so that $\frac{\partial T_i}{\partial z_i} = T_{i2} < 0$, $T_{i22} = 0$ and $T_{i23} = 0$. The production function of good i is given by $y_i \equiv y_i\left(H_i T_i,\ L_i\right)$, where L_i is labor demand.[12]

The government has only one policy instrument at its disposal, namely a land tax or subsidy on the biofuels sector. Since the tax is used to internalize a negative externality arising from land use, it is the first-best policy instrument. Revenue from the tax (cost of the subsidy) is distributed (collected) in a lump-sum fashion to the consumers.[13]

The ad-valorem land tax/subsidy drives a wedge between the value of land z and the cost of land to the biofuels sector, z_B. The tax/subsidy is denoted by the parameter t_B, such that $z_B \equiv \left(1 + t_B\right) z$. The cost of land to sector

F equals the value of land, z. $t_B > 0$ denotes a land tax and $-1 < t_B < 0$ a land subsidy.[14] The land tax/subsidy generates the per capita government revenue (expenditure) of

$$R(t_B,\ z) = t_B z T_B. \tag{1}$$

Individuals collect income from several sources. Firstly, they supply their labor endowment, l_h, where $\sum_h l_h = l$ is the aggregate labor supply, inelastically to the competitive labor market and receive the wage income $wl_h = l_h$. Secondly, each individual receives (pays) an equal share of any government revenue, $R(t_B,\ z)$. Thirdly, the farmers and the foresters own a share α_h^i of land in sector i and obtain the rent from land, totalling $z(T_B + T_F)$. We further assume the existence of a group of workers that constitute a share $\alpha_W = 1 - (\alpha_B + \alpha_F - \alpha_{BF}) > 0$ of the population, who own no land.

Those using land for purpose i are assumed to have similar interests in the land tax and to form a lobby group to influence the government's tax policy. The formation of lobby groups is not modeled here; the reader is referred to Olson (1965), or for models of endogenous lobby organization to Mitra (1999), Magee (2002) and Le Breton and Salanie (2003). We assume that at most two lobby groups, the biofuels and the forestry lobby, overcome the free riding problem inherent to interest group organization and organize, following Aidt (1998), functionally specialized lobby groups that offer a menu of contributions to the government depending on its choice of land tax policy.[15] That a lobby group is functionally organized means that it only cares about profits to the sector it represents, and does not consider other sources of income, for instance government transfers or income from labor to its members. The organized land users coordinate their political activities so as to maximize the respective lobby's welfare. The lobby representing industry i thus submits a contribution schedule $C_i(t_B)$ that maximizes

$$v_i = \hat{W}_i(t_B,\ z) - C_i(t_B), \tag{2}$$

where

$$\hat{W}_i(t_B,\ z) \equiv \Pi_i[p_i,\ z_i,\ H_i] \tag{3}$$

gives the gross of contribution profits (welfare) of the members of lobby group i.

Facing the contribution schedules offered by the various lobbies the incumbent government sets the land tax (subsidy). The government's objective is to maximize its own welfare. We assume that the government cares about the contributions paid by the lobbies and possibly also about social welfare. The government's objective function is assumed to be linear and is given by

$$G = \sum_{i \in A} C_i(t_B) + a\hat{W}(t_B,\ z),\ a \geq 0 \tag{4}$$

where A is the set of organized industries, and

$$\hat{W}(t_B,\ z) \equiv l + \sum_{i=B,\ F} \Pi_i[p_i,\ z_i,\ H_i] + R(t_B,\ z) + S(\mathbf{p}) + z(T_B + T_F) - \phi(T_B) \tag{5}$$

measures the average (gross) welfare. Parameter a represents the government's weighing of a unit of social welfare compared to a unit of contributions and is taken to measure the government's non-susceptibility to lobbying (the higher the a, the less susceptible the government is to lobbying).

The total amount of land available is normalized to one so that

$$T_B\left[p_B,\ (1+t_B)\,z,\ H_B\right]+T_F\left[p_F,\ z\right]=1. \tag{6}$$

We can use this to solve for the equilibrium value of land as a function of the output prices, the land tax rate and the technology. We denote this functional relationship by $z\,(\mathbf{p},\ t_B,\ H_B)$.[16]

According to Ricardo (1817) and Calvo et al. (1979), a tax on land rents gets fully capitalized in the value of land. This was refuted by Feldstein (1977), who nevertheless allows for a fall in land price as a land tax is introduced.[17] We obtain the change in the value of land when a land tax is introduced by differentiating equation (6) with respect to t_B to obtain[18]

$$\frac{\partial z/\partial t_B}{z}=-\frac{T_{B2}}{(1+t_B)\,T_{B2}+T_{F2}}<0. \tag{7}$$

Thus, because land demand by the forestry sector increases as land in biofuels production is being taxed, the tax will not be wholly capitalized in the value of land. This result is well in line with Feldstein (1977), since land allocation in the model is determined by the point at which the value of marginal product of land in forestry equals the value of marginal product of land in biofuels production. Since the tax changes the value of marginal product of land in biofuels production, the land allocation adjusts accordingly, and the value of land also adjusts. The second order condition of the land price function with respect to the land tax is given by

$$\frac{\partial^2 z/\partial t_B^2}{z} = \frac{2T_{B2}^2}{\left[(1+t_B)\,T_{B2}+T_{F2}\right]^2} > 0. \tag{8}$$

The land value function is thus a falling and convex function of the land tax.

Changes in the taxation of land thus affect the allocation of land between the two land using sectors. We formulate the following lemma to elaborate on the changes in land demand:

Lemma 1 *An increase in the land tax on biofuels leads to a decrease in land demand by the biofuels sector and to an increase in land demand by forestry.*

Proof. Totally differentiating land demand in each sector with respect to t_B and substituting in Equation (7) yields for biofuels production $\frac{dT_B}{dt_B} = \frac{\partial T_B}{\partial z_B}\frac{\partial z_B}{\partial t_B} = \frac{zT_{B2}T_{F2}}{(1+t_B)T_{B2}+T_{F2}} < 0$ and for forestry $\frac{dT_F}{dt_B} = \frac{\partial T_F}{\partial z}\frac{\partial z}{\partial t_B} = -\frac{zT_{B2}T_{F2}}{(1+t_B)T_{B2}+T_{F2}} > 0$. ■

The derivation of the equilibrium in differentiable strategies can be done in similar fashion to Grossman and Helpman (1994), Dixit (1996) and Fredriksson (1997), alternatively it can be modeled as a Nash-bargaining game in the fashion of Goldberg and Maggi (1999), and is left out.

To summarize, we model policy making under lobby influence as a two-stage common agency game. In the first stage, lobbies confront the government with their contribution schedules, which are assumed to be (both locally and) globally truthful, continuous, and differentiable at least in the neighborhood of an equilibrium. Each lobby takes the actions of the other lobby as given. In the second stage, the policy maker sets environmental policy and receives the corresponding political contributions. The assumption of global truthfulness implies that the politically optimal policy vector can be characterized by the following equation:

$$\sum_{i=B,\ F} \bigtriangledown W_i\left(t_B\right) + a \bigtriangledown W\left(t_B\right) = 0. \tag{9}$$

3 The politically optimal tax rate

We differentiate the lobbies' welfare functions given by equation (3) and the general welfare function given by equation (5) with respect to t_B and enter the obtained derivatives into equation (9) to find the equilibrium characterization of the government's policy choice, given by

$$\begin{aligned} &- I_B T_B \left[z + \left(1 + t_B\right) \frac{\partial z}{\partial t_B}\right] - I_F T_F \frac{\partial z}{\partial t_B} \\ &\qquad + a\left[t_B z - \phi\left(T_B\right)\right] T_{B2} \left[z + \left(1 + t_B\right) \frac{\partial z}{\partial t_B}\right] = 0 \end{aligned} \tag{10}$$

The second order condition of equation (10) is discussed in Appendix A.

I_i is an indicator variable taking a value of one if lobby i organizes and zero otherwise. Dividing equation (10) by $-zT_{B2}\left[z + \left(1 + t_B\right) \frac{\partial z}{\partial t_B}\right]$ and moving t_B to the other side of the equality sign, simplifying and substituting in the partial of z given by equation (7), we can further simplify and solve for the equilibrium ad valorem land tax given implicitly by $t_B = \frac{z_B - z}{z}$, namely

$$t_B^0 = \delta^0 \left[-\frac{I_B}{\varepsilon_{T,\ z}^B} + \frac{I_F}{\varepsilon_{T,\ z}^F} + \frac{a\phi\left(T_B^0\right)}{z^0}\right] \tag{11}$$

where $\varepsilon_{T,\ z}^{i} = -\frac{\partial T_i}{\partial z_i}\frac{z_i}{T_i} > 0$ denotes the price elasticity of land demand in sector i, and the multiplicand $\delta^0 = \frac{\varepsilon_{T\ \ z}^{B}}{a\varepsilon_{T,\ z}^{B}+I_B}$ is positive. The maximization problem thus yields a modified Ramsey rule. The superscript 0 denotes the politically optimal values of the variables. Appendix B solves for the tax equation using specified functional forms for the land demand and the externality equations. We also discuss the second order conditions of the welfare functions underlying Equation (11).

Equation (11) gives the ad valorem land tax rate as a sum of three components. The first two arise from lobbying by the respective lobby, where lobby B lobbies for a lower tax rate (the first term is negative), whereas lobby F lobbies for a higher tax rate (the positive second term). The economic rationale behind lobby activities will be discussed in Section 4. The third term in equation (11) is positive and arises from the marginal damages that land use for biofuels production gives rise to. It serves to raise the tax rate.

It is easy to see from equation (11) that the socially optimal tax rate is $t_B^{so} = \frac{\phi'\left(T_B^{so}\right)}{z^{so}}$. This corresponds to the familiar environmental economics result that the environmental tax rate should be set equal to the marginal damages from the external effect.[19] Thus, in the social optimum, the government imposes a land tax on the biofuels sector equal to the marginal damages from land use for biofuels production.

It is lobbying by the biofuels producers that creates an ambiguity to the level of tax rate, as this sector lobbies for a lower tax rate. Lobbying by the forestry sector serves to raise the tax rate. Unlike the rest of the literature based on Grossman and Helpman, in our model both lobby groups can organize and all individuals can belong to a lobby, and the tax rate can still deviate from the socially optimal one. In Grossman and Helpman (1994) and rest of the literature following that article, if all individuals are members of some lobby group, the resulting equilibrium tariff rate is socially optimal. We study the question of lobby strenth more closely in Section 4. Before that, we state this property of our model in the next proposition.

Proposition 2 *The socially optimal land tax rate* $t_B^{so} = \frac{\phi'\left(T_B^{so}\right)}{z^{so}}$ *can only be reached in three circumstances. 1. It is reached in the social optimum (as* $a \to \infty$*), regardless of lobby organization; 2. It is reached if no lobby groups organize; or 3. It is reached if both lobby groups organize and they have proportional elasticity of land demand:* $\varepsilon_{T,\ z}^{B} = \gamma \varepsilon_{T,\ z}^{F}$.

Proof. Setting $t_B^0 = \frac{\phi'(T_B)}{z}$ and solving for the weight on $\varepsilon_{T,\ z}^{F}$ in circumstance 3 yields $\gamma = \frac{I_B}{I_F}\left[1 + \frac{\phi'\left(T_B^0\right)}{z^0}\right] > 0$. The rest of the proof arises from an examination of Equation (11) and is trivial. ■

Circumstances 1 and 2 in Proposition 2 are similar to those of the model in Grossman and Helpman (1994) and the literature following it. Property 3 differs from the earlier literature. We now turn to it by examining the determinants of lobby strength and the lobbies' incentives.

4 An analysis of the lobby strength

In order to shed more light to the lobby strategies, we return to the lobbying game. The lobbying game has two (plus one) stages. In the first stage, lobbies confront the government with their contribution schedules. In the second stage, the policy maker sets the environmental policy and recives the corresponding political contributions. In the last stage, the firms take their political contributions and the tax rate t_B^0 as given and produce using T_B^0 and T_F^0 of land, respectively, at a land value z^0. Solving backwards, the government fully anticipates the industries' land adjustment and output repsonse, and chooses the land tax rate to maximize its objective function (4). The firms determine their contributions by anticipating the government's policy choice.

The truthful contribution schedule of each lobby is given by $C_i\left(t_B^0\right) = max\left(0,\ W_i\left(t_B^0,\ z^0\right) - c_i\right)$, where the scalars c_i (the net welfare anchors for the lobby groups) are determined in equilibrium (Mitra (1999)). Then, from the local truthfulness condition of the model, which is a necessary but not a sufficient condition for any interior subgame perfect Nash equilibrium in differentiable strategies, we know that that the marginal contributions for changing the tax rate must equal the marginal benefits ($\nabla C^i\left(t_B\right) = \nabla W^i\left(t_B,\ z\right)$) (see, e.g., (Dixit, 1996, 380)). Differentiating Equation (3) with respect to the optimal tax rate t_B^0 and using Equation (7) to simplify yields

$$\frac{dC_B^0}{dt_B^0} = -\left[z^0 + \left(1 + t_B^0\right)\frac{\partial z}{\partial t_B^0}\right]T_B^0 = -\frac{T_{F2}}{\left(1 + t_B^0\right)T_{B2} + T_{F2}}z^0 T_B^0 < 0 \quad \text{(12a)}$$

$$\frac{dC_F^0}{dt_B^0} = -\frac{\partial z}{\partial t_B^0}T_F^0 = \frac{T_{B2}}{\left(1 + t_B^0\right)T_{B2} + T_{F2}}z^0 T_F^0 > 0 \quad \text{(12b)}$$

The second order conditions of the lobby groups' welfare functions are discussed in Appendix A. Thus, the biofuel lobby's contribution function is a falling and convex function of t_B, whereas the forestry lobby's contribution function is an S-shaped increasing function of t_B, with a convex and a concave part depending on the sector's land demand. Figure 1 depicts examples of possible contribution functions as functions of the land tax.

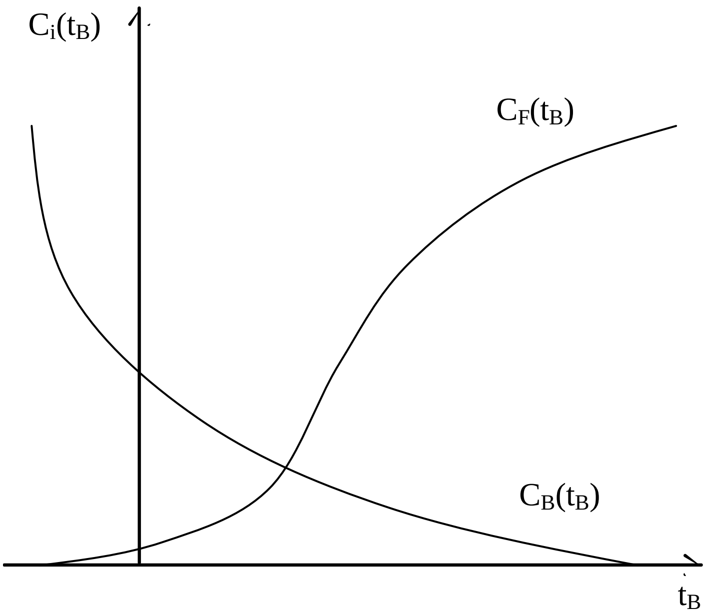

Figure 1: The contribution function of sector B falls in the land tax rate t_B, but at a diminishing rate. The contribution function of sector F increases in the land tax rate t_B, first at an increasing and then at a decreasing rate. In the figure we have assumed that the sector's land use increases sufficiently as t_B increases for the breaking point to be included in the figure.

The marginal contribution from the biofuels sector B falls the higher the land tax rate that the government sets, a subsidy or a low tax rate thus eliciting the highest contribution from this sector. The contribution function from the forestry sector is more complicated as it depends on the sector's land demand. A higher land tax t_B, however, increases the sector's land demand, and could take the sector from the convex to the concave part of the contribution function.[20] At this level of generality it is impossible to say, however, how a given level of land tax impacts the forestry sector's marginal contribution, as we have not defined the sector's level of land demand, and how a given (marginal) increase in the tax impacts on the sector's land demand. This hinges on the sector's elasticity of land demand, which is a question to which we turn next, by making the following proposition

Proposition 3 *The sector with a less elastic land demand, adjusted for the land tax rate for the biofuels sector, gives the greater marginal contribution.*

Proof. Examining which sector gives a higher marginal contribution in absolute terms, i.e., whether $\left|\frac{dC_B^0}{dt_B^0}\right| \gtrless \left|\frac{dC_F^0}{dt_B^0}\right|$ we find $\frac{1+t_B^0}{\varepsilon_{T,\ z}^B} \gtrless \frac{1}{\varepsilon_{T,\ z}^F}$. In other words, if land demand by sector B, adjusted for the land tax rate, is less elastic than land demand by sector F ($\frac{\varepsilon_{T,\ z}^B}{\left(1+t_B^0\right)} < \varepsilon_{T,\ z}^F$), then sector B gives a greater marginal contribution than sector F, and vice versa. ■

Proposition 4 *The sector with a more inelastic land demand, weighted by a constant γ, is the more effective one in lobbying and determines the direction in which the land tax deviates from the socially optimal tax.*

Proof. Examining when $t_B \gtrless \frac{\phi(T_B)}{z}$ yields $\varepsilon_{T,\ z}^B \gtrless \gamma\varepsilon_{T,\ z}^F$ where γ was defined in the proof of Proposition 2. Thus, a more elastic land demand in the biofuels sector than the by γ weighted elasticity of land demand in forestry implies a land tax that is higher than would be socially optimal. A more inelastic land demand by the biofuels sector than the by γ weighted elasticity of land demand in forestry implies a land tax that is lower than would be socially optimal. ■

What is the economic rationale behind this? An inelastic land demand in the biofuels sector means that the deadweight loss from the tax is small. Thus, the government can "support" the sector by lowering the land tax without incurring a large deadweight loss, i.e., at a low cost to itself. Similarly, as the land tax on biofuels is essentially a "subsidy" to land use in forestry, the more inelastic the land demand in the forestry sector is, the lower the cost to the government for providing them with this "subsidy", i.e., the lower the deadweight loss from the subsidy (for a similar result, see, e.g., Grossman and Helpman (1994) or Dixit (1996)). Besides, in the lobbying game the sector with the more inelastic land demand provides the government with the greatest marginal contribution. Consequently it "wins" as it is the one that the government can "support" at the greatest marginal benefit and lowest cost to itself. Even the sector with the more elastic land demand can, however, still have an incentive to contribute as its contribution cancels some of the effect from the "stronger" sector's contribution. This incentive falls as a sector's land demand becomes more elastic, as the contribution has less net effect.

We continue by examining how the land tax rate impacts on the elasticity of land demand. For this purpose we differentiate the elasticities of land demand by the land tax to obtain:

$$\frac{\partial \varepsilon_{T,\, z}^{B}}{\partial t_{B}^{0}} = \frac{\varepsilon_{T,\, z}^{B}}{(1+t_{B}^{0})}\left[1+\frac{\varepsilon_{T,\, z}^{B}}{(1+t_{B}^{0})}-\frac{\left(1+\varepsilon_{T,\, z}^{B}\right)\varepsilon_{z,\, t_{B}}}{t_{B}^{0}}\right] \gtrless 0 \qquad (13a)$$

$$\frac{\partial \varepsilon^F_{T,\ z}}{\partial t^0_B} = -\frac{\varepsilon^F_{T,\ z}\left(1+\varepsilon^F_{T,\ z}\right)\varepsilon_{z,\ t_B}}{t_B} < 0, \tag{13b}$$

where $\varepsilon_{z,\ t_B} = -\frac{\partial z}{\partial t_B}\frac{t_B}{z} > 0$ is the elasticity of land value to the land tax. An increase in the land tax thus lowers the land demand elasticity in forestry by Equation (13b). The effect arises partly directly from a change in the cost of land and partly indirectly from the change in land demand by the forestry sector, which is due to the fall in the cost of land to that sector. Both effects work in the same direction.

The change in the elasticity of land demand in biofuels is, however, of ambiguous sign in Equation (13a), consisting partly of the land value effect (the same effect that lowers the land demand elasticity in forestry), but also of the land tax effect, which serves to raise the elasticity. However, since we know that the cost of land to the biofuels sector increases in the land tax ($\frac{\partial z_B}{\partial t_B} > 0$ by Equation (7)), we differentiate the elasticity of land demand in biofuels by z_B to obtain $\frac{\partial \varepsilon^B_{T,\ z}}{\partial z^0_B} = \frac{\varepsilon^B_{T,\ z}\left(1+\varepsilon^B_{T,\ z}\right)}{z^0_B} > 0$. Consequently we conclude that the elasticity of land demand in biofuels increases in the land tax.

In order to summarise, we formulate the following proposition:

Proposition 5 *The politically optimal land tax rate serves to lower the elasticity of land demand by the sector whose land demand to begin with was lower, and to increase the other sector's elasticity of land demand. Thus, the tax rate is self-enhancing.*

Proof. The sector whose elasticity of land demand to begin with is lower determines the deviation in the land tax by Proposition 4. If this sector is the forestry sector, the tax rate deviates upwards, and by Equation (13a) serves to raise the elasticity of land demand in biofuels and by Equation (13b) lowers the elasticity of land demand in forestry. The discrepancy between the elasticities increases. In a similar manner, if the biofuels sector's elasticity of land demand to begin with is lower, the tax deviates downwards. The biofuels sector's elasticity of land demand falls with the introduction of the tax, and the forestry sector's elasticity increases. Again, the discrepancy between the elasticities grows. Consequently, the tax is "self-enhancing". ■

Proposition 5 implies that the sector that from the beginning loses continues to lose in the tax-setting game. It can be compared to the result in Dixit (1996), where the marginal incentive to lobby for a further increase in price rises as the price rises. Unlike in Dixit's model, where the sectors' profits and incentives are independent of each other except for the revenue motive, here one sector clearly loses while the other one wins, however.

We end by constructing the following thought experiment: In the "beginning", a forestry sector is the more productive of the two and uses most land.[21] Thus, it produces at the point where the value of its marginal product of land equals the value of land. If the government introduces some exogenous policy to support the use of biofuels, alternatively, if the world-market price of biofuels increases exogenously, the value of the marginal product of biofuels production increases.[22] Its land demand increases, and the value of land increases.[23] Since we have assumed linear land demand in z_i, the elasticity of land demand in forestry (ceteris paribus) increases as its land demand falls, and the elasticity of land demand in biofuels falls as its land demand increases.

In our hypothetical model, then, a government that introduces a policy that supports the production of biofuels, but which attempts to internalise the external effects that arise from biofuels production relative to the forestry sector by introducing a land tax, can have created a self-enhancing policy instrument that leads to a sub-optimal allocation of land to either sector. If, at the time at which the land tax is introduced, land allocation towards biofuels has taken the sectors to the point where land demand by biofuels is less elastic than that in forestry, the tax will be set at a sub-optimal level because of lobbying by the biofuels sector. This lowers the elasticity of land demand in biofuels further, and increases that in forestry, thus increasing the gap in the "lobbying efficiency" of the two sectors. As the cost of setting a low tax on biofuels falls from the government point of view, the tax rate can fall further, thus creating a self-enhancing system.

Naturally, the converse also applies. Thus, if the land tax is introduced when the elasticity of land demand in forestry is still less elastic than that in biofuels, the land tax will be set at a higher than optimal level. The elasticity of land demand in forestry becomes even less elastic whereas the elasticity of land demand in biofuels becomes more elastic, and the cost for the government for increasing the tax falls. This effect would counter some of the (exogenous) support given to biofuels by the government, thus raising the cost of achieving, for instance, some biofuels mandate.

5 Technological change

In this section we analyze the effect of technological change in the biofuels sector. Technological change is assumed to be exogenous. As was noted in Section 2, we assume land-augmenting technology (Romer, 2001, 9), and denote it with a technology parameter H_B, so that technology enters the production function as a multiplicator to land demand: $y_B(H_B T_B)$. We assume that technological change affects the external effect arising from biofuels production only so far as it increases land demand by the biofuels sector.

From Equation (6), using the envelope theorem, we find the derivative of the land value function with respect to H_B:

$$\frac{\partial z}{\partial H_B} = -\frac{T_{B3}}{(1+t_B)\,T_{B2} + T_{F2}} \geq 0, \tag{14}$$

where $\frac{\partial T_B}{\partial H_B} \equiv T_{B3} \geq 0$ (see Appendix C) is the partial of the land demand function in agriculture to the technology parameter. We can use this and Equation (6) to state the effect of technological change in biofuels on land allocation:

Lemma 6 *Technological change in biofuels increases the biofuel sector's demand for land. The forestry sector's land demand falls in technological change in biofuels.*

Proof. Total land use in the model is constant, so that $\frac{dT_B}{dH_B} + \frac{dT_F}{dH_B} = 0$. Since $\frac{dT_F}{dH_B} = T_{F2}\frac{\partial z}{\partial H_B} < 0$ by downward sloping land demand functions and Equation (14), then it must be that $\frac{dT_B}{dH_B} = (1+t_B)\,T_{B2}\frac{\partial z}{\partial H_B} + T_{B3} > 0$. We show in Appendix C that $\frac{\partial T_B}{\partial H_B} \equiv T_{B3} > 0$. ■

In order to determine the effect of technological change on the two sectors' welfare and on general welfare, we must define the cross-differentials of land demand to technology. $T_{i23} = \frac{\partial^2 T_i}{\partial z \partial H_B}$ does not necessarily equal zero for either sector. $T_{i23} > 0$ then implies that land demand falls slower (the land demand function becomes flatter) when technology in sector B improves, whereas $T_{i23} < 0$ would imply that the land demand function became steeper. Assuming that the effect is small (and since it equals zero for instance for the land demand functions used in Appendix B), for simplicity we set $T_{i23} = 0$. We can then solve for the cross-derivative of land value to the land tax and technology to obtain

$$\frac{\partial^2 z}{\partial t_B \partial H_B} = \frac{T_{B2} T_{B3}}{\left[(1 + t_B) T_{B2} + T_{F2}\right]^2} < 0. \tag{15}$$

Starting our examination from the effect that technological change has on welfare, we differentiate the lobby groups' welfare functions, given by Equation (3), and the general welfare function (Equation (5)) with respect to H_B to obtain

$$\frac{\partial W_B(t_B,\ z)}{\partial H_B} = \left[p_B y_{B1} - (1 + t_B) \frac{\partial z}{\partial H_B}\right] T_B \geq 0 \tag{16a}$$

$$\frac{\partial W_F(t_B,\ z)}{\partial H_B} = -\frac{\partial z}{\partial H_B} T_F < 0 \tag{16b}$$

$$\frac{\partial W(t_B,\ z)}{\partial H_B} = p_B y_{B1} T_B + z\left[t_B - \frac{\phi'(T_B)}{z}\right] \frac{dT_B}{dH_B} \tag{16c}$$

From Equation (16a) we see that the welfare in the biofuels sector increases as technology H_B increases given that the change in the value of the marginal product of land, $p_B y_{B1}$ exceeds the added cost to the sector from the change in the value of land (which increases). We assume this to be the case; were it not so, the sector could choose to continue producing with its old technology and would not be worse off than before.

The forestry sector, however, only suffers from the increased cost of land due to the improved technology in biofuels. Thus, its welfare falls.

Finally, the change in the general welfare depends on the level of land tax, t_B. If $t_B \geq \frac{\phi'(T_B)}{z}$, i.e., if the land tax is equal to or higher than socially optimal, then general welfare always increases when H_B increases. This depends on the improvement in the marginal product of land in sector B, when the tax rate either completely or over internalises the external effect. If t_B is lower than would be socially optimal, then general welfare increases as long as $t_B > \frac{\phi'(T_B)}{z} - \frac{p_B y_{B1} T_B}{z(dT_B/dH_B)}$. Thus, the greater the improvement in the marginal productivity of land in biofuels (y_{B1}), and/or the lower the change in land demand as the technology improves (dT_B/dH_B), the more likely the general welfare will improve in H_B. For instance Chakravorty et al. (2009) note that it is fully possible that a newer generation of biofuel technologies is less land intensive than the old ones, which in our framework would improve the general welfare. Nevertheless, if the land tax is set at a sufficiently low rate, general welfare will fall in H_B because the tax does not suffice to internalise the external effect.

We turn next to the contributions functions and examine how they behave as the technology in the production of biofuels improves. For the biofuels sector we differentiate the marginal contribution function with respect to H_B and substitute from Equations (7), (14) and (15) to obtain

$$\frac{\partial^2 C_B(t_B)}{\partial t_B \partial H_B} = \frac{T_{F2} T_{B3}}{[(1+t_B) T_{B2} + T_{F2}]^2} \left(T_B + T_F \varepsilon^F_{T,\, z}\right) < 0. \tag{17a}$$

Since the biofuel sector's contribution function is falling in t_B, the negative cross-derivative indicates that an increase in H_B makes the sector's contribution function steeper.

The effect of technological change on the forestry sector's contribution function is ambiguous, however. Solving yields

$$\frac{\partial^2 C_F(t_B)}{\partial t_B \partial H_B} = -\frac{T_{B2}T_{B3}}{\left[(1+t_B)\,T_{B2}+T_{F2}\right]^2} T_F \left(1-\varepsilon^F_{T,\ z}\right) \tag{17b}$$

which is positive if $\varepsilon^F_{T,\ z} < 1$, thus making the forestry sector's contribution function less steep, and negative otherwise. Thus, if the elasticity of land demand in forestry is low, then technological progress in biofuels serves to make the forestry sector's contribution function flatter. If, however, the forestry sector has very elastic land demand ($\varepsilon^F_{T,\ z} > 1$), then its contribution function becomes steeper in H_B.

We examine the question further by differentiating the land demand elasticities of both sectors with respect to technology, H_B. Holding t_B constant we obtain

$$\frac{\partial \varepsilon^B_{T,\ z}}{\partial H_B} = -\frac{\varepsilon^B_{T,\ z}}{H_B}\left[\mu_{z,\ H}\left(1+\varepsilon^B_{T,\ z}\right)+\varepsilon^B_{T,\ H}\right] < 0 \tag{18a}$$

$$\frac{\partial \varepsilon^F_{T,\ z}}{\partial H_B} = -\frac{\varepsilon^F_{T,\ z}\mu_{z,\ H}}{H_B}\left(1+\varepsilon^F_{T,\ z}\right) > 0 \tag{18b}$$

where $\varepsilon^B_{T,\ H} = \frac{T_{B3}H_B}{T_B}$ is the elasticity of land demand in the biofuels sector to technology, and $\mu_{z,\ H} = \frac{\partial z}{\partial H_B}\frac{H_B}{z}$ is the elasticity of the value of land to technology. We summarise by formulating the following proposition:

Proposition 7 *The biofuels sector's elasticity of land demand falls in technology and its marginal contribution increases, while the forestry sector's* *elasticity of land demand increases and its marginal contribution tends to fall. This increases the biofuel sector's lobbying strength compared to that of the forestry sector, and leads to a fall in the land tax rate.*

Proof. The proof follows from the signs of Equations (17a) and (17b) for the effects on the contributions functions and from Equations (18a) and (18b) for the elasticities (assuming $\varepsilon^{F}_{T,\ z} < 1$). As for the effect on the tax rate, regardless of which sector has had a lower elasticity of land demand before technological change in biofuels, as the elasticity in forestry increases and the elasticity in biofuels falls, the land tax rate falls. If the land tax was initially set on a level higher than would be socially optimal, then technological change would lower it so, that it would approach social optimum or fall below it. If the land tax was initially lower than would be socially optimal, it would fall further (and could eventually become a subsidy). ■

It is then clear that the biofuels sector becomes "stronger" as it gets access to better technologies. The fall in its elasticity of land demand lowers the deadweight loss from giving the sector a lower tax rate. The effect is reinforced by the effect on the forestry sector. That sector's land demand becomes more elastic, thus increasing the deadweight loss from the implicit subsidy to the sector.

If the land tax rate to begin with was set at a level higher than would have been socially optimal, then technological progress in the biofuels sector helps to push the economy towards the socially optimal tax rate and consequently, socially optimal land allocation. If, however, the tax rate to begin with was set "too low" or the change in lobby strength is sufficient to push it over from being "too high" to being lower than would be socially optimal, then technological change leads to excessive deforestation and to a sub-optimal land allocation, where the biofuels sector uses too much land and the forestry sector too little.

6 Conclusions

In this article we have constructed a political economy model based on Grossman and Helpman (1994) to study the implementation of a hypothetical land tax on the biofuels sector, where that sector causes a negative external effect compared to a forestry sector, with which it competes of land. We have shown that when two lobbies compete for a common factor of production, the supply of which is fixed but where its allocation between the sectors is variable, the existence of lobby groups representing both sectors is not enough to ensure a socially optimal outcome from the lobbying game. Instead, according to a modified Ramsay rule, the sector which the government can "subsidise" in a less distorting way decideds the direction in which the land tax rate deviates from the socially optimal land tax rate. Thus, from a social optimum point of view the land tax becomes a subsidy either for land use in biofuels or in forestry, depending on which sector has the lower deadweight loss from the subsidy. The other sector's lobbying serves to lessen the effect from the first sector's lobbying, however, so that the net subsidy is lower than it would be in the absence of the competing lobby group.

Furthermore, we show that the tax rate is self-enhancing. Thus, the deadweight loss of a subsidy falls for the sector which to begin with had a lower deadweight loss from the subsidy, and it rises for the other sector, as the land tax is set to its politically optimal level. This would make it profitable for the government to adjust the land tax rate further in the direction benficial to the sector with the lower deadweight loss. This question has not been pursued further, however.

We have also considered how technological change in the biofuels sector impacts on the two sectors' lobbying strength. Thus, we find that the elasticity of land demand in the biofuels sector falls in technology, while the elasticity rises for the forestry sector. This effect lowers the deadweight loss from subsidising the biofuels sector and increases the deadweight loss for subsidsing the forestry sector. This can either take the economy closer to a socially optimal tax rate, if the tax to begin with was set at a level too high, or further away from the optimum, if the tax rate to begin with was inefficiently low.

The introduction of different support policies for biofuels has been studied, among others, by de Gorter and Just (2009b) and by de Gorter and Just (2009a). They show, among other things, that a biofuel consumer tax exemption is partly redundant, and how the introduction of tax credits for biofuels, in the presence of a biofuels mandate, ends up subsidizing fuel consumption instead of biofuels. The present paper complements the literature on biofuels by showing how political economy considerations, when setting biofuel policies, can lead to self-enhancing circles of adjustment, which can lead to unwanted side effects, such as deforestation. On the other hand, it also shows how lobbying in some circumstances could dwarf attempts to promote the production of biofuels.

As for the other related literature, without including resource dynamics, we can explain an effect similar to that in Barbier et al. (2005), namely that the relative share of land use by a non-forestry sector can be higher when the government is susceptible to lobbying. Unlike Barbier, Damania and Léonard, however, our model allows even for the opposite effect where a forestry lobby can dwarf the attempts to support a non-forestry sector's production.

We have further shown how technological progress in the non-forestry sector affects the forestry sector. Our model completes that by Ehui and Hertel (1989), who show that the steady-state forest stock falls in technological progress in agriculture, by including a political economy mechanism through which the effect can work and be reinforced.

Finally, we offer a plausible explanation to the rarity of land taxation in the real world, which (to our knowledge) is lacking from the existing literature. Our setting differs, however, from the rest of the land tax literature in that instead of a public economics motive to land taxation, we have an environmental motive. Constructing a model of lobbying in a public economics setting is left for future research.

Notes

[1] Production of biogas from various wastes does not require land to grow the raw materials for biogas production. In this paper we consider those biofuels that are grown specifically for biofuel use, for instance, sugar cane, sugar beet, palm oil, corn or reed canary grass.

[2] According to WWF (2009) (assets.panda.org/downloads/forest_conversion_brochure.pdf

accessed on June 12th, 2009), Malaysia and Indonesia dominate the global market for palm oil, accounting for almost 90% of all exports. Between 1990 and 2005, these countries increased the area of palm oil plantations by nearly 5 million hectares, half of which replaced natural forests. See also Yacobucci and Schnepf (2007).

[3]Another oft-used policy instrument to influence land use is zoning. We deem zoining not to be a relevant policy instrument to determine land allocation between biofuels production and forestry. For the determination of zoining versus taxes we refer the reader to Netzer (2003), which is a volume investigating the impact of various tax mechanisms on regulating land use, or to Pogodzinski and Sass (1994) for a political theory of zoning.

[4]E.g., van der Laak et al. (2007), de Gorter and Just (2009b) and de Gorter and Just (2009a).

[5]E.g., Petersen (2008), Soimakallio et al. (2009) and Yang et al. (2009).

[6]E.g., Pimentel et al. (2009) and Chakravorty et al. (2009).

[7]The case for taxing land in order to spur economic growth is strong. For instance, George (1882), Feldstein (1977), Calvo et al. (1979) and Eaton (1988) all argue in its favor, mainly because land taxation is seen to encourage capital formation and therefore, to benefit economic growth.

[8]See, e.g., Fredriksson (1997), Fredriksson (1999), Aidt (1998), Schleich (1999), Schleich and Orden (2000), Eliste and Fredriksson (2002), Conconi (2003) and McAusland (2005).

[9]Of the previous studies examining the political economy of environmental policy the one that is closest to this one is by Aidt (1998). Aidt includes three factors of production: labor, sector-specific capital and raw materials (e.g., oil or environmental goods such as clean water). The use of raw materials causes an externality and the imposition of an environmental tax changes the use of these. There is, however, no competition for the raw materials in Aidt's model, and consequently, no price changes.

[10]A common feature of all the other political economy models based on Grossman and Helpman is that they assume that the (industrial) lobbies organize around a fixed sector-specific input factor, the quantity of which does not vary in the policy instrument studied.

[11]H_i is assumed to be exogenous since, as we study a small open economy, the country imports technological innovations from abroad.

[12]The "technology" or the "effectiveness of land use" parameter H_i used here is of the same form as that used in the Solow growth model. We thus refer to $H_i T_i$ as effective land use. See, e.g., (Romer, 2001, 9).

[13]The political economy models often assume that besides for normative reasons, such as the internalization of externalities, taxes are also raised in order to influence the income distribution (see, e.g., Grossman and Helpman (1994)), which provides a reason for the government to need to raise tax revenue. The argument cannot reasonably be used here, however, since farmers (who usually are the ones growing biofuels) most often are rather in the receiving end of income transfers. Therefore, the only justification for a land tax on land under biofuels production here is the negative externality arising from land use for biofuels. Alternatively we could argue for some non-modeled government sector of the economy needing tax revenue.

[14]The lower restriction arises from an assumption that the cost of land for the biofuels sector is always positive. Otherwise t_B belongs to some set $\mathbf{T}$, the set of possible land taxes from which the government may choose.

[15]For simplicity we assume that those owning land in both uses, α_{BF}, belong to both lobby groups. Their net lobbying depends thus on the relative strength of respective lobby group.

[16]As we only assume technological change in the biofuels sector we supress the technology term H_F on forestry.

[17]In Feldstein's model it is either land taxes inducing capital accumulation that raise the rent on land, or a portfolio-balance effect where individual portfilios differ because of differences in risk perception or risk aversion, which raise the rent on land.

[18]It is further easy to verify that $-1 \leq \frac{dz/dt_B}{z} < 0$ given that $t_B \geq -\frac{T_{F2}}{T_{B2}}$, where the RHS is negative.

[19]For the same result within the framework of the Grossman and Helpman model, see, e.g., Fredriksson (1997), Aidt (1998), Fredriksson (1999) or Schleich (1999).

[20]In Appendix B, using very simplified specified land demand functions, we find the breaking point to be $T_F = \frac{1}{3}$. I.e., at $T_F < \frac{1}{3}$, the forestry sector's contribution function is convex, and at $T_F > \frac{1}{3}$ it is concave.

[21] It can be thought that in a traditional industrialised country where the energy system has mainly been based on coal, oil, gas, hydropower and nuclear electricity, demand for biofuels has been low. Then it is feasible that the value of forestry products, as imputs for instance to a paper and pulp industry or as construction materials has greatly exceeded the value of biofuels production.

[22] Motives for policies that support the use of biofuels were discussed in the Introduction.

[23] At this point, it could be argued that even the externalities that the biofuels production causes increase, and that the government decides to impose a land tax on biofuels production. Whether such a tax would direct the investment in biofuels towards less land intensive biofuels, or have some other economic effects in the presence of the other supporting policies is not analysed here. For an analysis of the interaction of several policies supporting biofuels production the reader is referred to, for instance, de Gorter and Just (2009b) or de Gorter and Just (2009a).

A Appendix

The maximization problem requires that the equilibrium characterization function (equation (9)) has a negative second order condition for a maximum. The biofuel lobby's welfare functions is convex, however, their welfare thus reaching some minimum at some tax rate. Thus, we have

$$\begin{aligned}\frac{\partial^2 W_B\left(t_B,\ z\right)}{\partial t_B^2} &= -\left[2\frac{\partial z}{\partial t_B} + \left(1+t_B\right)\frac{\partial^2 z}{\partial t_B^2}\right]T_B - \left[z + \left(1+t_B\right)\frac{\partial z}{\partial t_B}\right]^2 T_{B2} \\ &= \frac{zT_{B2}T_{F2}\left[2T_B - zT_{F2}\right]}{\left[\left(1+t_B\right)T_{B2}+T_{F2}\right]^2} > 0 \quad (19)\end{aligned}$$

where we have substituted in the first order derivative of the value of land to the land tax from Equation (7) and the second order derivative from Equation

(8).

The forestry lobby's welfare function is of indeterminite sign:

$$\frac{\partial^2 W_F\left(t_B,\ z\right)}{\partial t_B^2} = -\left[\frac{\partial^2 z}{\partial t_B^2} T_F + \left(\frac{\partial z}{\partial t_B}\right)^2 T_{F2}\right] = -\frac{z T_{B2}^2\left[2T_F + z T_{F2}\right]}{\left[\left(1+t_B\right) T_{B2} + T_{F2}\right]^2} \quad (20)$$

where even here we have substituted in Equations (7) and (8). Even equation (20) is positive if the second order derivative of land value to land tax, $\partial^2 z/\partial t_B^2$ is sufficiently small or zero. This is the case if $T_F < -\frac{zT_{F2}}{2}$, i.e., at a sufficiently low level of land demand by the forestry sector. If land demand by forestry is higher than $-\frac{zT_{F2}}{2}$, then its welfare function is concave.

What is the economic rationale behind the ambiguous second order condition of the forestry sector's welfare function as given by Equation (20)? In equation (10) the second term represents the marginal welfare of the forestry sector, which is an increasing function of the land tax t_B. The case where the function is concave is straightforward: when $z\left(t_B\right)$ is sufficiently convex, a small increase in the land tax induces a large fall in the value of land (cost of land to the forestry sector). This in turn leads to a large increase in the marginal welfare of the forestry sector. As the land tax increases, it induces a lesser fall in the value of land, and also the marginal welfare gain to the forestry sector becomes smaller.

If, however, the land value function $z\left(t_B\right)$ is (approximately) linear, an increase in the land tax leads to an equally large fall in the value of land, regardless of the level of the tax. In this case the forestry sector's welfare function is convex. Then, a low tax increases forestry sector's marginal welfare but less than a high tax: the effect from the tax on the value of land becomes cumulative and so does the effect on the forestry sector's welfare, which increases exponentially the higher the tax.

The forestry sector's welfare function is thus S-shaped in T_F. At low levels of land demand by the forestry sector (and when the value of land function is approximatively linear), the land tax does not matter much to the marginal welfare of the sector. As the tax rate grows, the sector's welfare grows exponentially. If the cost of land to forestry falls enough (is low enough) for it to reach and exceed the point where land demand $T_F \geq -\frac{zT_{F2}}{2}$, then the welfare function reaches the portion where it is concave and the effect of further tax increases gradually leads to lesser marginal increases in the sector's welfare. At this point, the land value function $z(t_B)$ is strictly convex.

The general welfare function has the following s.o.c., where we have already substituted in Equations (7) and (8):

$$\frac{\partial^2 W(t_B,\ z)}{\partial t_B^2} = \frac{zT_{B2}T_{F2}\left\{(T_{B2}+T_{F2})\,z - \phi''(T_B)\,zT_{B2}T_{F2} - 2z\left[t_B - \frac{\phi'(T_B)}{z}\right]T_{B2}\right\}}{\left[(1+t_B)\,T_{B2}+T_{F2}\right]^2} \tag{21}$$

The multiplier in front of the "wavy" brackets is positive, and the denominator is also positive. The first and the second terms in the wavy brackets are negative, and the third term is of indeterminate sign. If the tax rate is set at the socially optimal level, it is clear, however, that this term is equal to zero (in the social optimum $t_B^{so} = \frac{\phi'(T_B)}{z}$). If the tax rate t_B^0 is lower than would be socially optimal ($t_B^0 < \frac{\phi'(T_B)}{z}$), then the whole term is negative and the s.o.c. of the welfare function is unambiguously negative, the function thus reaching a maximum. If, however, the tax rate is higher than would be socially optimal ($t_B^0 > \frac{\phi'(T_B)}{z}$), then the third term is positive, thus creating an ambiguity to the sign of equation (21).

What is the economic rationale behind this? Marginal general welfare is given by the last term in equation (10). Marginal general welfare is positive, i.e., welfare grows in t_B as long as $t_B \leq \frac{\phi'(T_B)}{z}$, i.e., as long as the tax rate is lower than would be socially optimal. At this portion of the welfare function the s.o.c. in (21) is unambiguously negative, and the welfare function reaches a local maximum at $t_B = \frac{\phi'(T_B)}{z}$. General welfare falls in t_B when $t_B > \frac{\phi'(T_B)}{z}$, i.e., when the tax rate is higher than would be socially optimal. If t_B grew sufficiently for the last term in equation (21) to overweigh the two first ones, then the welfare function would turn convex. We consider such high land tax rates to be improbable and do not consider them further.

B Appendix

In this appendix we derive the land tax equation and its properties using specified functional forms for land demand by respective sector and the externality equation.

Land demand in biofuels is given by $T_B = H_B - (1 + t_B) z$, and land demand in forestry by $T_F = H_F - z$, where we will normalize $H_F = 1$ yielding $T_F = 1 - z$. The negative net externality from land use for biofuels is given by $\phi(T_B) = \frac{b}{2} T_B^2$, with $b > 0$.

The first order derivatives of the land demand functions are given by $T_{B2} = T_{F2} = -1$. Solving further for the value of land from $T_B + T_F = 1$ yields $z = \frac{H_B}{2+t_B}$. This has the first order derivative $\frac{\partial z}{\partial t_B} = -\frac{H_B}{(2+t_B)^2} < 0$ and the second order derivative $\frac{\partial^2 z}{\partial t_B^2} = \frac{2H_B}{(2+t_B)^3} > 0$.

Substituting the land value function into the land demand functions yields land demand by biofuels, $T_B = \frac{H_B}{2+t_B}$, and by forestry, $T_F = \frac{(2+t_B)-H_B}{2+t_B}$. Thus, at a sufficiently high level of technology in biofuels, i.e., if $H_B \geq 2 + t_B$, land demand by forestry is zero. Substituting these into equation (10) yields

$$\begin{aligned} - I_B \frac{H_B}{2+t_B} \left[\frac{H_B}{2+t_B} - (1+t_B) \frac{H_B}{(2+t_B)^2} \right] + I_F \frac{(2+t_B) - H_B}{2+t_B} \frac{H_B}{(2+t_B)^2} \\ - a \left[t_B \frac{H_B}{2+t_B} - b \frac{H_B}{2+t_B} \right] \left[\frac{H_B}{2+t_B} - (1+t_B) \frac{H_B}{(2+t_B)^2} \right] = 0. \quad (22) \end{aligned}$$

The elasticities of land demand in equation (11) are given by $\varepsilon^B_{T,\ z} = 1$ and $\varepsilon^F_{T,\ z} = \frac{H_B}{(2+t_B)-H_B}$. Examining property 3 in Proposition 2, we note that $\varepsilon^B_{T,\ z} = \gamma \varepsilon^F_{T,\ z}$ only if $H_B = \frac{2+t_B}{2+b}$. This is the case when land demand by biofuels $T_B = \frac{1}{2+b}$ and land demand by forestry $T_F = \frac{1+b}{2+b}$, which we consider to be a special case. Thus, at most levels of technology in biofuels, the strengths of the two lobby groups differ from one another.

Simplifying (22) yields

$$t_B = \frac{H_B}{aH_B - I_F} \left[-I_B + \frac{I_F (2 - H_B)}{H_B} + ab \right]. \quad (23)$$

In the social optimum we have $t_B = b$.

Examining further the second order conditions of the welfare functions it is easy to show that

$$\frac{\partial^2 W_B\left(t_B,\ z\right)}{\partial t_B^2} = \frac{3H_B^2}{\left(2+t_B\right)^4} > 0 \tag{24a}$$

$$\frac{\partial^2 W_F\left(t_B,\ z\right)}{\partial t_B^2} = \frac{H_B\left[3H_B - 2\left(2+t_B\right)\right]}{\left(2+t_B\right)^4} \tag{24b}$$

$$\frac{\partial^2 W\left(t_B,\ z\right)}{\partial t_B^2} = \frac{H_B^2\left(2t_B - 3b - 2\right)}{\left(2+t_B\right)^4} \tag{24c}$$

As was shown in Appendix A, the biofuels sector's welfare function is unambiguously convex. The forestry sector's welfare function is S-shaped; the s.o.c. is positive if $H_B > \frac{2}{3}\left(2+t_B\right)$ and negative otherwise. Substituting in $H_B = \frac{2}{3}\left(2+t_B\right)$ into the equation for T_F yields $T_F = \frac{1}{3}$. Thus, if the share of land in forestry is less than $\frac{1}{3}$, then the sector's welfare function has a positive s.o.c. and it is convex, and if its share of land is greater than $\frac{1}{3}$, then the welfare function is concave. Finally, the s.o.c. of the general welfare function is negative (the function reaches a maximum at $t_B = b$) if $t_B < \frac{3}{2}b + 1$, which is the case at $t_B = b$. Assuming t_B never reaches such a high level, we do not analyse of the portion of the function which has a positive s.o.c further.

We end by examining when land use in biofuels production could be subsidized instead of taxed (i.e., when t_B is negative). Rearranging yields

$$I_B > \frac{I_F\left(2-H_B\right)}{H_B} + ab$$

Three cases arise. If $I_B = 0$, i.e., the biofuels lobby does not organize, it is impossible for t_B to be a subsidy. If $I_B = 1$, i.e., the biofuels lobby organizes, but $I_F = 0$, i.e., the forestry lobby does not organize, it is sufficient that $b < \frac{1}{a}$ for t_B to be a subsidy. The lower a, i.e., the more susceptible the government is to lobbying, the easier it is for the biofuels lobby to get a subsidy given b. As $a \to \infty$, the RHS becomes arbitrarily small and even for low levels of marginal externalities, land use in biofuels will be taxed. Finally, if both lobby groups organize ($I_B = I_F = 1$), land use in biofuels can be subsidised if $b < \frac{I_F(2-H_B)}{aH_B}$. $\frac{I_F(2-H_B)}{aH_B} > \frac{1}{a}$, i.e., it is easier for the biofuels sector to obtain a subsidy in the presence of the forestry lobby if $H_B > 2$, which in turn implies that land demand by forestry is very low (land demand by the forestry sector occurs only because of the land tax; would land use by biofuels be subsidized in this case, land demand by forestry would be zero). Thus, given positive land demand by the forestry sector, the presence of its lobby group makes it less likely that the biofuels sector gets a subsidy for its land use than would be the case in its absence.

C Appendix

In this appendix we prove the sign taken by the first order derivative of the land demand function for sector i with respect to H_i. We start by solving for the marginal product of land as

$$y_T^i = \frac{p_j\,(1+t_i)\,H_j}{p_i\,(1+t_j)\,H_i} y_T^j. \tag{25}$$

Totally differentiating equation (25) with respect to H_i yields

$$
\begin{aligned}
\frac{dy_T^i}{dH_i} &= y_{TT}^i \left(\frac{\partial T_i}{\partial H_i} + \frac{\partial T_i}{\partial z_i} \frac{\partial z_i}{\partial H_i} \right) + y_{TL}^i \left(\frac{\partial L_i}{\partial H_i} + \frac{\partial L_i}{\partial z_i} \frac{\partial z_i}{\partial H_i} \right) \\
&= \frac{p_j (1 + t_i) H_j}{p_i (1 + t_j) H_i} \left(\frac{1}{p_j H_j} \frac{\partial z_j}{\partial H_i} - \frac{y_T^j}{H_i} \right). \qquad (26)
\end{aligned}
$$

Substituting in the first order condition of the marginal product of the labor -function with respect to H_i: $\frac{dy_L^i}{dH_i} = y_{LT}^i \left(\frac{\partial T_i}{\partial H_i} + \frac{\partial T_i}{\partial z_i} \frac{\partial z_i}{\partial H_i} \right) + y_{LL}^i \left(\frac{\partial L_i}{\partial H_i} + \frac{\partial L_i}{\partial z_i} \frac{\partial z_i}{\partial H_i} \right) = 0$ and $\frac{\partial z_j}{\partial H_i} = (1 + t_j) \frac{\partial z}{\partial H_i}$ and simplifying yields

$$
T_{i3} = \frac{\partial T_i}{\partial H_i} = -\frac{y_{LL}^i y_T^i}{H_i \Upsilon_i}, \qquad (27)
$$

where $y_T^i > 0$ is the marginal productivity of land. Since we assume that the production function y_i is increasing in T_i and L_i but at a falling rate, we have $y_{TT}^i < 0$ and $y_{LL}^i < 0$. $\Upsilon_i = y_{TT}^i y_{LL}^i - (y_{TL}^i)^2 > 0$. This completes the proof.

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