European Journal of Political Economy
Vol. 15 (1999) 311–329

European Journal of POLITICAL ECONOMY

Environmental taxes on exhaustible resources

Eirik S. Amundsen [a,*], Ronnie Schöb [b]

[a] *Department of Economics, University of Bergen, Fosswinckels gate 6, N-5007 Bergen, Norway*
[b] *Department of Economics, University of Munich, Schackstrasse 4, D-80539 Munich, Germany*

Received 1 May 1997; received in revised form 1 November 1997; accepted 1 September 1998

Abstract

Environmental problems are tied to the use of exhaustible resources. A resource tax extracts rents from the resource owning countries, without creating significant incentives for consumers to reduce their resource consumption. The placement of the tax burden on resource owners affects the international distribution of wealth. In this paper we show that it is optimal for small countries who do not coordinate their national environmental policies, to impose a time-variant Pigovian tax. With coordination, however, an additional tax on the exhaustible resource can be levied—one which, if set optimally, entirely appropriates the rents from the foreign resource owners. Coordination of national environmental policies thereby changes the international distribution of income, while still resulting in Pareto optimality. © 1999 Elsevier Science B.V. All rights reserved.

JEL classification: H21; H23; Q38

Keywords: Environmental tax; Resource tax; Resource rent; International redistribution

1. Introduction

In the last two decades of the 20th century, environmental problems have been prominent in the political agenda. As different environmental problems have arisen, environmental policy has been directed to address an increasing range of

* Corresponding author. Tel.: +47-55-58-92-05; Fax: +47-55-58-92-10; E-mail: eirik.amundsen@econ.uib.no

PII: S0176-2680(99)00008-7

concerns. Although environmental policy often takes the form of the so-called ‘command-and-control’ approach, the question of how to use market mechanisms in environmental policy has also been widely discussed. In particular, emission taxes are an efficient instrument for improving the environment. Since, environmental issues are typically tied to the use of exhaustible resources, the analysis of environmental tax incidence should take account of the impact of such taxes on the use of exhaustible resources such as gas and oil products. The literature on environmental taxes has, until recently, not considered this relation. [1]

Resource prices are principally determined by the user cost of the resource, i.e., the rent the resource owner can obtain from extracting the resource. An excise tax normally distorts the optimal time path of extraction, but an appropriately set rent tax leaves the optimal time path unaffected. Such a rent tax can, in principle, tax away all pure profits from the resource owners (cf. e.g., Dasgupta and Heal, 1979, or Sinn, 1982). Independently of the effect of the taxes on the time path of extraction, both types of taxes shift much of the tax burden to the resource owners. In an international context, Newbery (1976) and Bergstrom (1982) show that resource-consuming countries can secure the entire resource rent from the resource-owning countries by coordinating their tariffs or their national excise tax policy.

The theoretical findings are in line with the empirical evidence. For example, in the countries of the European Union, tax rates on gasoline have increased substantially over time. Although these taxes were not primarily introduced to internalize national or global externalities, their effects are similar to those of environmental taxes. [2]

Fig. 1 shows that since the mid eighties the real producer price has fallen while the real tax rate has increased steadily. These countervailing developments have left the consumer price more or less unaffected. The consequence is that the tax burden of gasoline taxes has primarily fallen on resource owners. This has implications for the international distribution of wealth. The gasoline tax extracts rents from the resource-owning countries, without providing significant incentives for consumers to reduce their consumption.

We show that this additional benefit creates a strong incentive for countries' governments to coordinate national environmental tax policies, even if coordination is not required for environmental purposes. Taxes on exhaustible resources may serve a dual objective of internalizing domestic external effects from the consumption of an exhaustible resource and capturing resource rents from re-

[1] See however Van der Ploeg and Withagen (1991), Kolstad and Krautkraemer (1993), and Farzin (1996).

[2] Hoeller and Coppel (1992) calculate the *implicit carbon tax* of fuel taxes and conclude that, at least for most European countries, the implicit carbon tax is already much higher than the taxes suggested by recent energy tax reform proposals.

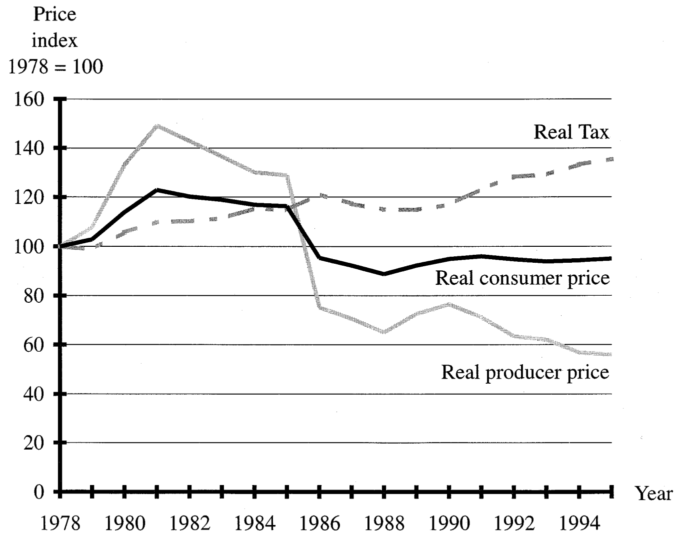

Fig. 1. Real producer price and consumer price for gasoline consumption.
Source: International Energy Agency Statistics, Energy Prices and Taxes, various issues, OECD: Paris; International Energy Agency (1995): Energy Policies of IEA Countries, 1994 Review, OECD: Paris, Table A11, p. 597; Main Economic Indicators, Historical Statistics, various issues. Legend: The curves show the real producer price (without tax) and the end-user price (with tax) as a weighted average of the real domestic prices of premium leaded gasoline consumption of all countries of the European Union. Nominal prices are deflated by the consumer price index. The prices are weighted by the relative oil supply of each country in 1993. 1978 = 100.

source-exporting countries. This dual effect is studied by bringing together (i) the literature on optimal dynamic Pigovian taxes and (ii) on optimal tariffs.

The paper proceeds as follows. To assess the intertemporal tax incidence of environmental taxes on exhaustible resources, we introduce a decentralized version of the neo-classical growth model. Within this framework, we first analyse the case of non-coordinated environmental policy of a small country that internalizes domestic externalities (Section 2). This serves as a reference case, as no coordination between countries is required to attain a global (in the sense of world-wide) first-best optimum. Section 3 then shows that international coordination of purely nationally motivated environmental policies nevertheless allows all participating countries to increase their domestic welfare at the cost of resource-extracting countries. For a resource-consuming country, the total optimal tax levied on exhaustible resources therefore differs from the Pigovian tax, which optimally internalizes the external effects. Coordination allows small resource-consuming countries to impose an additional tax on energy which enables these countries to appropriate shares of the resource rent. Although coordination attains the global first-best solution, it has significant impacts on the international distribution of income. The consequences are briefly discussed in Section 4.

2. Non-coordinated environmental tax policy

We consider an economy that satisfies standard assumptions for a general equilibrium, with well-defined property rights, perfect information, and rational behaviour of all private agents. The model is a development of Sinn (1982). We consider four types of agents: households, domestic firms that produce a 'normal' consumption good, a domestic government, and a foreign resource-extracting country. All agents are intertemporal maximizers with infinite time horizons. Households maximize utility, firms maximize profits, governments maximize domestic welfare, and the resource-extracting country maximizes the resource rent.

2.1. The model

The economy consists of J identical countries (jurisdictions), each with D inhabitants. The countries import a natural resource from a single resource-extracting country. In the J countries each household i $(i=1,\ldots,D)$ consumes a quantity $x_i(t)$ of a domestically produced normal good at time t and a quantity $y_i(t)$ of a natural resource imported from the resource-extracting country. The domestic industry produces the normal good $x(t)$ using capital $K(t)$, labour $l(t)$, and the natural resource $y_0(t)$ as inputs in production.

2.1.1. Externality

The aggregate consumption of the resource in each country creates a negative externality, called the environmental damage $E(t)$, which affects all households in the country. The aggregate consumption of the natural resource consists of household consumption $(i=1,\ldots,D)$ and the resource input in production $(i=0)$. Hence, the environmental damage is given by

$$E(t)=E\left(\sum_{i=0}^{D}y_i(t)\right), \tag{1}$$

with $\partial E(t)/\partial y_i(t)=E_y(t)>0$ and $\partial^2E(t)/\partial y_i(t)^2=E_{yy}(t)\geq 0$. These assumptions ensure that both environmental damage and marginal environmental damage increase in $y(t)$. Eq. (1) represents a pure flow externality. [3] The external effect only affects domestic households, i.e. we abstract from transboundary pollution problems.

2.1.2. Consumption

Each household offers a time-independent flow of labour normalized to unity. The preferences of a household are described by a twice continuously differen-

[3] Given the complexity of models with more than two state variables (cf. Kolstad and Krautkraemer, 1993), we focus on pure flow externalities in order to avoid introducing a third state variable in addition to the resource stock and the capital stock. For an analysis of stock externalities in a neo-classical growth model see Van der Ploeg and Withagen (1991) or Farzin (1996).

tiable, strictly quasi-concave utility function. The objective function of a household is

$$u(0)=\int_0^{+\infty} u(x_i(t),y_i(t),E(t))\mathrm{e}^{-\rho t}\mathrm{d}t, \tag{2}$$

where $\rho>0$ denotes the household's time preference rate. We assume throughout that the marginal utilities $u_x(t)$ and $u_y(t)$ are positive with $\lim_{y\to 0}u_y(x,y,E)\to +\infty$, while the marginal utility of emissions $u_E(t)$ is negative. The second derivatives are $u_{xx}(t)<0$, $u_{yy}(t)<0$ and $u_{EE}(t)\le 0$, respectively. With respect to the cross derivatives, we assume that $u_{xy}(t)=u_{yx}(t)\ge 0$ and $u_{Ex}(t)=u_{Ey}(t)=0$, i.e., we assume separability between private consumption and environmental quality.

The initial wealth of a household equals the market value of the shares the households own in the domestic firm, $\pi(0)/D$, plus the present value of the flow of wage incomes $w(t)$ and lump-sum transfers $T(t)$ from the government. Denoting the capital market interest rate by $r(t)$, the household's initial wealth is given by [4]

$$V(0)=\frac{\pi(0)}{D}+\int_0^{+\infty}(w(t)+T(t))\mathrm{e}^{-\int_0^t r(s)\mathrm{d}s}\mathrm{d}t. \tag{3}$$

The intertemporal budget constraint is then given by

$$\dot{V}(t)=r(t)V(t)-x_i(t)-p(t)y_i(t), \tag{4}$$

where $p(t)$ denotes the consumer price of the natural resource. The change in the household's wealth $\dot{V}(t)$ in each period is equal to the interest payments on its wealth stock minus the expenditures on consumption of the normal good and the natural resource. The normal good $x_i(t)$ is the numéraire.

The household maximizes the present value of its utility (2) subject to conditions (3) and (4). It disregards the impact of its consumption of the natural resource on the aggregate level of pollution. This gives the current value Hamiltonian

$$H_H=u(x_i(t),y_i(t),E(t))+\lambda_H(t)[r(t)V(t)-x_i(t)-p(t)y_i(t)]. \tag{5}$$

Solving for the first-order conditions yields [5]

$$\frac{\partial H_H}{\partial x_i(t)}=0\Leftrightarrow u_x(t)=\lambda_H(t), \tag{6a}$$

[4] Each household calculates the lump-sum transfers, given its information about the tax policy and the plans of firms, and disregards the influence personal decisions have on the aggregate parameters (cf. Sinn, 1982, p. 365).

[5] Throughout the paper we define the time derivative by e.g. $\dot{\lambda}_H=\partial\lambda_H/\partial t$ and the growth rate by $\hat{\lambda}_H=\dot{\lambda}_H/\lambda_H$.

$$\frac{\partial H_H}{\partial y_i(t)} = 0 \Leftrightarrow u_y(t) = \lambda_H(t)\,p(t), \tag{6b}$$

$$-\frac{\partial H_H}{\partial V(t)} = \dot{\lambda}_H(t) - \lambda_H(t)\,\rho \Leftrightarrow \hat{\lambda}_H(t) = \rho - r(t). \tag{6c}$$

Eqs. (6a) and (6b) yield the standard condition for the optimal composition of consumption in each period t, i.e.,

$$\frac{u_y(t)}{u_x(t)} = p(t). \tag{7}$$

The marginal rate of substitution should be equal to the consumer price of the resource in each period of time. Eq. (6c) describes the condition for the optimal time path of consumption. The consumption of the two goods should be allocated over time in a way that makes the growth rate of the marginal utility of income equal to the time preference rate minus the current interest rate. [6]

2.1.3. *Domestic production*

The domestic firm produces a normal good using capital, labour and energy. The technology is described by a linear homogeneous production function $f(K(t), l(t), y_0(t))$ where K denotes capital input, l labour input and y_0 energy input. The firm behaves as a price taker on both input and output markets. The normal good is either used for sales $x(t)$ or for investment $\dot{K}(t)$ which equals the difference between goods produced and goods sold less depreciation. The depreciation rate of the firm's capital stock is $0 \leq \delta \leq 1$ and is assumed to be time invariant.

The aim of the firm is to maximize its market value, i.e., the present value of dividend payments $\pi(0)$. Dividend payments are determined by the difference between sales and wage payments. The maximization problem of the firm thus becomes

$$\max_{x(t), l(t), y_0(t)} \pi(0) = \int_0^{+\infty} [x(t) - w(t)\,l(t) - p(t)\,y_0(t)]\,\mathrm{e}^{-\int_0^t r(s)\mathrm{d}s}\mathrm{d}t \tag{8}$$

s.t.

$$\dot{K}(t) = f(K(t), l(t), y_0(t)) - \delta K(t) - x(t). \tag{9}$$

The current value Hamiltonian for the firm is given by

$$H_F = x(t) - w(t)\,l(t) - p(t)\,y_0(t) + \lambda_F(t)[\,f(K(t), l(t), y_0(t)) - \delta K(t) - x(t)]. \tag{10}$$

[6] For the special case of $u_{xy}(t) = u_{yx}(t) = 0$, we obtain $\hat{x}_i(t) = (r(t) - \rho)/\eta_x(t)$, with $\eta_x(t) = -(u_{xx}(t)/u_x(t))x_i(t)$ being the elasticity of marginal utility of consuming the normal good.

The first-order conditions are

$$\frac{\partial H_F}{\partial x(t)} = 0 \Leftrightarrow 1 = \lambda_F(t), \tag{11a}$$

and, by using Eq. (11a),

$$\frac{\partial H_F}{\partial l(t)} = 0 \Leftrightarrow w(t) = f_l(K(t), l(t), y_0(t)), \tag{11b}$$

$$\frac{\partial H_F}{\partial y_0(t)} = 0 \Leftrightarrow p(t) = f_{y_0}(K(t), l(t), y_0(t)), \tag{11c}$$

$$-\frac{\partial H_F}{\partial K(t)} = \dot{\lambda}_F(t) - \lambda_F(t) r(t) \Leftrightarrow r(t) = f_K(K(t), l(t), y_0(t)) - \delta. \tag{11d}$$

Conditions (11b) and (11c) state that labour, energy and capital inputs are paid in each period according to the value of their marginal product.

2.1.4. Resource extraction

Next we consider the resource-extracting country which is also assumed to behave as a price taker. The objective of the resource-extracting country is to maximize the resource rent. Given the producer price at date t, $q(t)$, the time-invariant per unit extraction cost c and the initial total resource stock $Y(0) = Y_0$, the maximization problem can be represented by

$$\max_{y(t)} \int_0^{+\infty} (q(t) - c) y(t) \mathrm{e}^{-\int_0^t r(s) \mathrm{d}s} \mathrm{d}t \tag{12}$$

s.t.

$$\dot{Y}(t) = -y(t), \tag{13}$$

where $y(t)$ denotes extraction in period t. The current value Hamiltonian of the optimization problem is given by

$$H_R = (q(t) - c) y(t) - \lambda_R(t)[y(t)]. \tag{14}$$

Solving for the first-order conditions yields

$$\frac{\partial H_R}{\partial y(t)} = 0 \Leftrightarrow q(t) - c = \lambda_R(t), \tag{15a}$$

$$-\frac{\partial H_R}{\partial Y(t)} = \dot{\lambda}_R(t) - \lambda_R(t) r(t) \Leftrightarrow \hat{\lambda}_R(t) = r(t). \tag{15b}$$

Eqs. (15a) and (15b) determine the optimal time path of extraction, given by

$$\left[\widehat{q(t) - c}\right] = r(t), \tag{16}$$

which represents the Hotelling rule for the case of constant extraction costs. In this expression, $[q(t)-c]$ constitutes the competitive price of the in situ resource (or synonymously, the user cost of the resource), i.e., the resource which is still in the resource stock. The resource-owning country will be indifferent between extracting today and extracting tomorrow, if the increase in the user cost equals the interest the resource owner would obtain by investing today's proceeds on the capital market. The solution to this standard resource extraction problem implies that it is optimal to extract the whole resource stock in infinite time. The initial producer price $q(0)$ is then determined in such a way that the price path develops in accordance with Eq. (16). Total extraction of the resource is stretched out to infinity as the marginal utility of the resource consumption is infinite at $y=0$. [7]

2.1.5. Market equilibrium

A decentralized equilibrium requires market clearing in all markets. In the domestic labour market, the labour demand of the domestic firm equals the fixed amount of labour in this country, i.e.

$$l(t)=D, \tag{17}$$

which, given the capital stock and energy input at time t determines the wage rate $w(t)$. As the resource is imported from the resource-owning country, the foreign trade balance requires that the amount of the normal good exported $x_f(t)$ equals the payments for the resource consumed, plus the interest paid on foreign loans $B(t)$, and minus the change in the debts $\dot{B}(t)$: [8]

$$x_f(t)=\sum_{i=0}^{D} q(t)\,y_i(t)+r(t)\,B(t)-\dot{B}(t), \tag{18}$$

with $y(t)=J\sum_{i=0}^{D} y_i(t)$ describing the equilibrium on the world resource market.

In each country, the market equilibrium for the normal good is given by

$$x(t)=\sum_{i=1}^{D} x_i(t)+x_f(t). \tag{19}$$

Total production in each period equals total domestic consumption plus exports.

2.2. National environmental policy

Since the households disregard the impact their resource consumption has on the environment, the laissez-faire market outcome cannot be Pareto-efficient. In this section we analyse how the government can internalize the external cost of the

[7] Formally, the transversality condition, not presented here, must hold.

[8] The present value of interest payments the domestic households receive equals the present value of the foreign loans. Hence $B(t)$ does not affect domestic wealth (cf. Eq. (3)).

domestic consumption of the natural resource. More precisely, we focus on the optimal tax policy of the government of a small country, assuming that the imported resource causes a pure national externality.

The country's tax policy does not influence the world resource price $q(t)$, i.e. $\sum_{i=0}^{D} y_i(t) \ll y(t)$. To internalize the externality the government imposes a tax $\tau_E(t)$ on the consumption of the natural resource such that

$$\tau_E(t) = p(t) - q(t). \tag{20}$$

Since there are no other activities of the government, all revenues are refunded. With the government using lump-sum rebates of all tax revenues, the budget constraint of the government is given by

$$\tau_E(t) \sum_{i=0}^{D} y_i(t) = \sum_{i=1}^{D} T_i(t). \tag{21}$$

Demand variations in a single country do not affect the producer price; the whole tax burden is borne by the consumers of the natural resource. The change in the tax rate equals the change in the consumer price: $\mathrm{d}\tau_E(t) = \mathrm{d}\,p(t)$. In order to determine the optimal environmental tax, the government maximizes the sum over all utilities (2) subject to the change in the domestic capital stock (9) and the foreign trade balance condition (18). From the first-order conditions, (which are easily derived and not presented here) we can calculate the domestic social optimum, which is characterized by:

$$\frac{u_y(t)}{u_x(t)} + D\frac{u_E(t)}{u_x(t)} = q(t). \tag{22}$$

Note that as domestic resource consumption is efficiently allocated between households and the domestic firm, we have $f_{y_0}(K(t),l(t),y_0(t)) = u_y(t)/u_x(t)$. The social optimum can be achieved by imposing a *Pigovian tax* equal to

$$\tau_E(t) = -D\frac{u_E(t)}{u_x(t)}. \tag{23}$$

The externality depends on the quantity consumed which in turn depends on the consumer price. Hence, the Pigovian tax depends on the current producer price. As the producer price of the resource is unaffected by a change in domestic demand of a single country, the Pigovian tax system increases the consumer price of the resource in each period. This induces a reduction of demand and also a reduction of imports of the natural resource. Consequently, there is a reduction in the exports of the domestically produced good. Since tax revenues are transferred back to the households, [9] the consumption of the domestically produced good increases in

[9] In a perfect foresight model the households have already taken account of the lump-sum rebate of the tax revenues from such a tax policy: $T(t) = D\tau_E(t)y_i(t)$.

every period.[10] As the marginal environmental damage decreases with decreasing consumption of the resource, the tax rate falls as time passes. This implies that the domestic consumer price will increase at a lower rate than the producer price.

2.3. A non-coordinated world market equilibrium

In this section, we consider the case where all J small countries impose a tax on domestic resource consumption, but without coordinating their policies. Each country's government behaviour is the Cournot–Nash assumption. Each country's government expects that its own tax policy will not affect other countries' tax policies. In this case, it is always optimal for a single country to impose $\tau_E(t)$ according to Eq. (23).

If, however, every country were to adopt a tax policy according to Eq. (23), producer prices would change. For identical countries with identical taxes, the producer price is determined by the aggregate consumer demand and the time path of the environmental tax. Solving Eq. (20) for $q(t)$ and substituting into Eq. (16) we obtain

$$[\widehat{p(t) - \tau_E(t) - c}] = r(t). \tag{24}$$

Condition (24) determines the producer price path of the resource-owning country when all resource-importing countries introduce identical non-coordinated national environmental policies in order to decrease national pollution.

The aggregate demand curve of the resource-exporting country shifts inward in response to the introduction of environmental taxes in all countries. For any producer price the consumer price will therefore be higher. The resource-exporting country will then recalculate the optimal extraction path. As a consequence, it will obtain a lower rent than in a laissez-faire market equilibrium without environmental taxes.

To see this, consider the total rent that the resource-extracting country can acquire before and after the introduction of environmental taxes. In the profit maximum, the resource-extracting country is indifferent about when to extract the resource, and the present value of a unit of the resource is given by $(q(0)^{\text{before}} - c)$. Total rent is therefore given by $(q(0)^{\text{before}} - c)Y_0$, and is increasing in $q(0)$.

If all resource-importing countries introduce Pigovian taxes, total demand will fall in each period if the producer price remains constant. This cannot be an equilibrium, as the total resource stock would not be exhausted and a price taker would have an incentive to increase sales in some periods. As a consequence, both

[10] This is due to the assumption of a fixed labour supply.

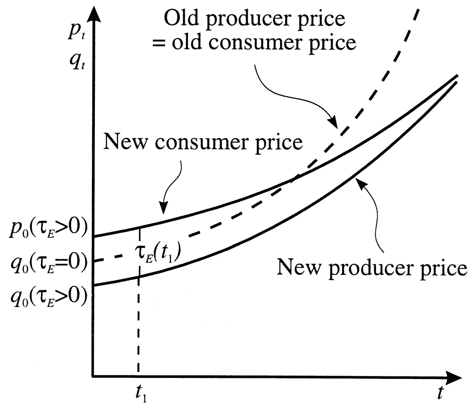

Fig. 2. Producer and consumer price paths in a non-coordinated equilibrium.

the producer price and the resource rent obtained by the resource-extracting country falls.

Since the marginal environmental damage is an increasing function of resource consumption, a shift from present consumption towards future consumption is welfare enhancing. A delay in consumption reduces both the absolute amount of emissions (this can be seen from the assumption that $E_{yy} > 0$) and the present value of the environmental damage.

Fig. 2 shows the shift in the path of the producer price for the resource-extracting country and the path of the consumer price for a representative small country. While the consumer price goes up initially, it will be lower than the original (dotted) price path in later periods, in order to guarantee complete exhaustion of the resource. The producer price will be reduced and stay below the pre-tax producer price path at all instants of time. The resource rents of the resource-extracting country decline. As resource consumption falls, marginal environmental damage decreases, as therefore does the Pigovian tax. [11] Hence, the new consumer price and the new producer price will approach each other asymptotically as time passes.

One could therefore take the view that if consumption of the natural resource is not taxed, the resource-consuming countries actually subsidize the resource-extracting country by an amount equal to the value of the environmental damage that the households inflict upon themselves. In this sense, it is not the polluter who pays for the internalization of the externality, but the producer of the non-renewable resource.

[11] As Ulph and Ulph (1994) emphasize, what matters is the time path of the environmental tax rather than its level. To delay extraction, a falling environmental tax is required.

It should be noted that the time path given by condition (24) guarantees an efficient allocation of the resource stock over time. To see this, substitute Eqs. (11d) and (20) into Eq. (24). This yields

$$\widehat{\left[\frac{u_y(t)}{u_x(t)}+D\frac{u_E(t)}{u_x(t)}-c\right]}=f_K(K(t),D,y_0(t))-\delta. \tag{25}$$

The left-hand side shows the growth rate of the net benefit of resource consumption in period t. This is equal to the marginal rate of substitution between $y(t)$ and $x(t)$ minus the marginal environmental damage $[-Du_E(t)/u_x(t)]$ and minus marginal extraction cost c, all measured in units of $x(t)$.[12] The right-hand side denotes the marginal product of capital in period t. Eq. (25) then basically states that the growth rate of the marginal rate of substitution between the normal good and the resource (or, alternatively, the marginal product of energy in domestic production) less the social cost of extracting and consuming the non-renewable resource should be equal to the marginal product of capital. This is known as the Solow–Stiglitz condition for Pareto-efficiency, modified for the presence of externalities.[13]

With transboundary externalities, non-coordination does not provide an efficient allocation of the resource stock over time, as a single country does not take into account the external costs of its resource consumption on other countries. In this case, countries can benefit from coordinating their environmental policies (cf. e.g., Hoel, 1992). However, our main purpose of the present paper is to demonstrate, that even if there is no reason to coordinate policy from an environmental viewpoint, the prospect of capturing resource rents leads countries to coordinate their national environmental policy. This is the case we will turn to in Section 3.

3. Coordinating national environmental policies

Is there more resource-consuming countries can do to increase their domestic welfare? As we have seen in Section 2, a single country cannot affect the producer price. Therefore, it is always optimal to levy a tax $\tau_E(t)=Du_E(t)/u_x(t)$. If, however, all countries agree to increase taxes uniformly beyond the Pigovian level, they might extract more of the resource rent.

[12] This result is similar to proposition 1 of Farzin (1996). In the presence of environmental stock externalities, however, the shadow price of the natural resource would also depend on the environmental scarcity rent.

[13] Cf. Solow (1974) and Stiglitz (1974). According to the transversality condition, given the allocation of the resource rent, there is exactly one extraction path which is Pareto-efficient: the one which leads to complete extraction.

To see the argument, let us develop the following thought experiment. The starting point is the non-coordinated solution where all countries have imposed an optimal Pigovian tax in each period. As the optimal extraction path follows the Hotelling rule, this establishes a global first-best optimum, given the income distribution determined by the time path of the producer price. Denoting the original outcome by O, we rewrite Eq. (24) as

$$\left[\widehat{p^O(t) - \tau_E^O(t) - c} \right] = r^O(t), \tag{26}$$

with $p^O(t) - \tau_E^O(t) = q^O(t)$.

If the resource-consuming countries are able to extract some rent from the resource-extracting country, domestic income and hence demand for the natural resource, demand for the normal commodity, and the environmental quality all change. To see this, assume that the initial wealth of all D households in each of the resource-importing countries increases by an amount ΔV_0. Such an increase in wealth changes the consumption pattern. The new equilibrium can be characterized by an optimal time path of extraction, say (denoting the new equilibrium prices with N)

$$\left[\widehat{p^N(t) - \tau_E^N(t) - c} \right] = r^N(t), \tag{27}$$

where $p^N(t) - \tau_E^N(t) = q^N(t)$, represents the producer price which, given the new income distribution, increases according to the Hotelling rule (16). Note that we assume here that the government has recalculated the Pigovian tax. Even though the profile of the producer price changes, efficient use of the resource stock over time is assured since the Hotelling rule is satisfied.

Integrating and reformulating condition (27), we obtain

$$p^N(t) - \tau_E^N(t) = \left(q^N(0) - c \right) e^{\int_0^t r^N(s) \mathrm{d}s} + c. \tag{28}$$

Eq. (28) states that the producer price in period t equals the in situ price in period t plus the extraction cost c.

Now consider the case where all countries decide to impose an additional uniform tax $\tau_R^N(t)$ on resource consumption, with the already existing domestically determined Pigovian tax is kept constant at the level $\tau_E^N(t)$. A new equilibrium would be characterized by

$$\tilde{p}(t) - \tau_E^N(t) - \tau_R^N(t) = \left(\tilde{q}(0) - c \right) e^{\int_0^t \tilde{r}(s) \mathrm{d}s} + c. \tag{29}$$

where $\tilde{p}(t)$ and $\tilde{q}(t)$ denote the new equilibrium consumer and producer prices, respectively, and $\tilde{r}(t)$ denotes the new equilibrium interest rate. For any given wealth, the tax τ_R^N will be non-distortionary if the consumer prices and the extraction path do not change, i.e., if $p^N(t) = \tilde{p}(t)$ and $r^N(t) = \tilde{r}(t)$.

A non-distortionary additional tax τ_R^N must therefore satisfy the following condition,

$$\tau_R^N(t) = \left(q^N(t) - \tilde{q}(0)\right)\mathrm{e}^{\int_0^t r^N(s)\mathrm{d}s}. \tag{30}$$

which can be derived by subtracting Eq. (29) from Eq. (28). If the government of the resource-importing country now designs the additional tax so that the new tax increases with the interest rate, i.e.,

$$\tau_R^N(t) = \tau_R^N(0)\mathrm{e}^{\int_0^t r^N(s)\mathrm{d}s}, \tag{31}$$

a comparison of Eqs. (30) and (31) shows that, we have:

$$\tau_R^N(0) = q^N(0) - \tilde{q}(0). \tag{32}$$

By choosing the additional tax in period 0 as

$$\tau_R^N(0) = p^N(0) - \tau_E^N(0) - c, \tag{33}$$

the initial producer price will fall to the extraction cost c, the minimum price required by the resource-extracting country in order to extract the resource. Using $q^N(0) = p^N(0) - \tau_E^N(0)$, a comparison of Eqs. (32) and (33) shows that

$$\tilde{q}(0) = c. \tag{34}$$

By coordinating tax policies, the resource-importing countries can leave the resource-extracting country with zero rent as, according to the Hotelling rule, the producer price will equal extraction cost in each period $\tilde{q}(t) = \tilde{q}(0) = c$ (cf. Eq. (29)). [14] Each of the small resource importing countries appropriates its share of the resource rent as determined by its share of total resource consumption.

In introducing the additional tax $\tau_R^N(t)$ we have implicitly assumed that the additional tax revenues do not change the domestic income and thus the time patterns of consumption. In the new equilibrium, these additional revenues have to equal the initially assumed increase in domestic wealth ΔV_0, i.e.,

$$\Delta V_0 = \frac{1}{D}\sum_{i=0}^{D}\int_0^\infty \left[\left[\tau_R^N(t) + \tau_E^N(t)\right] y_i^N(t) - \tau_E^O(t)\, y_i^O(t)\right]\mathrm{e}^{\int_0^t r^N(s)\mathrm{d}s}\mathrm{d}t. \tag{35}$$

Eqs. (27), (30) and (34) represent another global first-best optimum that fully

[14] This is only true if the countries make known the time path of the tariff and commit themselves to keeping to it. Newbery (1976) and later Kemp and Long (1980) and Karp and Newbery (1991a) point out that the optimal import tax is dynamically inconsistent in the presence of a choke price, i.e., if $u_y(x(t),0,E(t))$ is finite.

extracts the rent from the resource-extracting country. [15] To show that this maximizes domestic welfare of a resource-importing country, we differentiate the Hamiltonian of the government's maximization problem in any resource-importing country, i.e.,

$$H_G = \sum_{i=1}^{D} u(x_i(t), y_i(t), E(t)) + \lambda_G(t) \times \left[f(K(t), D, y_0(t)) - \sum_{i=1}^{D} x_i(t) - q(t) \sum_{i=0}^{D} y_i(t) \right] \tag{36}$$

with respect to the producer price paid to the resource-extracting country. [16] The partial derivative with respect to the producer price gives

$$\frac{\partial H_G}{\partial q(t)} = -\lambda_G(t) \sum_{i=0}^{D} y_i(t) < 0. \tag{37}$$

National welfare decreases with the producer price throughout. As $q(t) = c$ is the minimum producer price a country has to pay, it can be seen that Eqs. (27), (30) and (34) determine the domestic optimum. Hence, small countries can benefit from coordinating national environmental policies by agreeing on a uniform tax component on resource consumption that will increase with the interest rate, allowing for additional Pigovian taxes to internalize national externalities. As was pointed out in Section 2.3, however, for any given producer price, a single country's best policy is to impose a Pigovian tax only. Therefore, although all countries can benefit from coordination, a single country always has an incentive to deviate from the coordinated tax scheme. To overcome this prisoner's dilemma situation, coordination requires binding and enforceable contracts.

Although the additional taxes do not change consumer prices, producer prices do change significantly. Fig. 3 shows, for the case without wealth effects, the effect of the additional tax component on the producer price. The price the resource-owning country receives will be c in each period, leaving the resource-owning country with zero rent. While the rent tax component increases with the interest rate, the Pigovian tax component decreases as the consumption of the resource and the emissions fall. Without income effects, the consumer price path is

[15] The strong result obviously depends on the assumption that the resource extracting country does not consume the resource itself.

[16] Note that, unlike the normative solution for all countries, the producer price for the single country is given.

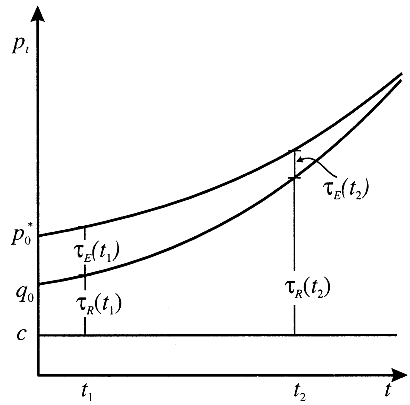

Fig. 3. Producer and consumer price paths in a coordination equilibrium.

equal to the new consumer price path in Fig. 2 which has been shown to internalize completely domestic externalities. Hence, the combination of the tax rate components both internalizes domestic externalities and captures all rent associated with the consumption of the natural resource.

It is worth briefly discussing the impact that two possible extensions of our model would have on our results. First, if the resource-owning country can exercise some market power, the optimal policy for resource-consuming countries in the non-coordination case is still only the imposition of a Pigovian tax. However, monopolistic resource owners may attempt to raise the initial resource price, because this would reduce the Pigovian tax and allow the resource owner to capture some of the tax revenues that the resource-consuming countries would otherwise collect (cf. Wirl, 1994). In the coordination case, the resource-consuming countries would certainly fail to *completely* extract rents. Nevertheless, coordination would always allow the resource-consuming countries to capture *some* of the resource rent (and the monopoly rent). Indeed, as was shown by Karp and Newbery (1991b), in the absence of externalities, the buyer's market power exceeds that of the sellers as they succeed in reducing the initial producer price.

Second, for global environmental problems arising from transboundary pollution (e.g., the emissions of greenhouse gases), our analysis suggests that the rent-capturing effect generates a further incentive for polluting countries to coordinate, beyond the potential welfare gains countries can realize from internalizing transboundary externalities. In the presence of political or other constraints that involve coordination costs, the additional benefit may, however, lead resource-consuming countries to coordinate, even though the global welfare gains fall short of the coordination costs. In this case, coordination would not lead to a global optimum. Furthermore, it should be noted that, even if coordination is welfare enhancing, the rent-capturing effect can only promote the introduction of some type of energy tax but it provides *ceteris paribus* no incentive for an efficient reduction of greenhouse gas emissions.

4. Concluding remarks

Our analysis of non-coordinated national environmental policies has revealed that it is optimal for a small country to impose a national Pigovian tax. Compensation is provided for national environmental damage, and the burden of the tax is partly borne by today's resource consumer and partly by the resource-extracting country which incurs from a reduction of the resource rent.

The coordination of national environmental policies further allows the resource-consuming countries to capture the resource rent completely by imposing a common tax in addition to the already domestically determined Pigovian taxes. This provides incentives for coordinating environmental policies, even if there are no transboundary or global pollution problems present. The literature considers the latter as the reason to coordinate of environmental policies (cf. e.g., Hoel, 1992). If there is a need for coordination because of global environmental problems, as in the case of a global warming, then we have shown that the rent-extracting effect gives an additional bonus to countries willing to coordinate their policies. The tax component that is harmonized has no effect on the environment. A carbon tax which increases at a constant rate in real terms (as proposed for example by Bach et al., 1995) should therefore not be considered as an environmental tax, but as a rent-extracting tax which is designed as additional to excise taxes and VAT that already exist, and to other national environmental taxes. [17] Such a tax scheme would therefore not benefit the developing countries whose populations in future will suffer from global warming, but will benefit those countries that consume the exhaustible resources today.

An ongoing discussion of whether or not to implement such a tax may even have adverse effects on the environment. Announcing the imposition of coordinated taxes (even if the taxes are not intended to extract rents) acts like an expropriation threat to the resource owners. As a consequence, the resource-owning countries have incentives to increase present extraction prior to the date the tax is introduced, so as to reduce future losses (cf. Long, 1975, Konrad et al., 1994).

In order to design environmental taxes that improve the environment, a thorough analysis of the intertemporal tax incidence is needed, but also the tax needs to be introduced quickly. Because resource rents are large components of

[17] Similar effects can be expected from the proposal of the Commission of the European Community (1992). It suggests imposing a carbon tax which starts at US$3 per barrel of oil (about US$27 per ton of carbon) and increases by US$1 (US$9) per year up to US$10 per barrel of oil (about US$90 per ton of carbon).

the national incomes of many developing countries, we should also be aware of the impact that environmental programs can have on the international distribution of wealth.

Acknowledgements

Helpful comments by David Bradford, Kai Konrad, Karl-Gustaf Löfgren and two anonymous referees are gratefully acknowledged. The usual disclaimer applies.

References

Bach, S. et al., 1995. Wirtschaftliche Auswirkungen einer ökologischen Steuerreform, Deutsches Institut für Wirtschaftsforschung Sonderheft 153, Duncker and Humblot, Berlin.

Bergstrom, T.C., 1982. On capturing oil rents with a national excise tax. American Economic Review 72, 194–201.

Commission of the European Community, 1992. The Climate Challenge: Economic Aspects of the Community's Strategy for Limiting CO_2 Emissions. European Economy 51.

Dasgupta, P.S., Heal, G.M., 1970. Economic Theory and Exhaustible Resources. Cambridge Univ. Press, Cambridge.

Farzin, Y.H., 1996. Optimal pricing of environmental and natural resource use with stock externalities. Journal of Public Economics 62, 31–57.

Hoel, M., 1992. Carbon taxes. An international tax or harmonized domestic taxes. European Economic Review 36, 400–406.

Hoeller, P., Coppel, J., 1992. Carbon taxes and current energy policies in OECD countries. OECD Economic Studies 19, 167–193.

International Energy Agency, 1995. Energy Policies of IEA Countries: 1994 Review, OECD, Paris.

Karp, L., Newbery, D.M., 1991a. Optimal tariffs on exhaustible resources. Journal of International Economics 30, 285–299.

Karp, L., Newbery, D.M., 1991b. OPEC and the U.S. oil import tariff. Economic Journal 101, 303–313.

Kemp, M.C., Long, N.V., 1980. Optimal Tariffs on Exhaustible Resources. In: Kemp, M.C., Long, N.V. (Eds.), Exhaustible Resources, Optimality, and Trade, North Holland, Amsterdam, pp. 187–195.

Kolstad, C.D., Krautkraemer, J.A., 1993. Natural Resource Use and the Environment. In: Kneeese, A.V., Sweeney, J.L. (Eds.), Handbook of Natural Resource and Energy Economics, Vol. III. Elsevier, Amsterdam, pp. 1219–165.

Konrad, K.A., Olsen, T.E., Schöb, R., 1994. Resource extraction and the threat of possible expropriation: the role of Swiss bank accounts. Journal of Environmental Economics and Management 26, 146–162.

Long, N.V., 1975. Resource extraction under uncertainty about possible nationalization. Journal of Economic Theory 10, 42–53.

Newbery, D., 1976. A Paradox in Tax Theory: Optimal Tariffs on Exhaustible Resources. SEER Technical Paper, Stanford Univ., mimeo.

Van der Ploeg, F., Withagen, C., 1991. Pollution control and the Ramsey problem. Environmental and Resource Economics 1, 215–236.

Sinn, H.W., 1982. Taxation, growth, and resource extraction. A general equilibrium approach. European Economic Review 19, 357–386.
Solow, R.M., 1974. Intergenerational equity and exhaustible resources. Review of Economic Studies 41, 29–45.
Stiglitz, J.E., 1974. Growths with exhaustible natural resources: Efficient and optimal growth paths. Review of Economic Studies 41, 123–127.
Ulph, A., Ulph, D., 1994. The optimal time path of a carbon tax. Oxford Economic Papers 46, 857–868.
Wirl, F., 1994. Pigouvian taxation of energy for flow and stock externalities and strategic, noncompetitive energy pricing. Journal of Environmental Economics and Management 26, 1–18.