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Net national emissions, CO_2 taxation and the role of forestry

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Abstract

The concept of net national emissions suggests that accumulation of carbon in forestry should be taken into account when countries buy CO_2 permits or pay CO_2 taxes. The paper analyses the question of the correct tax/subsidy programme for giving proper incentives to forest owners and utilizers of wood. The analysis uses a dynamic general equilibrium model with productive capital and the stock of forests as state variables. It turns out that in a decentralized economy forest owners should be subsidized and CO_2 emissions should be taxed independently of whether they originates from wood or fossil fuels.

JEL classification: Q20; Q40; Q43; Q48

Keywords: CO_2 taxation; Forestry; Energy

1. Introduction

Utilization of fossil fuels in energy production results in carbon being emitted into the atmosphere and thus contributes to atmospheric CO_2 accumulation and climate change. In addition to fossil fuels, a considerable amount of CO_2 emissions is caused by deforestation. The annual emission due to deforestation is approximately 2×10^9 tons of CO_2, compared with approximately 6×10^9 tons caused by the burning of fossil fuels (Smith et al., 1993).

In contrast to deforestation, growing forests store carbon. According to the estimates in Kauppi and Tomppo (1993), the contribution of forest growth to net national emissions varies considerably between different European countries. In

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EFTA countries the net accumulation of carbon due to forest growth is about 49–96% of the emissions deriving from the fossil fuels of the same countries. At the EC + EFTA level the figure is smaller, 7–14%. Extreme examples are Nordic countries like Sweden and Finland, where accumulation of carbon may exceed emissions from fossil fuels by 25–50%. At the other extreme are Belgium, The Netherlands and the UK, where accumulation of carbon in forest growth is negligible. The role of forests has led to the concept of net national emissions, which defines the net impact of each individual country on the accumulation of CO_2 in the atmosphere. According to the Climate Convention, each country should report 'emissions by sources and removals by sinks'. Each country may have the freedom to choose efficient strategies for controlling its net national emissions.

International cooperation to slow down carbon accumulation in the atmosphere may require emission taxation or markets for emission permits. According to the concept of net national emissions, individual countries should pay for permits or should be taxed according to their net emissions. This has led to a discussion of how carbon emissions arising from the burning of wood should be taxed at the national level. The most common argument is that, in contrast to fossil fuels, CO_2 emissions caused by the burning of wood should be neglected in carbon taxation because sustainable forestry guarantees that the same amount of carbon will accumulate in new year classes of growing forests. Accordingly, it is argued that forest owners need not be subsidized.

The purpose of this paper is to study the national CO_2 taxation problem using a dynamic general equilibrium model. The model contains the stock of capital and forests as state variables. The social planner or perfectly competitive markets determine optimal consumption, capital accumulation, the use of forest as fuel, the use of wood as raw material, and the import of fossil fuels from abroad. The economy buys CO_2 emission permits or pays taxes according to net national emissions. The problem is to find a tax/subsidy programme which equalizes the outcome of perfectly competitive markets and social optimum.

The analysis shows that, because forests are capable of storing carbon, it is optimal to increase the size of the forest stock beyond the level which maximizes the conventional raw material net benefits. In a decentralized economy this requires that forest owners should produce positive externalities. This is impossible without subsidies which make the stock of growing forest a more profitable capital investment. It is shown that this subsidy must equal the amount of carbon stored by a given stand multiplied by the internationally determined carbon tax. In addition, it is necessary to tax CO_2 emissions independently of whether they originate from fossil fuels or wood. However, when wood is used in durable commodities the optimal tax per carbon content may be lower than in the case where wood is burned.

The paper is organized as follows. Section 2 presents the dynamic optimization model and analyses the properties of social optimum. Section 3 presents the

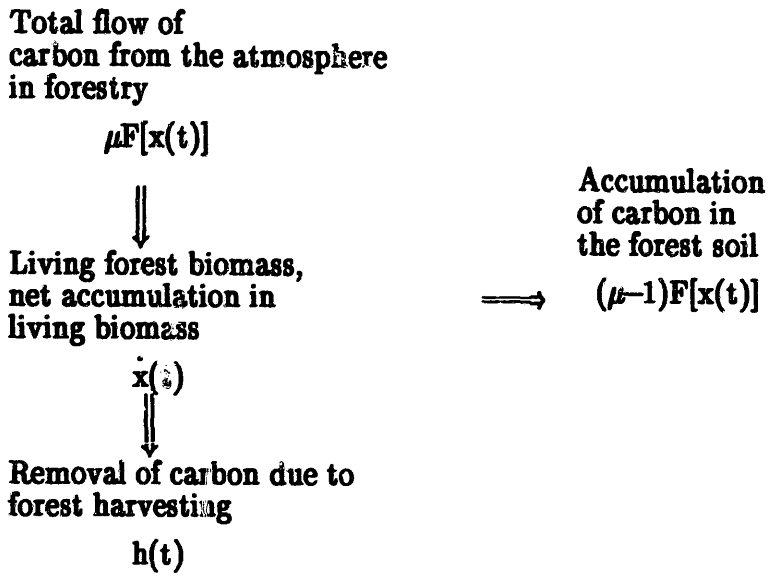

Fig. 1. Flows of carbon in forestry. $F[x(t)]$ is the growth of harvestable timber, $x(t)$ is the harvestable biomass, $(\mu-1)F[x(t)]$ gives the accumulation of carbon in the forest soil, $\mu \geqslant 1$, and $h(t)$ is the rate of harvest (modified from Kauppi and Tomppo, 1993).

optimal subsidy/tax programme and considers various special cases. Section 4 concludes the paper.

2. Carbon taxation and optimal accumulation of the forest stock

According to Kauppi and Tomppo (1993), the total annual flow of carbon can be divided into three flow components: (1) the removal of carbon due to forest harvesting, (2) the accumulation of carbon in the forest soil (detritus formation), and (3) the net accumulation of carbon in living forest biomass (Fig. 1).

Let us denote the timber harvest by $h(t)$ and the stock of harvestable timber by $x(t)$. Both are measured in carbon units. The growth of harvestable biomass is given by $F[x(t)]$. $F[\cdot]$ is assumed to be strictly concave with the properties $F[0] = F[\bar{x}(t)] = 0$, where $\bar{x}$ is some maximum level of forest stock given the land area allocated to forestry. [1]

Because of detritus formation forests also store carbon in the forest soil. Thus the total flow of carbon exceeds the level of carbon which is accumulated in the harvestable biomass. The total flow of carbon is denoted by $\mu F[x(t)]$, where

[1] This formulation of the growth function does not separate the year classes of forest biomass. In spite of this, it is frequently used in forest economics especially in two-period models on forest taxation and the behaviour of forest owners; see e.g. Kuuluvainen (1989) and Ovaskainen (1993).

$\mu \geq 1$. The accumulation of carbon in the forest soil is thus [2] $(\mu - 1)F[x(t)]$. Finally, the accumulation of carbon in harvestable forest biomass equals $\dot{x} = F[x(t)] - h(t)$.

Let τ denote the tax level per ton of CO_2 emissions or the price of a permit per ton of emissions. The level of τ is determined in international negotiations and is taken here to be exogenously given. For simplicity τ is assumed to be constant in time. $q(t)$ denotes the level of imported fossil fuel consumption in terms of CO_2 emissions and p_3 the price of fossil fuels. The domestic forest stock can be consumed as fuel or as raw material by the wood processing industry. The former is denoted by $h_1(t)$ and the latter by $h_2(t)$, both in terms of the carbon content. Because part of the carbon content in $h_2(t)$ will remain in forest products, the emissions from $h_2(t)$ are denoted by $\alpha h_2(t)$ where $\alpha \leq 1$. According to the concept of net national emissions the international authority takes into account the amount of carbon which accumulates in the unharvested forest stock and in the forest soil. Thus the net payments in the form of CO_2 tax or emission permits for a given country equal [3]:

$$\tau\{q(t) + h_1(t) + \alpha h_2(t) - \mu F[x(t)]\}. \tag{1}$$

Denote the stock of the productive capital by $k(t)$. The production function of the economy is $P(k, h_1, q, h_2)$. $P(\cdot)$ is assumed to be strictly concave and increasing with all arguments. In addition, all cross derivatives are assumed to be positive. These assumptions imply that there are substitution possibilities between all inputs but that no inputs are perfect substitutes. [4] Let $c(t)$ denote the level of consumption and $U(c)$ a strictly concave utility function with $\lim_{c \to 0} U'(c) = \infty$. The problem of the social planner is to [5]

$$\underset{\{q, h_1, h_2, c\}}{\text{maximize}}\; W = \int_0^{\infty} U(c) e^{-\delta t}\, \mathrm{d}t \tag{2}$$

$$\text{s.t. } \dot{k} = P(k, h_1, q, h_2) - c - p_3 q - \tau[q + h_1 + \alpha h_2 - \mu F(x)],$$

$$k(0) = k_0, \tag{3}$$

$$\dot{x} = F(x) - h_1 - h_2,\; x(0) = x_0, \tag{4}$$

$$q \geq 0, \tag{5}$$

$$h_1 \geq 0, \tag{6}$$

$$h_2 \geq 0. \tag{7}$$

[2] A more accurate description of carbon accumulation in the forest soil requires more state variables than is used in this analysis. The case $\mu > 1$ approximates the possibility that the pool of carbon in soil is increasing and is not in a steady state.

[3] In the case where the international agreement specifies an upper limit to net national emissions τ may be interpreted as a Lagrangian multiplier.

[4] It may be possible that wood and fossil fuels are perfect substitutes in energy production. In this case the production function may take the form: $P(k, h_1 + q, h_2)$. Using this formulation does not change the main results of the analysis.

[5] The time arguments are neglected for the sake of notational simplicity.

The current value Hamiltonian, $\mathscr{H}$, and the necessary conditions for optimum are (Seierstad and Sydsæter, 1987, Theorem 3.12):

$$\mathscr{H} = U(c) + \lambda[P(k, h_1, q, h_2) - c - p_3 q - \tau[q + h_1 + \alpha h_2 - \mu F(x)]$$
$$+ \varphi[F(x) - h_1 - h_2], \tag{8}$$

$$\mathscr{H}_c = U'(c) - \lambda = 0, \tag{9}$$

$$\mathscr{H}_{h_1} = \lambda P_{h_1}(k, h_1, q, h_2) - \lambda\tau - \varphi \le 0,\ h_1 \mathscr{H}_{h_1} = 0,\ h_1 \ge 0, \tag{10}$$

$$\mathscr{H}_{h_2} = \lambda P_{h_2}(k, h_1, q, h_2) - \lambda\tau\alpha - \varphi \le 0,\ h_2 \mathscr{H}_{h_2} = ,\ h_2 \ge 0, \tag{11}$$

$$\mathscr{H}_q = P_q(k, h_1, q, h_2) - p_3 - \tau \le 0,\ q\mathscr{H}_q = 0,\ q \ge 0, \tag{12}$$

$$\dot{\lambda} = \lambda[\delta - P_k(k, h_1, q, h_2)], \tag{13}$$

$$\dot{\varphi} = -\lambda\tau\mu F'(x) + \varphi[\delta - F'(x)], \tag{14}$$

and conditions (3)–(7).

Before studying the optimal tax/subsidy programme let us consider the basic properties of the optimal solution. Eqs. (10)–(12) determine the optimal levels of wood and coal utilization as functions of the shadow prices for capital and the forest stock. Differentiating the system (10)–(12) totally gives: $h_1 = h_1(\varphi, \lambda, k)$, $h_{1_\varphi} < 0$, $h_{1_\lambda} > 0$, $h_{1_k} > 0$, $h_2 = h_2(\varphi, \lambda, k)$, $h_{2_\varphi} < 0$, $h_{2_\lambda} > 0$, $h_{2_k} > 0$ and $q = q(\varphi, \lambda, k)$, $q_\varphi < 0$, $q_\lambda > 0$, $q_k > 0$. Eq. (9) determines the level of consumption as a function of the shadow price of capital. Denote this by $c = c(\lambda)$. Now we can write the Modified Hamiltonian Dynamic System:

$$\dot{k} = P[k, h_1(\varphi, \lambda, k), q(\varphi, \lambda, k), h_2(\varphi, \lambda, k)] - c(\lambda)$$
$$- \tau[q(\varphi, \lambda, k) + h_1(\varphi, \lambda, k) + \alpha h_2(\varphi, \lambda, k) - \mu F(x)],$$
$$\dot{x} = F(x) - h_2(\varphi, \lambda, k) - h_2(\varphi, \lambda, k),$$
$$\dot{\lambda} = \lambda\{\delta - P_k[k, h_1(\varphi, \lambda, k), q(\varphi, \lambda, k), h_2(\varphi, \lambda, k)]\},$$
$$\dot{\varphi} = -\lambda\tau F'(x) + \varphi[\delta - F'(x)].$$

Let us use Soreger's (1989) Corollary 2c. It states that the system is globally stable for bounded solutions if the 'curvature matrix',

$$\mathbb{C} = \begin{bmatrix} \mathscr{H}^*_{ii} & -(\delta/2)I \\ -(\delta/2) & -\mathscr{H}^*_{jj} \end{bmatrix},$$

where $\mathscr{H}^*$ is the maximized Hamiltonian, $i = k$, x and $j = \lambda$, φ, is negative definite. The matrices $\mathscr{H}^*_{ii}$ and $\mathscr{H}^*_{jj}$ are negative definite with negative eigenvalues by the strict concavity assumptions on $P(k, h_1, q, h_2)$, $U(c)$ and $F(x)$. This implies that the matrix $\mathbb{C}$ is negative definite given that the rate of discount is small enough (Brock and Scheinkman, 1976) and furthermore that with small rates of discount the steady state equilibrium is unique and globally stable for bounded solutions. This means that given the initial levels of capital and the forest stock, the approach path toward the saddle point steady state is the optimal solution for this model (cf. Tahvonen and Kuuluvainen, 1993). The existence of this solution can be shown by using the existence theorems for ordinary differential equations (see e.g. Brock and Malliaris, 1989, Theorems 4.1 and 6.1).

At the steady state $\dot{\varphi} = 0$, i.e. $-\lambda\tau\mu F'(x) + \varphi[\delta - F'(x)] = 0$ (Eq. 14). Given $\delta > 0$, the size of the steady state forest stock cannot be so large that $F'(x) \leq 0$ because this would imply that $\varphi < 0$. Correspondingly, the steady state forest stock cannot be so small that $\delta - F'(x) \leq 0$ because this would imply $\dot{\varphi} < 0$. Thus the optimal size of the forest stock is somewhere between the stock level where marginal growth equals the rate of discount and the stock level which implies maximum sustainable yield. However, if $\delta = 0$ the optimal steady state stock size equals the level with a maximum sustainable yield. Using Eqs. $\dot{\varphi} = 0$, (14) and (10), the steady state forest stock can be characterized by $\delta = \tau\mu F'(x)/[P_{h_1}(\cdot) - \tau] + F'(x)$. The term $\tau\mu F'(x)/[P_{h_1}(\cdot) - \tau]$ represents the stock effect. In this case it equals the decrease in carbon taxes due to a marginal increase in the growing forest stock divided by the (net) productivity of a marginal unit of wood used in energy production (i.e. the investment costs for the marginal forest capital). At the steady state $F(x) - h_1 - h_2 = 0$ which implies that $\tau[h_1 + \alpha h_2 - \mu F(x)] < 0$. This means that at the steady state the net taxation from forest-based emissions is negative (recall that $\alpha < 1$ and $\mu \geq 1$). This follows because even when the harvestable forest stock is constant carbon is accumulating in durable forest products and in the forest soil [6]. If the rate of fossil fuel utilization is low enough the carbon taxation of the given country may be negative i.e. the country may receive net revenues from carbon taxation.

Let us next consider how the socially optimal solution can be implemented in a decentralized economy using taxes and subsidies.

3. Decentralized solutions with domestic taxes and subsidies

This section will show that the optimal outcome studied above can be implemented in a decentralized economy by taxing all carbon emissions at the international tax rate τ and by subsidizing the forest sector and individual forest owners at the rate equal to the value of removed carbon, i.e. at the rate $\tau\mu F(x)$.

Assume that the economy consists of a representative consumer/forest owner, a representative firm and the government. The consumer maximizes the present

[6] However, recall Footnote 3.

value of utility from consumption by optimal allocation of his capital stock between consumption and savings (the amount of labor sold by the consumer is assumed to be fixed). In addition, the consumer harvests his forest and sells the wood for energy production or as a raw material for wood processing. In his harvesting decision he also takes into account the accumulation of CO_2 and the related subsidies from the government. The consumer rents his capital to the representative firm at the market interest rate r and as the owner of the firm he also receives profits π. Note that both π and r are functions of time. The firm is a price taker and maximizes its instantaneous profits and pays carbon taxes as part of its production costs.

Denote the price for wood as an energy source by p_1 and as a raw material in wood processing by p_2. The problem of the representative consumer/forest owner is to

$$\underset{\{c,h_1,h_2\}}{\text{maximize}}\ W_2=\int_0^{\infty}U(c)e^{-\delta t}\,dt \tag{15}$$

$$\text{s.t. } \dot{k}=\pi+rk-c+p_1h_1+p_2h_2+\tau\mu F(x),\ k(0)=k_0, \tag{16}$$

$$\dot{x}=F(x)-h_1-h_2,\ x(0)=x_0, \tag{17}$$

$$h_1\geq 0,\ h_2\geq 0. \tag{18}$$

Denote the consumer's shadow price for his capital stock by σ and the shadow price (stumpage price) for wood by ϕ. The necessary (interior) conditions for this problem are:

$$U'(c)-\sigma=0, \tag{19}$$

$$\sigma p_1-\phi=0, \tag{20}$$

$$\sigma p_2-\phi=0, \tag{21}$$

$$\dot{\sigma}=\sigma(\delta-r), \tag{22}$$

$$\dot{\phi}=-\sigma\tau\mu F'(x)+\phi[\delta-F'(x)], \tag{23}$$

and conditions (16)–(17).

The problem of the firm is to

$$\underset{\{k,h_1,q,h_2\}}{\text{maximize}}\ \pi=P(k,h_1,q,h_2)-rk-(p_1+\tau)h_1-(p_2+\alpha\tau)h_2 -(\tau+p_3)q. \tag{24}$$

Necessary (interior) conditions for optimum are:

$$P_k(k,h_1,q,h_2)-r=0, \tag{25}$$

$$P_{h_1}(k,h_1,q,h_2)-p_1-\tau=0, \tag{26}$$

$$P_{h_2}(k,h_1,q,h_2)-\alpha\tau-p_2=0, \tag{27}$$

$$P_q(k,h_1,q,h_2)-p_3-\tau=0. \tag{28}$$

Now we can compare the necessary conditions in the planner's problem with the conditions of the decentralized economy. From (25) it follows that $r = P_k(\cdot)$. Eqs. (19) and (9) imply that $\sigma = \lambda$. This implies that (22) and (13) are equivalent. Given $\phi = \varphi$ it follows that (23) is equivalent to (14). Now (20) implies $p_1 = \varphi/\lambda$. This implies that (26) is equivalent to (10). Similarily (27) $\Leftrightarrow$ (11). The equivalence of (28) and (12) is obvious. By (19), Eqs. (16) and (3) are equivalent. Finally, (17) is equivalent to (4). Together this shows that the decentralized solution with the proposed taxation/subsidy programme equals the Pareto optimal solution of the social planner.

Because the growing biomass decreases the net expenditures from pollution taxation optimality requires that the accumulation of the forest stock exceeds the accumulation without the CO_2 taxation. To include the appropriate incentive in the forest owner's problem requires a subsidy which depends on the rate of carbon accumulation of the growing forest.

Wood can cause different amounts of emissions depending on how it is utilized. As it is an energy source, emissions will be released immediately. In the form of durable commodities and paper products the decay may take years or decades but, if used in construction, wood can store carbon much longer. These differences require that carbon taxation must also be differentiated over different utilization purposes. This is reflected in the carbon taxes, which equal τ for wood used in energy production and $\alpha\tau$ for wood used as a raw material for other purposes. Because of this the correct price structure cannot be created merely by subsidizing the forest owners.

4. Conclusions

According to the concept of net national emissions, the role of forest as carbon sinks must be taken into account when the emission levels of individual countries are estimated. If different countries are able to reach some kind of agreement for abating CO_2 emissions, this agreement can be implemented by using emission taxes or markets for emission permits. This raises the question of how different countries should control forest harvesting and the use of wood as an energy source at the national level. Common arguments suggest that if forests are harvested at a sustainable level, the wood-based CO_2 emissions need not be taxed and accordingly forest owners need not be subsidized. The analysis of this paper shows that the reverse is true. The ability of forests to decrease national expenditures on CO_2 taxation increases the productivity of unharvested forests. As a consequence, the steady state level of the forest stock increases. In a decentralized economy this means that private forest owners should produce positive externalities. This is not possible without subsidies to forest owners. An optimal subsidy equals the (annual) amount of carbon stored by a given forest stand multiplied by the international price of emission permits. In addition to this, optimality requires that all CO_2 emissions must be taxed independently of whether they have their origin in forests or fossil fuels.

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