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International Redistribution of Resource Rents: An alternative perspective on the Kyoto process

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Abstract

The purpose of this paper is to elucidate the resource rent distribution aspect of the Kyoto process. The paper focuses on the "battle for resource rents" with oil consuming countries on one side and oil producing countries on the other. Our analysis is carried out within the framework of a theoretical model of resource extraction over time. In particular, it is shown how CO2 emission caps may be used by the oil consuming countries, acting under the realm of the Kyoto process, to maximize the rent acquisition from oil producing countries and how the oil producing countries may constrain this possibility by exercising market power. The paper also compiles data and numerical results regarding the order of magnitudes of resource rents redistribution.

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1. Introduction[3]

In a single country perspective a tax on CO_2-emissions has two effects. The first is to raise the consumer price of imported fossil fuels and thus induce firms and households to reduce the emissions of CO_2. The second is to bring revenues to the public sector. A system of tradable emission permits will have similar effects, although the extent of income redistribution between the private and public sectors depends on the initial distribution of emission permits. However, unless the country in question is a major importer of fossil fuels the world market price of these fuels will not be affected by the national climate policies.

In contrast internationally coordinated CO_2-taxation, or CO_2-emissions trading, may affect the producer price of fossil fuels. In effect this means that resource importing countries may capture resource rents by implementing policies that constrain CO_2-emissions. The signatories of the Kyoto agreement, which came into effect in February 2005, can be seen as a "club" whose members have agreed to coordinate their efforts to reduce CO_2 emissions. Needless to say concern for the global climate is the prime motivation for forming the "club". Yet the club may also function as an instrument for international redistribution of resource rents to the benefit of the consuming countries. At the same time a cartel on the producer side remains a powerful instrument for redistribution in the opposite direction.

The purpose of this paper is to elucidate the resource rent redistribution aspect of the Kyoto process. Our analysis is carried out within the framework of a theoretical model of resource extraction over time. Thus we focus on the "battle for resource rents" within a partial equilibrium framework, thus neglecting the macroeconomic [4] and general equilibrium effects of climate policies. As the vast literature on general equilibrium

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[4] There is a possibility that tax induced increases of the consumer price on an energy resource such as crude oil triggers a lasting recession like the one that took place after the first oil crises of 1973/74. The effect of this would be reduced oil demand in the recession period and thus reduced level of total oil wealth.

effects of climate policies[5] shows these effects may be significant and therefore likely to affect the design of national climate policies. We also neglect public reactions against increasing fossil fuel taxes. The events in 2000, when several European countries experienced upheavals over soaring fuel prices in general and fossil fuel taxes in particular, show that fossil fuel taxation in reality may be subject to severe political constraints. However, neither general equilibrium effects nor political constraints on the use of policy instruments would change the main conclusions of our analysis.

Before discussing the details of our modelling approach a brief background is needed. Models of resource extraction over time have been extensively used for analyses of the impact of taxation on resource extraction and prices over time. One key finding in this literature is that a constant *ad valorem* tax on a competitively supplied resource, that is available in a fixed amount and costless to extract, will fall entirely on the supplier.

This result, which is due to Bergstrom (1982), holds both under perfect competition and monopoly. It is valid in a closed economy, as well as in a setting of an internationally traded resource with competitive suppliers and non-cooperative consuming countries applying constant *ad valorem* taxes. In fact, as noted by Bergstrom (1982) and Maskin and Newbery (1990) this result carries through even for models characterised by constant unit extraction cost. However, in models where marginal cost is an increasing function of extraction (Karp, 1984)[6] the rent acquisition by consuming parties is not total but may still be sizeable.

In the Bergstrom model the tax does not distort the allocation of resources in the economy. Hence, an *ad valorem* tax or a profit tax on oil production will simply lead to a

[5] See the Special Issue of *The Energy Journal* (1999).

[6] However, several papers (e.g. Newbery, 1976; Maskin and Newbery, 1991, Karp and Newbery, 1991 (a,b), 1992) point to the problem of dynamic inconsistencies that may arise in these kinds of "open loop" models (i.e. models where plans are determined at the initial date and that depend on initial conditions and calendar time only). Problems like this may seriously restrict the relevance of "open loop" models in a real world setting, in particular if dominant players are involved. Karp and Newbery (1991) show, however, that an "open loop" Nash equilibrium with competitive or oligopolistic suppliers and competitive or oligopsonistic consumers all are dynamically consistent in a tariff setting game. The model to be presented in section 2 is of this kind.

lower producer price, and thus redistribution of the resource rent, while leaving the consumer price unaffected. From the point of view of the Kyoto process this means that internationally coordinated CO_2-taxation is extremely powerful with respect to capturing resource rents, but completely powerless with respect to curbing the CO_2-emissions.

However, an environmental tax generally is not an *ad valorem* or a profit tax but rather an excise tax. It is an established result in the literature (e.g. Dasgupta and Heal, 1979; Conrad and Hool, 1981) that an excise tax distorts the time profiles for price and extraction of an exhaustible resource. More precisely an excise tax leads - on the one hand - to higher current prices and reduced current consumption of the resource and - on the other hand - to reduced future prices and increased future consumption[7]. With CO_2-emissions being proportional to fossil fuel consumption this means that current CO_2-emissions will be reduced, while future CO_2-emissions will be increased[8].

Hence, according to theory increasing excise taxes on fossil fuels should result in some increase of consumer prices and an increasing gap between consumer and producer prices. Empirical observations on prices and taxes on oil products seem to confirm the development suggested by the theoretical results. For example, in the G7 countries, tax rates on gasoline have increased substantially over time[9]. Although these taxes were not primarily introduced to internalise national or global externalities, their effects are similar to those of environmental taxes. For the European members of G7 the consumer prices have shown an increasing trend, while the producer price has shown a decreasing trend in

[7] The effect of an excise or severance tax on the extraction profile of a depletable resource depends, however, also on the quality composition and the heterogeneity of the resource in question (See, Krautkraemer, 1988 and Deacon, 1993).

[8] Even though an environmental tax may succeed in shifting CO_2-emission away from the present to the future, the tax levied may have to be rather sizeable in order to be potent. The reason for this is that rent acquisition will still be a feature with an excise tax. Hence, by levying environmental taxes, the consumer countries extract resource rent from the producer countries, which in its turn generates an increase of demand for the resource in the consumer countries (Farzin, 1996, Amundsen and Schöb, 1999). The tax must be sufficient to take account of this rebound effect on demand and yet being able to tilt the extraction profile of the resource in the preferable direction.

[9] In 1980 the percentage of taxes in gasoline prices of the European members of the G7 countries was in the range of 45 - 60%. In 2004 this percentage had increased to 65 - 75%. Compared to this, the percentage of taxes in gasoline prices in the USA was about 12% in 1980, where as it increased to 23% in 2004. During the latter part of the 80'ies and the whole 90'ies the percentage of taxes in gasoline prices were, however considerable higher than what they were in 2004 (see IEA: Energy Prices and Taxes, various issues, OECD, Paris).

this period. The much lesser use of the tax instrument in North America (notably by the USA) has resulted in much more stable relationship between consumer and producer prices[10].

However, the Kyoto process is about internationally coordinated CO_2 emission caps in conjunction with emission trading rather than excise taxes. But emission permit prices in effect are excise taxes. The main difference is that an excise tax is determined in a political/administrative process, while an emission permit price is determined by the cap on total emissions in conjunction with a regular market process[11]. The question then is how and to what extent CO_2 emission caps in the "Kyoto countries" may affect the international distribution of resource rents.

Our model is focused on the division of resource rent between producer and consumer countries. There are two policy instruments in the model: A CO_2 emission constraint in the consuming countries, and the degree of cartelization in the producing countries. The CO_2 emission constraint is the instrument by which the consuming countries can affect the division of resource rent to their own benefit. From the point of view of the producing countries the price of emission permits is an excise tax on the resource imposed by the consuming countries. The degree of cartelization is the instrument by which the producing countries can affect resource rent division to their favour.

As already noted a number of papers have addressed the question as to how the consuming countries may capture resource rents by imposing taxes or import tariffs. The literature is somewhat more limited when it comes to studying the double objective of capturing resource rents and internalising external effects (see e.g Farzin, (1996) and Amundsen and Schöb, (1999)) and even more so when it comes to studying the role of market structure in this setting.

[10] See IEA: Energy Prices and Taxes, various issues, OECD, Paris.

[11] Yet another difference, is that the revenue from selling emission permits goes to those parties that have initially been endowed with permits by the government (e.g. by "grandfathering" of free permits), whereas the revenue from an excise tax goes directly to the government. Hence, the government possesses in this respect the power to redistribute the resource rent onto specific productive industries and groupings in the economy (e.g. the energy intensive industry).

A notable exception is Wirl (1994) who studies the importance of market structure in a rent game with Pigovian taxes to internalise flow and stock externalities. Compared with Wirl (1994), however, we concentrate on announced levels of emission constraints (and not on Pigovian taxes as such) and seek to arrive at analytic expressions for the division of resource rent between the parties involved. These allow us more explicitly to study how and to what extent resource rent may be captured, and how important market structure is in this respect. We follow Wirl in restricting the analysis to study how variation of environmental measures affect pricing under given markets structures and do not investigate strategic Stackelberg outcomes.

2. Optimal pricing and extraction under perfect competition

We consider the global economy and divide the countries into resource producing countries and resource consuming countries. Furthermore, we assume there is a one to one correspondence between resource consumption and emission of CO_2. Hence, constraining CO_2-emission implies constraining resource consumption. As the objective of the paper is to illustrate principles and derive basic results, we set out to formulate optimal extraction models (competitive and monopolistic) of the simplest kind assuming a time invariant demand function and no extraction costs.

2.1. Model

We apply the following notation

p_t : Price of the resource at date t

x_t : Extraction of the resource at date t

S_t : Remaining reserves of the resource at date t

δ : Discount rate

$p = p(x)$: Demand for the resource, with $\frac{\partial p(x)}{\partial x} < 0$

$\bar{p}$: Choke off price for the resource, i.e. $\bar{p} = p(0)$

$\hat{x}$: Consumption cap of the resource due to CO_2-emission constraints

At first we seek an equilibrium price path compatible with the actions of profit maximising competitive producers and competitive consumers jointly complying with a given CO_2-emission cap, $\hat{x}$. The equilibrium price path may be found by considering the following optimisation problem

$$Max \int_0^{T^C} p_t^C x_t^C e^{-\delta t} dt$$

subject to

$$x_t^C = -\dot{S}_t^C, \quad S_0 = \overline{S}, \quad S_{T^C} \geq 0, \quad x_t^C \geq 0, \quad x_t^C \leq \hat{x}, \quad p_t^C \leq \overline{p}$$

Denoting the co-state variable and the Lagrangian multiplier by λ_t^C and μ_t^C, respectively, the Hamiltonian function corresponding to this problem reads

$$H_t^C = p_t^C x_t^C e^{-\delta t} - \lambda_t^C x_t^C - \mu_t^C \left(x_t^C - \hat{x} \right)$$

Necessary conditions for a maximum are

1) $\dfrac{\partial H_t^C}{\partial x_t^C} = p_t^C e^{-\delta t} - \lambda_t^C - \mu_t^C \leq 0$

2) $-\dfrac{\partial H_t^C}{\partial S_t^C} = \dot{\lambda}_t^C$

3) $\dfrac{\partial H_t^C}{\partial \mu_t} = x_t^C - \hat{x} \leq 0$

4) $\dfrac{\partial H_t^C}{\partial \mu_t} \mu_t = \mu_t^C (x_t^C - \hat{x}) = 0$

5) $H_{T^C}^C = p_{T^C}^C x_{T^C}^C e^{-\delta T} - \lambda_{T^C}^C x_{T^C}^C - \mu_{T^C}^C \left(x_{T^C}^C - \hat{x} \right)$

6) $\lambda_{T^C}^C \geq 0$

These conditions imply that the optimal extraction path is to keep $x_t^C = \hat{x}$ in the interval $t \in \left[0, \theta^C\right]$ i.e. from date 0 until date, $\theta^C(\hat{x})$ at which date the constraint cease to be binding. Clearly, θ^C is a function of $\hat{x}$. After this date extraction proceeds according to the standard Hotelling rule for competitive producers given the remaining stock of the resource available at date θ i.e. S_θ^C. The price path is so determined that it hits the choke off price at the date T^C at which the stock is depleted.

2.2. Optimal tax

The next step is to determine the optimal excise tax, i.e. the price of emission permits that would induce the producing countries to comply with the emission constraint set by the consuming countries. The optimal tax in this sense is simply given by

$$7) \quad \tau_t^C = \mu_t^C e^{\delta t}$$

To verify this we consider the optimisation problem faced by the competitive producers under the tax proposed in 7). Hence, we have the following problem

$$Max \int_0^{T^C} (p_t^C - \tau_t^C) x_t^C e^{-\delta t} dt$$

subject to

$$x_t^C = -\dot{S}_t^C, \quad S_0 = \overline{S}, \quad S_{T^C} \geq 0, \quad x_t^C \geq 0, \quad p_t^C \leq \overline{p}$$

In solving this problem we arrive at the following condition for the net producer price

$$8) \quad (p_t^C - \tau_t^C) e^{-\delta t} = p_0^C - \tau_0^C = \overline{p} e^{-\delta T^C} \qquad for\ t \in (0, T^C)$$

Hence, the net present value of marginal profit is constant and the Hotelling rule is satisfied for the whole extraction period. This implies that consumption and extraction comply with the emission constraint and thus that the price and tax paths are equilibrium paths.

The optimal tax at a given date t may then be expressed as

$$9)\quad \tau_t^C = \hat{p}\left[1 - e^{-\delta(\theta^C - t)}\right] \quad for\ t \in (0, \theta^C)$$

Here $\hat{p} = p(\hat{x})$ and we have used the fact that $\mu_t^C = 0 \quad for\ t \in \left[\theta^C, T^C\right]$. Hence, according to the above condition the tax should decline (exponentially) over time until the consumption constraint cease to be binding at date θ^C where it becomes equal to zero.

3. Acquisition of resource rent under perfect competition

By constraining emissions, and thus resource consumption, the consuming countries manage to capture a part of the resource rent from the producing countries[12]. The size of these rent elements (rent captured by the consuming countries and rent remaining with the resource producing countries) differ according to the size of the consumption constraint and market form.

3.1. Rent partition

Resource rent remaining with the competitive producers (pc) is equal to

$$10)\quad \Pi_{pc}^C = \left[\hat{p} - \tau_0^C\right]\overline{S}$$

Resource rent captured by the resource consuming (cc) countries is equal to

$$11)\quad \Pi_{cc}^C = \hat{p}\hat{x}\left[\frac{1 - e^{-\delta\theta^C}}{\delta} - \theta^C e^{-\delta\theta^C}\right]$$

Hence, total resource rent may be written

[12] It should be noted that the surplus captured by the resource consuming countries also contains consumer surplus captured from its own consumers in addition to pure resource rent captured from the resource producing countries.

$$12)\quad \Pi^C = \Pi^C_{pc} + \Pi^C_{cc} = \hat{p}\hat{x}\left[\frac{1-e^{-\delta\theta^C}}{\delta} - \theta^C e^{-\delta\theta^C}\right] + \left[\hat{p} - \tau^C_0\right]\overline{S} = \hat{p}\hat{x}\left[\frac{1-e^{-\delta\theta^C}}{\delta}\right] + \hat{p}S_{\theta^C} e^{-\delta\theta^C}$$

The size of this expression changes as $\hat{x}$ changes. If $\hat{x} \geq x_0^{C*}$ where x_0^{C*} is equal to the optimal unconstrained extraction at date 0, then the total rent $\Pi^C = p(x_0^{C*})\overline{S}$ (i.e. $\tau_t^C = 0$) and if $\hat{x} = 0$ then $\Pi^C = 0$. For the competitive case there may exist values of $\hat{x}$, $0 < \hat{x} < x_o^{C*}$ that actually imply larger values of total rent than the total rent under the optimal unconstrained extraction ($p(x_0^{C*})\overline{S}$). The reason for this is that the emission constraint stretches the optimal extraction path so that it comes closer to the optimal unconstrained monopoly extraction path that implies maximum resource rent. The level of the emission constraint maximising total rent, $\hat{x}^{C*}$, must satisfy the following necessary first order condition

$$13)\quad \frac{\partial \Pi^C}{\partial \hat{x}} = \frac{\partial \Pi^C_{cc}}{\partial \hat{x}} + \frac{\partial \Pi^C_{pc}}{\partial \hat{x}} = \left[1 + \frac{1}{\hat{\varepsilon}}\right]\frac{\Pi^C_{cc}}{\hat{x}} + \delta\hat{p}\hat{x}\theta^C e^{-\delta\theta^C}\frac{\partial \theta^C}{\partial \hat{x}} - \delta\Pi^C_{cp}\frac{dT^C}{d\hat{x}} \quad = 0$$

In evaluating this expression one should observe that $(\partial\theta^C / \partial\hat{x}) < 0$ and $(\partial T^C / \partial\hat{x}) < 0$. The first element on the right hand side (RHS) of 13) is indeterminate and depends on the size of the price elasticity (see below). The second element is negative and the third element is positive. Hence, in general, it is not possible to decide whether there exists a value of the emission constraint, $\hat{x}^{C*}$ ($0 < \hat{x}^{C*} < x_0^{C*}$) that maximises total resource rent under perfect competition. However, with the variable elastic demand function applied in the Appendix, such a value exists. This is illustrated in Fig. 2. using specific parameter values.

3.2. Maximising rent take

Assuming that the resource consuming countries are only interested in internalising the external environmental effect from CO_2-emission, the choice of $\hat{x}$ will be independent of the size of the resource rent that the resource using countries capture. However, the resource consuming countries may have a further objective of maximising the rent take from the resource producing countries using CO_2-abatement as a rationale. Hence, we are looking for a value $\hat{x}_{cc}^{C*}$ that maximises Π_{cc}^{C}. In the competitive case the first order condition for such a maximum is equal to

$$14)\quad \frac{\partial \Pi_{cc}^{C}}{\partial \hat{x}} = \left[1 + \frac{1}{\hat{\varepsilon}}\right]\frac{\Pi_{cc}^{C}}{\hat{x}} + \delta \hat{p}\hat{x}\theta^{C} e^{-\delta\theta^{C}} \frac{\partial \theta^{C}}{\partial \hat{x}} = 0$$

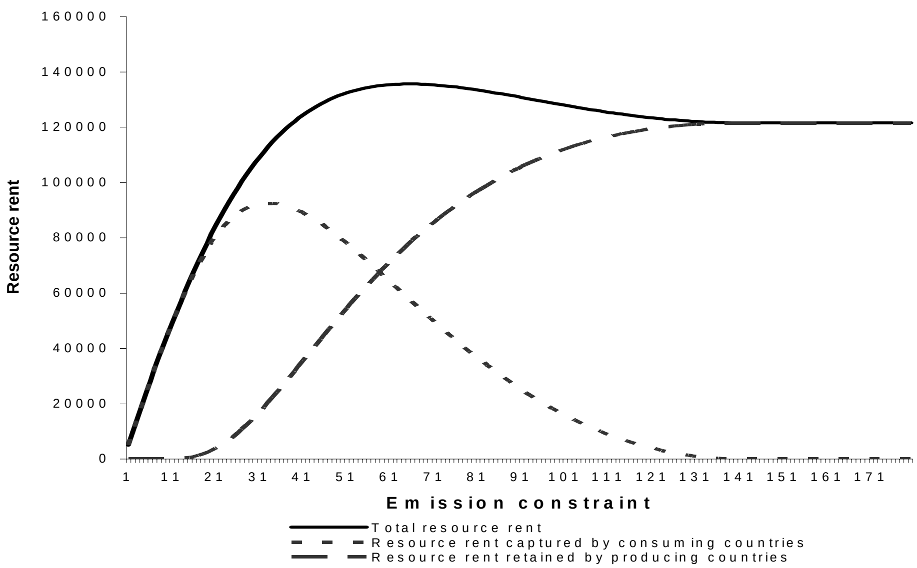
Hence, the RHS of 14) is seen to contain the two first elements of the RHS of 13). As already observed, the sign of the first element on the right hand side is indeterminate while the second is negative. The sign of the first element is determined by the price elasticity. If demand is price inelastic (i.e. $-1 < \hat{\varepsilon} < 0$), the first element is also negative and a marginally harsher emission constraint will lead to an increased acquisition of resource rent on the part of the consuming countries. However, in order for 14) to be satisfied, the demand at the optimum value, $\hat{x}_{cc}^{C*}$, must be elastic (i.e. $\hat{\varepsilon} < -1$). Hence a necessary condition for the existence of such a value is that the demand function can attain values for which it is elastic. Broad classes of demand functions satisfy this requirement, including linear demand functions and functions of the form considered in the Appendix.

Comparing 14) to 13) it turns out that the level of emission constraint maximising tax take by the consuming countries is less than the emission constraint that maximises total resource rent, i.e. $\hat{x}_{cc}^{C*} < \hat{x}^{C*}$. This can be seen by evaluating 13) at $\hat{x}_{cc}^{C*}$

$$15)\quad \frac{\partial \Pi^{C}(\hat{x}_{cc}^{C*})}{\partial \hat{x}} = \frac{\partial \Pi_{cc}^{C}(\hat{x}_{cc}^{C*})}{\partial \hat{x}} + \frac{\partial \Pi_{cp}^{C}(\hat{x}_{cc}^{C*})}{\partial \hat{x}} = 0 - \delta \Pi_{p}^{C} \frac{dT^{C}(\hat{x}_{cc}^{C*})}{d\hat{x}} \quad > 0$$

Hence, total rent, Π^{C}, will increase by a marginal relaxation of the constraint (i.e. a marginal increase of $\hat{x}$ above $\hat{x}_{cc}^{C*}$). For an illustration see Fig. 1 which has been generated by means of the numerical model described in the Appendix.

Fig.1. Resource rent as a function of emission constrained extraction



4. Recapturing resource rent by the use of market power

Confronted with consuming countries that maximise rent take using environmental taxes, the producing countries may enter into collusion (or strengthen an already existing cartel) in order to recapture some of the rent. At one extreme the producers may form a monopoly and even though the producers will still be subjected to taxation the producers may limit the rent acquisition of the consuming countries.

4.1. Model

In this section we seek an equilibrium price path compatible with the actions of a profit maximising monopolist and competitive consumers jointly complying with a given CO_2-emission cap, $\hat{x}$. This may be found by considering the following optimisation problem

$$Max \int_0^{T^M} p(x_t^M) x_t^M e^{-\delta t} dt$$

subject to

$$x_t^M = -\dot{S}_t^M, \quad S_0 = \overline{S}, \quad S_{T^M} \geq 0, \quad x_t^M \geq 0, \quad x_t^M \leq \hat{x}, \quad p_t^M \leq \overline{p}$$

Denoting the co-state variable and the Lagrangian multiplier by λ_t^M and μ_t^M, respectively, the Hamiltonian function corresponding to this problem reads

$$H_t^M = p(x_t^M) x_t^M e^{-\delta t} - \lambda_t^M x_t^M - \mu_t^M \left(x_t^M - \hat{x}\right)$$

Necessary conditions for a maximum are

16) $$\frac{\partial H_t^M}{\partial x_t^M} = p_t^M \left[1 + \frac{1}{\varepsilon_t^M}\right] e^{-\partial t} - \lambda_t^M - \mu_t^M \leq 0$$

17) $$-\frac{\partial H_t^M}{\partial S_{ty}^M} = \dot{\lambda}_t^M$$

18) $$\frac{\partial H_t^M}{\partial \gamma_t} = x_t^M - \hat{x} \leq 0$$

19) $$\frac{\partial H_t^M}{\partial \mu_t^M} \mu_t^M = \mu_t^M (x_t^M - \hat{x}) = 0$$

20) $$H_{T^M}^M = p(x_{T^M}^M) x_{T_M}^M e^{-\delta T} - \lambda_{T^M}^M x_{T^M}^M - \mu_{T^M}^M \left(x_{T^M}^M - \hat{x}\right)$$

21) $$\lambda_{T^M}^M \geq 0$$

As for the competitive solution we observe that the optimal extraction path is to keep $x_t^M = \hat{x}$ in the interval $t \in \left[0, \theta^M\right]$ i.e. from date 0 until date $\theta^M(\hat{x})$ at which date the constraint cease to be binding. Date θ^M is a function of $\hat{x}$. After this date extraction proceeds according to the standard Hotelling rule for a monopoly, given the remaining stock of the resource available at date θ^M i.e. $S^M_{\theta^M}$. The price path is so determined that it hits the choke off price at the date T^M at which date the stock is depleted.

It should be noted that $S^C_{\theta^C} < S^M_{\theta^M}$ and consequently that $\theta^C(\hat{x}) > \theta^M(\hat{x})$ and that $T^C < T^M$. The reason for this is that the price path under monopoly evolves at a slower rate than the competitive price path (except for the special case of a constant elastic demand function at which the price paths are identical, see Stiglitz, 1976). The only constellation compatible with the Hotelling rules for the two market forms and the total resource constraint, $\bar{S}$ (assumed to be identical for the two cases) is that the monopoly price path starts to rise above $\hat{p}$ at an earlier date than the competitive price path starts to rise. At some later date the monopoly price path crosses the rising competitive price path and hits the choke off price at a later date than the competitive price path hits the choke off price.

4.2. Optimal tax

The next step is to determine the optimal tax (i.e. the permit prices) that would induce the producing countries to comply with the emission constraint set by the consuming countries. The optimal tax in this sense is given by

$$22) \quad \tau_t^M = \mu_t^M e^{\delta t}$$

To verify this we consider the optimisation problem faced by the competitive producers under the tax proposed in 7). Hence, we have the following problem

$$Max \int_0^{T^M} (p_t^M - \tau_t^M) x_t^M e^{-\delta t} dt$$

subject to

$$x_t^M = -\dot{S}_t^M, \quad S_0 = \overline{S}, \quad S_{T^M} \geq 0, \quad x_t^M \geq 0, \quad p_t^M \leq \overline{p}$$

Solving this problem we arrive at

$$23) \quad \left[p_t^M (1+\frac{1}{\varepsilon_t^M}) - \tau_t^M \right] e^{-\delta t} = p_0 (1+\frac{1}{\varepsilon_0^M}) - \tau_t^M = \overline{p} e^{-\delta T^M} \qquad \mathit{for}\ t \in (0, T^M)$$

Hence, the net present value of marginal profit is constant and the Hotelling rule for monopoly is obeyed for the whole extraction period. The price and tax paths are thus equilibrium paths.

The optimal tax path may then be expressed as

$$24) \quad \tau_t^M = \hat{p}(1+\frac{1}{\hat{\varepsilon}})\left[1 - e^{-\delta(\theta^M - t)}\right] \quad \mathit{for}\ t \in (0, \theta^M)$$

Here $\hat{p} = p(\hat{x})$ and we have used the fact that $\mu_t^M = 0 \quad \mathit{for}\ t \in \left[\theta^M, T^M\right]$. Provided that demand is elastic at the extraction level corresponding to the emission constraint, the tax should decline (exponentially) over time until the consumption constraint cease to be binding at θ^M . If demand is inelastic at this level 24) implies paying a subsidy in order to have the monopolist complying with the constraint. It should be noted, however, that without the constraint (i.e. free adaptation) the monopolist will set an initial extraction level, x_0^{M*}, for which demand is elastic, i.e. $\varepsilon(x_0^{M*}) < -1$[13]. Assuming that the elasticity is a non-decreasing function of consumption, (i.e. $(d\,\varepsilon/dx) > 0$, as is the case for linear demand functions and for the function considered in the Appendix), demand will remain elastic when imposing a binding constraint of emission. Hence, for broad classes of demand functions, consuming countries will be able to extract resource rent from the producers even under monopoly.

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[13] If demand is inelastic at all consumption levels (e.g. constant elastic), the monopolist will apply limit pricing i.e. set a price marginally below the choke off price.

4.3. Rent partition

Under monopoly the resource rent remaining with the monopolistic producer (pc) is equal to

$$25)\quad \Pi_{pc}^{M} = \hat{p}\hat{x}\left[\frac{1-e^{-\delta\theta^{M}}}{\delta}\right] - \hat{p}\hat{x}\left[1+\frac{1}{\hat{\varepsilon}}\right]\left[\frac{1-e^{-\delta\theta^{M}}}{\delta} - \theta^{M} e^{-\delta\theta^{M}}\right] + \int_{\theta^{M}}^{T^{M}} p_t^{M} x_t^{M} e^{-\delta t} dt$$

Resource rent captured by the resource consuming countries (cc) is equal to

$$26)\quad \Pi_{cc}^{M} = \hat{p}\hat{x}\left[1+\frac{1}{\hat{\varepsilon}}\right]\left[\frac{1-e^{-\delta\theta^{M}}}{\delta} - \theta^{M} e^{-\delta\theta^{M}}\right]$$

Hence, total resource rent may be written

$$27)\quad \Pi^{M} = \Pi_{pc}^{M} + \Pi_{cc}^{M} = \hat{p}\hat{x}\left[\frac{1-e^{-\delta\theta^{M}}}{\delta}\right] + \int_{\theta^{M}}^{T^{M}} p_t^{M} x_t^{M} e^{-\delta t} dt$$

The size of this expression changes as $\hat{x}$ changes. If $\hat{x} \geq x_0^{M*}$ where x_0^{M*} is equal to the optimal unconstrained extraction at date 0, then the total rent $\Pi^{M} = \int_{0}^{T^{M}} p_t^{M} x_t^{M} e^{-\delta t} dt$ (i.e. $\tau_t^{M} = 0$) and if, $\hat{x} = 0$, then $\Pi^{M} = 0$. Under monopoly the largest value of total resource rent is attained for $\hat{x} \geq x_0^{M}*$ i.e. the unconstrained case. The reason for this is that the monopolist maximises resource rent wherefore an additional binding extraction constraint, $\hat{x}$, must lead to reduced resource rent. Hence, this result deviates from the competitive case. In general, a relaxation of the constraint will lead to an increase of total rent, i.e.

$$28)\quad \frac{\partial \Pi^{M}}{\partial \hat{x}} = \frac{\partial \Pi^{M}_{pc}}{\partial \hat{x}} + \frac{\partial \Pi^{M}_{cc}}{\partial \hat{x}} = \hat{p}\left[1+\frac{1}{\hat{\varepsilon}}\right]\left[\frac{1-e^{-\delta\theta^{M}}}{\delta}\right] - \delta\hat{p}\hat{x}e^{-\delta\theta^{M}}\ \frac{\partial \theta^{M}}{\partial \hat{x}} + \frac{\partial M^{M}_{\theta^{M}}(\hat{x})}{\partial \hat{x}} > 0$$

where

$$M^{M}_{t} = \int_{\theta^{M}}^{T^{M}} p^{M}_{t}\, x^{M}_{t}\, e^{-\delta t}\, dt$$

Assuming elastic demand at $\hat{x}$, inspection of signs shows that the above derivative is strictly positive for binding values of $\hat{x}$. Hence, a relaxation of the constraint $\hat{x}$ is definitely leading to an increase of total resource rent. To see this, observe that the first expression on the right hand side is positive under the assumption of elastic demand at $\hat{x}$. Furthermore, the second expression on the right hand side of the equality sign is also positive as $(\partial \theta^{M} / \partial \hat{x}) < 0$ and so is the third expression as $\left(\partial S^{M}_{\theta^{M}} / \partial \hat{x}\right) > 0$. An illustration is given in Fig.2.

4.4. Maximising rent take

However, as under perfect competition the resource consuming countries may have an additional objective of maximising the rent take from the resource producing countries under the cover of limiting emission from resource consumption. The value of $\hat{x}$ that maximises rent take under monopoly may differ from the value that maximises rent take under perfect competition. Under monopoly, the value of $\hat{x}$ that maximises Π^{M}_{cc} is determined by the following condition

$$29)\quad \frac{\partial \Pi^{M}_{cc}}{\partial \hat{x}} = \left[1+\frac{1}{\hat{\varepsilon}}\right]\left[\frac{\Pi^{M}_{cc}}{\hat{x}} + \delta\hat{p}\hat{x}\theta^{M} e^{-\delta\theta^{M}}\ \frac{d\theta^{M}}{d\hat{x}}\right] + \frac{d\left[1+\frac{1}{\hat{\varepsilon}}\right]}{d\hat{x}}\ \hat{p}\hat{x}\left[\frac{1-e^{\delta\theta_{M}}}{\delta} - \theta^{M} e^{-\delta\theta^{M}}\right] = 0$$

The first expression to the RHS of the equality sign of 29) is positive and the second is negative (provided that price elasticity is a non-decreasing function of consumption).

Comparing the size of the resource rent captured by the consuming countries under perfect competition and under monopoly for the same level of $\hat{x}$, it is clear that the former is larger than the latter[14], i.e.

$$30)\quad \Pi_{cc}^{C} = \hat{p}\hat{x}\left[\frac{1-e^{-\delta\theta^{C}}}{\delta} - \theta^{C}e^{-\delta\theta^{C}}\right] > \quad \Pi_{cc}^{M} = \hat{p}\hat{x}\left[1+\frac{1}{\hat{\varepsilon}}\right]\left[\frac{1-e^{-\delta\theta^{M}}}{\delta} - \theta^{M}e^{-\delta\theta^{M}}\right]$$

This follows from the fact that $\hat{\varepsilon} < -1$ and that $\theta^{C} > \theta^{M}$ implying that $\theta^{C}e^{-\delta\theta^{C}} < \theta^{M}e^{-\delta\theta^{M}}$ (provided that $\delta\theta > 1$). This relationship also implies that the consuming countries capture a larger maximal resource rent under perfect competition than under monopoly. To realise this observe that

$$31)\quad \Pi_{cc}^{C}(\hat{x}^{C*}) \geq \Pi_{cc}^{C}(\hat{x}^{M*}) > \Pi_{cc}^{M}(\hat{x}^{M*})$$

In the same way, the resource rent retained by the producers is larger under monopoly than under perfect competition. This can be realised in the following way. We know that $\Pi^{M}(\hat{x}) > \Pi^{C}(\hat{x})$ and that $\Pi_{cc}^{C}(\hat{x}) > \Pi_{cc}^{M}(\hat{x})$. Hence,

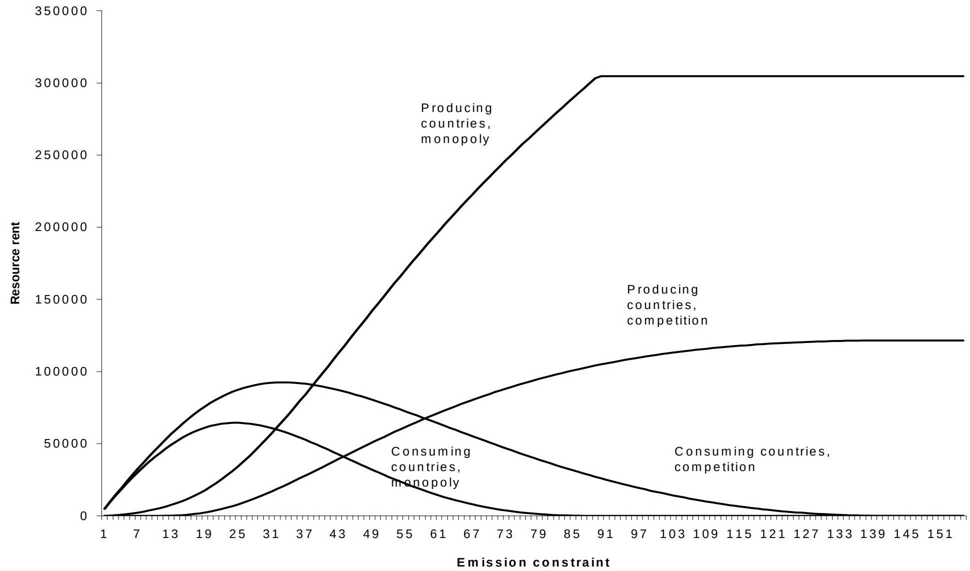
$$\Pi_{pc}^{M}(\hat{x}) = \Pi^{M}(\hat{x}) - \Pi_{cc}^{M}(\hat{x}) > \Pi^{C}(\hat{x}) - \Pi_{cc}^{C}(\hat{x}) = \Pi_{pc}^{C}(\hat{x})$$

From this we get

$$32)\quad \Pi_{pc}^{M}(\hat{x}^{M*}) \geq \Pi_{pc}^{M}(\hat{x}^{C*}) > \Pi_{pc}^{C}(\hat{x}^{C*})$$

[14] It is assumed that demand is elastic at $\hat{x}$, but not constant elastic. As noted, if demand were constant elastic, the price and extraction profiles under perfect competition and monopoly would coincide.

Fig.2. Resource rent acquisition under perfect competition and monopoly



For an illustration, see Fig. 2.

4. Robustness of the results

The conclusions derived this far are based on simplifying assumptions and the principle of Occam's razor. Thus it is assumed that demand is constant over time, and that there is no technological progress or substitution. The question then is to what extent our main results would change if these simplifying assumptions were relaxed. In this section we will briefly discuss the robustness of the results with respect to some of the factors left out of the model.

The case of demand increasing with time is not included in the numerical illustration but is, in fact, allowed by the mathematics of the model. However, this concerns a special case of demand increase where the back stop price remains constant along time while the demand schedule pivots in a north- easterly direction with the back stop price as the pivoting point. Hence, nothing essential happens to the mathematics derived when allowing for demand increase, but the illustrations would need to be adjusted accordingly.

If demand would increase over time the period of constant price (where the emission constraint is binding) would extend for a longer time and the necessary taxes to support a constant demand would be higher. This implies a larger rent take by the consuming countries. However, with increasing demand also the producing countries would increase their rent take as there is a general increase of total resource rent, attached to the demand increase. The general results on rent division, and rent maximisation will not be altered[15].

Technological progress can be seen as a general reduction of the back stop price as time passes i.e. that a perfect substitute to the resource considered becomes cheaper over time. In general such a development would, *ceteris paribus*, lead to a reduction of total resource rent since, in a sense, the resource in question becomes less scarce. The mathematics of the model would have to be changed and would become somewhat more complicated (though the Hotelling rule under competition and monopoly would still have to be satisfied in equilibrium).

However, with exogenous technological progress, the general results of the model would still be true, i.e. that consuming countries extract resource rent from the producing countries when internalising emission caps by way of taxes and that these countries can optimise on rent take by adjusting the emission caps. Also, the producing countries would still be able to constrain rent redistribution by collusion and the use of market power.

An interesting case to be considered is where technological progress is induced by the resource price itself, i.e. that a high price on the resource would induce technological progress and thus a long-term reduction of total resource rent. Such a development would not be in the interest of the producing countries and perhaps even not of the consuming countries that would otherwise stand to lose part of its rent acquisition.

[15] Referring to the case of crude oil it has been pointed out that the increasing prices are linked to restraining refinery capacity. It should be noted that increasing demand and shrinking refinery capacity give rise to increasing quasi rent on refinery capital. Hence, there are really three parties involved in splitting the resource rent: resource producers, tax authorities, and refinery owners.

The general conclusion of this brief discussion is that the assumptions about constant demand and no technological progress simplify the analysis but are not essential for the main results.

5. Orders of magnitude

Total resource rent and its annual redistribution among countries are considerable in terms of purchasing power. Hence, it would be of interest to try to assess the values involved. To our knowledge no single numerical model exists to capture all aspects of the problem considered in this paper i.e. external effects and emission targets, market forms, division of resource rent between producer and consumer countries and macro economic effects on the countries involved. However, there exist numerical models and studies that take account of some of the aspects of the problems at hand. Results from these studies may be used to give some indications as to the orders of magnitude involved.

Amundsen (1992) found that market form matters a lot when it comes to the size of the total resource rent. In a model taking account of various crude oil qualities, refinery capacity, transportation costs, distribution costs, and different levels and cost of proven and probable reserves, it was found that oil resource rent outside the former “socialist block” varied according to whether the petroleum markets were organised as a perfect competitive market, a monopoly or a (dynamically consistent) Nash-Cournot market. Under monopoly total oil wealth (net present value of future oil resource rent) amounted to 10,100 billion 1986 USD, while it was less then half of this under perfect competition (4,500 billion USD) and 8,100 billion USD under the Nash-Cournot solution. The part of oil rent captured by OPEC was highest under monopoly (92 %), intermediary under perfect competition (75 %) and lowest under the Nash-Cournot solution (58 %). These figures are based on the assumption that only the proven reserves (in 1986) were exploited. If also probable reserves were included the oil wealth under monopoly would increase by another 1,300 billion USD, while it would actually fall under perfect competition and under the Nash-Cournot solution due to the reduced scarcity of oil in that case.

The effect on oil wealth of introducing an emission permit system was investigated by Amundsen, Rasmussen and Lønning (1995) using a numerical model incorporating major regions of the world and including various traded goods and resources such as coal and oil/gas. In the model total future CO_2 emissions allowed was restricted to the 1990 emission level. Considering a system of tradable emission permits distributed in proportion to the level of CO_2 emissions for each region it was found that for five of the six regions of the world considered restrictions on CO_2 emission hardly mattered at all in terms of GNP changes (less than 1%). The sixth region and the major looser was OPEC who experienced a decrease in GNP of more than 10% as compared to the GNP level without CO_2 restrictions. With the permit system there was a general consumer price increase of oil/gas of 70% between 1990 and 2008 and a corresponding increase of 8% for the producer price of oil/gas. The effect on OPECs GNP would, however, depend on the way emission permits are distributed. For instance, OPEC would be somewhat better off if permits were distributed according to population size rather than by grandfathering.

Important insight may also be gained from a study by Berg et al. (1997) that applies a numerical model including oil, natural gas and coal. In their study they found that a 10 USD carbon tax resulted in a reduction of OPEC's oil wealth of 23 % while non-OPEC oil wealth was reduced by 8%. With a competitive organisation of the oil market OPEC's oil wealth would still be reduced by some 20% while that of Non-OPEC producers would be reduced by nearly 40 %. In assessing these figures it should, however, be noted that the problem addressed is not quite comparable to the problem considered in the present paper. Berg et al. (1997) consider the effect on oil wealth of a given CO_2-tax for various market forms. In that respect emission of CO_2 may increase over time and will not necessarily be below some given CO_2 constraint as in the present paper. Also the effect on CO_2 emission of the given tax will be different under various market forms.

Comparable results are obtained in a more recent study by Kverndokk et al. (2000) based on a modified version of the same model as used in Berg et al. (1997). In particular this model takes account of various marker baseline scenarios to represent different future worlds without greenhouse gas mitigation and investigates the effects of various caps for future CO_2 concentration in the atmosphere. Even though OPEC and other oil producers stand to loose oil revenue with the introduction of carbon taxes for all binding emission caps, a conclusion of this paper is that the oil producers will not face major reductions in their revenues as long as the concentration target is not too tight. In evaluating the results it should be noted, however, that the model uses constant CO_2 taxes for the whole period to achieve the target in 2150, that the GDP-development in the various regions are exogenously determined and that there are no macro module included. Hence, the emission paths for CO_2 as determined by the constant CO_2 taxes do not necessarily correspond to least cost emission paths.

6. Summary and concluding remarks

In February 2005 the Kyoto agreement finally came into effect. The prime motivation for this agreement is concern for the global climate and the corresponding need to reduce the emissions of greenhouse gases. However, the Kyoto agreement can also be seen in an alternative perspective. By coordinating their climate policies the oil consuming countries in effect will implement a coordinated reduction of the consumption of oil. This will have an impact on the producer price of oil and thus on the distribution of resource rents.

This paper offers a simple theoretical framework for understanding the fight over oil resource rent between the producer countries and the governments of the consumer countries using CO_2 emission caps as a means of acquiring resource rent. More precisely, it is shown that the oil consuming countries by fixing emission caps and introducing corresponding markets for emission permits, may manage to reduce the producer price of oil and at the same time acquire resource rents in terms of revenue from the emission permit system. Hence, in this sense, the emission permit price functions like an excise tax on oil.

One particular result obtained in the paper is that an emission cap with corresponding emission permit prices may, in fact, increase the total resource rent under perfect competition as compared with the total resource rent under perfect competition without the emission cap. The reason for this is that the extraction profile with the emission cap comes closer to what it would have been under monopoly, which implies the maximum size of the resource rent. The competitive producers will, however, receive a smaller and smaller resource rent the harsher are the CO_2-emission caps.

Furthermore, it is shown that the consuming countries may optimise with respect to the emission caps i.e. put the cap so as to maximise the resource rent that they capture. This may imply forcing the CO_2-emissions to a lower level than what it would have been out of pure environmental concern. Confronted with such a development the producers may unite and act collusively in order to capture more of the resource rent themselves. The producing countries may form a monopoly and thus tilt the extraction profile in the direction of reduced current extraction (which is known to be the result of collusion.) In the paper it is shown that the producers by this measure to some extent may respond to the consumer countries' wish of reducing current consumption. In this way current producer prices will increase and emission permit prices will decrease. The producer countries may, thus, avoid a massive transfer of resource rent to the consumer countries.

Appendix: An example

To illustrate the results of the model the following demand function is applied under perfect competition and under monopoly

$$p = \overline{P}e^{-\alpha x}$$

Otherwise we use the same notation as in the main text

Perfect competition

Solving the model for perfect competition we get

$$p_t^C = \begin{cases} \overline{P}e^{-\alpha\hat{x}} = \overline{P}e^{-\delta(T^C - \theta^C)} = \hat{p}, & for\ t \in (0,\theta^C) \\ \overline{P}e^{\delta(t-T^C)}, & for\ t \in (\theta^C, T^C) \end{cases}$$

$$x_t^C = \begin{cases} \hat{x} & for\ \ t \in (0,\theta^C) \\ \dfrac{\delta}{\alpha}\left[T^C - t\right], & for\ t \in (\theta^C, T^C) \end{cases}$$

$$\theta^C = \frac{\bar{S}}{\hat{x}} - \frac{\alpha\hat{x}}{2\delta},\ T^C = \frac{\bar{S}}{\hat{x}} + \frac{\alpha\hat{x}}{2\delta},\ S_{\theta^C} = \frac{\alpha\hat{x}^2}{2\delta},\ \hat{x} = \sqrt{\frac{2\delta S_{\theta^C}}{\alpha}},\ \hat{p} = \bar{P}e^{-\sqrt{2\beta\delta\bar{S}_{\theta^C}}}$$

$$\Pi_{cp}^C = \left[\hat{p} - \tau_0^C\right]\bar{S}$$

$$\Pi_{cc}^C = \hat{p}\hat{x}\left[\frac{1-e^{-\delta\theta^C}}{\delta} - \theta^C e^{-\delta\theta^C}\right]$$

$$\Pi^C = \hat{p}\hat{x}\left[\frac{1-e^{-\delta\theta^C}}{\delta}\right] + \hat{p}S_{\theta^C}e^{-\delta\theta^C}$$

Monopoly

Solving the model for monopoly we get

$$p_t^C = \begin{cases} \bar{P}e^{-\alpha\hat{x}} = \dfrac{\bar{P}e^{-\delta(T^M-\theta^M)}}{(1-\alpha\hat{x})} = \hat{p}, & for\ t \in (0, \theta^M) \\ \bar{P}e^{-\alpha x_t} = \dfrac{\bar{P}e^{-\delta(T^M-t)}}{(1-\alpha x_t)} & for\ t \in (\theta^M, T^M) \end{cases}$$

$$x_t^M \approx \begin{cases} \hat{x} & for\ \ t \in (0, \theta^M) \\ \dfrac{\delta}{h\alpha}\left[T^M - t\right], & for\ t \in (\theta^M, T^M) \end{cases}$$

$$\theta^M \approx \frac{\bar{S}}{\hat{x}} - \frac{\alpha h\hat{x}}{2\delta},\ T^M \approx \frac{\bar{S}}{\hat{x}} + \frac{\alpha h\hat{x}}{2\delta},\ S_{\theta^M} \approx \frac{\alpha h\hat{x}^2}{2\delta},\ \hat{x} \approx \sqrt{\frac{2\delta S_{\theta^M}}{h\alpha}},\ \hat{p} \approx \bar{P}e^{-\sqrt{\frac{2\beta\delta\bar{S}_{\theta^C}}{h}}}$$

$$\Pi_{cp}^M \approx \hat{p}\hat{x}\left[\frac{1-e^{-\delta\theta^M}}{\delta}\right] + \frac{\bar{P}\hat{x}e^{-\delta\left[\theta^M + \frac{T^M-\theta^M}{h}\right]}}{\delta\left[1-\frac{1}{h}\right]} - \hat{p}\hat{x}\bar{P}e^{-\alpha h\hat{x}}\left[\frac{1-e^{-\delta\theta^M}}{\delta} - \theta^C e^{-\delta\theta^M}\right]$$

$$\Pi_{cc}^M \approx \hat{p}\hat{x}\bar{P}e^{-\alpha h\hat{x}}\left[\frac{1-e^{-\delta\theta^M}}{\delta} - \theta^C e^{-\delta\theta^M}\right]$$

$$\Pi^M \approx \hat{p}\hat{x}\left[\frac{1-e^{-\delta\theta^M}}{\delta}\right] + \frac{\bar{P}\hat{x}e^{-\delta\left[\theta^M + \frac{T^M-\theta^M}{h}\right]}}{\delta\left[1-\frac{1}{h}\right]}$$

In the formulae the following approximation has been applied[16]

$$p_t + \frac{dp_t}{dx_t} x_t = \overline{P}(1 - \alpha x_t)e^{-\alpha x_t} \approx \overline{P} e^{-\alpha h x_t}$$

where $h = 2{,}5$.

For the illustrations we use the following parameters values[17]

$\overline{P} = 500,\ \alpha = 0{,}01,\ \delta = 0{,}1,\ \overline{S} = 1000$

[16] See Perman et al. (1999), p. 212
[17] In order to have a positive marginal revenue for the monopolist and thus avoid limit pricing α must be chosen sufficiently small such that $\alpha x_t < 1$.

Literature

Amundsen, E. S. (1992) *Théorie des ressources épuisables et rente pétrolière*. Paris: Economica.

Amundsen, E. S. and R. Schøb (1999) "Environmental Taxes on Exhaustible resources", *European Journal of Political Economy*, **15**, 311-329

Amundsen, E.S., D. Lønning, and H. Rasmussen (1995) "An Analysis of International CO2 Agreements", Norwegian Ministry of Foreign Affairs, Working Paper No 57/95, SNF

Berg, E, S. Kverndokk and K.E. Rosendahl (1997) "Market power, International CO2 Taxation and Petroleum Wealth", *Energy Journal* 18(4), 33 –71.

Bergstrom, T. (1982) "On capturing oil rents with a national excise tax", *American Economic Review*, **72**, 194-201.

Conrad, R.F. and B. Hool (1981) "Resource Taxation with Heterogeneous Quality and Endogenous Reserves", *Journal of Political Economy*, **16,** 17-33.

Dasgupta, P.S. and G. M. Heal (1979) *Economic Theory and Exhaustible resources*. London: Cambridge university Press.

Deacon, R.T. (1993) "Taxation, Depletion and Welfare: A Simulation Study of the U.S. Petroleum Resource", *Journal of Environmental Economics and Management*, **24**,159-87.

Farzin, Y.H. (1996) "Optimal pricing of environmental and natural resource use with stock externalities", *Journal of Public Economics*, **62**, 31-57.

IEA *“Energy Prices and Taxes, various issues”, OECD, Paris.*

Karp, L.S. (1984) “Optimality and Consistency in a Differential Game with Nonrenewable Resources”. *Journal of Economic Dynamics and Control*, **8** (1), 73-97.

Karp, L .S. and D. M. Newbery (1991) “OPEC and the U.S. Oil Import Tariff”, *The Economic Journal***,** **101**, 303-313.

Karp, L.S. and D. M. Newbery (1991) “Optimal tariffs on exhaustible resources”, *Journal of International Economics,* **30**, 285-299.

Karp, L.S. and D. M. Newbery (1992) “Dynamically consistent oil import tariffs”, *Canadian Journal of Economics***,** **25**, No1. 1-21.

Kverndokk, S., L. Lindholt and K.E. Rosendahl, “Stabilisation of CO2 concentrations: Mitigation scenarios using the Petro model”, Discussion Papers No. 267, February 2000, Statistics Norway, Research Department.

Krautkraemer, J.A. (1990) “Taxation, Ore Quality, and the Depletion of a Non-renewable Resouce”, *Journal of Environmental Economics and Management***,** **18**,120-35.

Maskin, E. And D. M. Newbery (1990) “Disadvantageous Oil Tariffs and Dynamic Consistency”, *The American Economic Review,* **80**, No 1, 143-56.

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

Perman, R. et al. (1999) “Natural Resource and Environmental Economics”, Longman, 2. Ed.

Prell, M.A. (1996), “Backstop Technology and Growth: Doomsday or Steady-State?”, *Journal of Environmental Economics and Management*, **30**(2), 252-254.

Stiglitz, J.E., “Monopoly and the rate of extraction of exhaustible resources”, *American Economic Review*, Sept., **66**, 655-661 (976).

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.

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