On the Joint Effects of Resource Taxes and Pollution Permits - Efficiency and North-South Considerations*

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Abstract

We look at the interacting effect of national resource taxes and a global permit scheme and its implications for welfare and rent distributions. Using a two country optimal growth model integrating both a non-renewable resource and pollution we characterize the optimal policies and study their implications. First, we analyze the distributional implications of different policies which crucially depend on the interaction of taxes and permits. We then look at the case where nationally different taxes on resource consumption are in place and study the optimal pollution permit system. The results suggest that a global permit trading scheme is not optimal in the presence of highly varying national resource taxes. While an international permit trading system (like the International Emissions Trading (IET) included in the Kyoto protocol) makes perfectly sense for a region with more homogenized taxes like in Europe, it leads to a distortion when it includes countries with very different resource (e.g., fuel) taxes.

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1. Introduction

The aim of this paper is to shed some light on the interaction between taxes on resource usage and permits for pollution. Since in many cases, there is a direct, linear relationship between the amount of resource consumed and the pollution from combustion, one should expect a strong relationship between the fiscal instruments like taxes on resource consumption and measures to reduce pollution (for instance, pollution permits). Moreover, since the pollution is a global problem, measures to combat e.g., climate change are frequently considered on a supranational level. The Kyoto protocol, but also the European trading System (ETS) for CO_2 permits are examples. These schemes imply that the price for pollution is equal amongst the participating countries. On the other hand, there exist wide differences in environmental policies (Ekins and Barker 2001, 349). One example are the strongly differing taxes on different fossil fuels. (see, e.g., figure 1[1]). Notably, the European Union is at least trying to reduce the wide differences, since it introduced a Directive in 2003, which aims at widening the scope of the EU's minimum taxation system from mineral oils to all energy products including coal, natural gas and electricity (European Union 2003).While taxes on fossil fuels could be regarded as simple commodity taxes, they are frequently also expected to pursue environmental goals like reducing the emissions from combustion. As such, they can be regarded as complementary to other measures to reduce emissions, like permit trading schemes or emission taxes.

This paper addresses the particular issue of environmental regulation in an international setting where two different instruments are used to combat pollution from non-renewable resources like oil or gas. It is probably most clear (and certainly most relevant) to understand it in the case of taxing fossil fuels (e.g., for power generation or transportation) and supranational CO_2 permit trading systems. We also take into account the case where permit trading schemes are implemented on the national level. By now, nationwide systems for trading CO_2 have been implemented in the United Kingdom, Denmark, Norway, and Sweden (Kitamori 2002) but are being considered in several other countries including Japan[2]. While such systems are often regarded as being particularly compatible with the requirements of the Kyoto protocol, we find that they can be even

[1] Including because of different modalities of taxation etc., international comparable data availability on the taxation of fossil fuels is lacking, which is why we choose the special case of Light Fuel Oil for industrial uses since we focus on firms.

[2] International Emissions Trading Association's website (www.ieta.org)

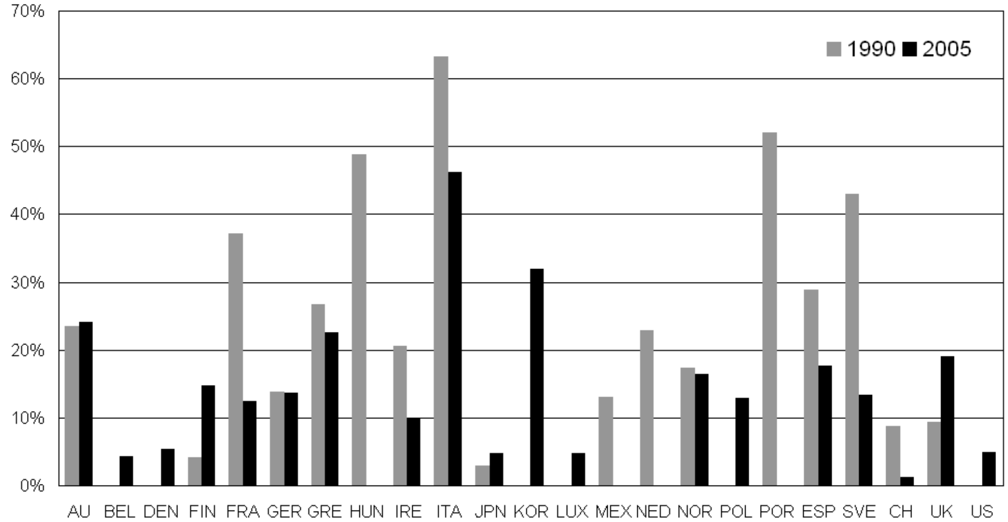

Figure 1: Percentage of Taxes in Light Fuel Oil Prices in Industry 2005 (IEA 2006, 303 and IEA 1998, 291)

preferable over an international permit trading scheme such as the International Emissions Trading (IET) proposed in article 17 of the Kyoto protocol.

We integrate both pollution and an exhaustible resource into an optimal growth model with two countries. In this setting, a system of both national (possibly different) taxes and global pollution permits is considered. This realistic combination of the two instruments is analyzed. In particular, we focus on the optimal permit system given existing taxes as 'in most cases, energy or carbon taxes pre-exist before introduction of (...) GHG emissions trading' (Kitamori 2002, 95).

This paper is organized as follows: In chapter two, the underlying literature is explored. Chapter three presents the basic model and describes both the optimal solution and the equilibria using either taxes or a permit scheme. The implications of a mixed policy under different assumptions are studied in chapter four. The findings are summarized in chapter five.

2. Literature review

While the theory of economic growth emphasized the role of capital accumulation and technological progress since the 60ies, the importance of natural resources has also been taken into consideration at an early stage. Their implications for long-run growth have been studied starting with Dasgupta and Heal (1979), Stiglitz (1974), and Garg and Sweeney (1978). It became evident that long-run growth can indeed be possible even with an exhaustible resource; however, this imposes some conditions on the possible technologies and specifications of the model. An important question for economic growth is, whether the resource is considered as being 'essential' for production. As Dasgupta and Heal (1979) point out, one pivotal factor is the elasticity of substitution between physical capital and the resource. If this elasticity is below unity, output will finally tend towards zero as the resource is being exhausted. If, on the other hand, it is greater than one, a consumption level strictly greater than zero can be sustained forever. For the case where this elasticity is exactly equal to one (which is amongst others the case for the widely used Cobb-Douglas production function), the answer whether long-run growth is feasible depends on the relative input shares of capital and the resource. If the share of capital is greater than that of the resource, a positive consumption level is still possible given that output per unit of the natural resource grows without bound and therefore economic activity does not cease even as the resource is being asymptotically depleted. Additionally, technical progress plays an important role since it increased the production possibilities even further. It is therefore not unreasonable to assume that the resource is "inessential" in that sense and therefore long-run growth is possible. In all these growth models with a exhaustible resource, Hotelling's (1931) famous rule was found to be the central efficiency condition for resource depletion.

Another strand of the literature is related to the effects of polluting activities as a by-product of production and its implications for welfare and economic growth. Due to the different types of pollutants, one can distinguish them along several lines. While some pollutants like SO_2 or ozone at the earth's surface have a more or less local impact, others affect the world as a whole, like CO_2 and other green house gases. Another distinction is the relevance of the regeneration capacity which is highly important for the long-run evolvement of pollution. In the case of global warming for instance, regeneration works only over very long time horizons while it is far more relevant for other types of pollution like SO_2. Thirdly, the impact of a specific pollutant can accrue either from total accumulated 'stock' of pollutant, i.e. the sum of all previous pollution, like the green house effect, or from the actual flow of a certain period.[3]

Frequently, pollution is studied as an optimal control problem in order to determine the effect on welfare (e.g., Dasgupta and Heal 1979). Based on this type of analysis, instruments like standards, licenses, quotas, tradeable permits or Pigouvian taxes are proposed to eliminate this negative externalities. Keeler et al. (1971) were one of the first to study the effect of pollution in a Ramsey-type growth model discussing under which conditions regulatory control policies will be employed. Ploeg and Withagen (1991) analyzed several different types of pollution specifications using similar optimal growth models and find that it differently affects capital accumulation patterns. Stokey (1998) raises the question whether sustainable growth is eventually possible with pollution. Jouvet et al. (2005) study a similar problem in an overlapping generations model. With the rise of endogenous growth models, these issues have been incorporated into those kinds of models. For instance, Grimaud (1999) studies pollution at the market equilibrium of a Aghion Howitt type model. One common result is that corrective measures such as taxes or pollution permits affect the interest rate such that production (and hence pollution) is postponed to some extent.

So far, we have discussed issues of pollution and non-renewable resources separately. But since one of the most important natural resources, namely fossil fuels, are directly related to pollution when they are eventually burned, it seems reasonable to consider the two problems jointly. This is particularly interesting since in practice, taxes on the use of fossil fuels are frequently used in order to reduce the emission of pollutants and are therefore not primarily commodity taxes but environmental regulation policies. Forster (1980) studied this joint effects and concluded that resource depletion should be delayed in the presence of pollution accruing from energy production from fossil fuels. Krautkraemer (1985) showed in a similar model where he assumes that the stock of resource has some amenity value (which is formally equivalent to saying that the resource burned so far acts like a stock of pollution), that extraction should be reduced. Sinclair (1992, 1994) and Ulph and Ulph (1994) discuss these issues jointly in Solow type growth models. One result is that the optimal resource tax that can implement the social optimum must be decreasing over time. Moreover, they confirm the finding of Dasgupta and Heal (1979) that the level of this tax does not matter

[3]Note that even though the recommendations fo the IPCC reports and also the Kyoto protocol are formulated in terms of a flow of pollutants, its criterion is the stock of greenhouse gasses in the athmosphere measured in parts per million (ppm).

at all given the fixed supply of the resource. Instead it is only the timely profile that shapes the extraction path. More advanced endogenous growth models are used discussed in Grimaud and Rougé (2005) and Schou (2002). While the latter finds that no instrument is needed to correct for the effect of pollution (due to the fact that the Hotelling rule already implies an increasing price of the resource), the former finds a (over time) decreasing Pigouvian tax. Generally, the famous Hotelling rule becomes in the presence of pollution more elaborate since it now has to take into account the environmental degradation. Hence, it is not a pure efficiency rule anymore but a condition for optimality.

Besides this literature on resources, pollution, economic growth and the optimal policies, there has been a long discussion on different environmental instruments, their interaction and analyses in second-best settings. In this paper we focus on taxes and pollution permits. These instruments are generally regarded as more efficient in economic terms than command and control measures since they imply a 'price' for pollution or the resource respectively.[4]

While permits and taxes are equivalent in a world of certainty, there is a strand of literature discussing the respective advantages in settings with uncertainty (see Weitzman 1974) for the general discussion and Ekins and Barker (2001) for the specific case of CO_2 emission regulation). However, in this paper we do not consider uncertainty.

When it comes to the implementation in a world with already existing taxes, there is a huge literature on the effects of environmental regulation. Bovenberg and de Mooij (1994), Goulder (1995), or Bennear and Stavins (2006) show that when there are distortionary (labor) taxes in place, environmental taxes create distortions since they interact with other taxes. As one result, the optimal environmental tax in a second-best world is lower than the first best (=Pigouvian) solution. This tax interaction affect contradicts the so-called revenue recycling effect which stems from the fact that the revenue generated from environmental taxes can be used to reduce other distortionary taxes. The gross impact of these two contrary effects has been labeled the 'double dividend' of environmental taxation and can increase the positive impact on welfare over the pure effect of correcting for the negative externality of pollution.

In this paper, we are interested in the simultaneous usage of two different envi-

[4]Obviously, there is a huge difference between taxes on resources like fossil fuels and taxes on pollution like carbon taxes. However, for the following, we abstract from different technologies of production. Therefore, a pollution tax is equivalent to a resource tax since pollution is typically proportional to the amount of resource burnt.

ronmental instruments. Those two instruments can function either as substitutes or complements. First, they can be used as substitutes like a permit system with penalties or trigger prices. It is argued that it is in general not environmentally effective "to kill one bird with two stones"(OECD 2003, 10). However, Roberts and Spence (1976) showed that a mix of two instruments can do better than one single instrument in an uncertain environment. Pizer (2002) shows that a hybrid system of taxes and permits that are substitutes is doing better than a pure permit system. Second, when the two instruments are complementary, they are both simultaneously relevant for the agents. While this case reflects the original 'two stones' case, there are still advantages of such a system. For instance, it is argued that e.g., carbon taxes can capture windfall gains that are created by a permit system (OECD 2003).

For our purpose, the latter case is relevant where the two instruments are complementary and we look at the case where these instruments are executed on different tiers, on the national and global level. In this context, it is generally argued that 'applying an economic instrument across countries can achieve a given emission reduction at lower cost than applying separate economic instruments within countries, because of transnational equalization of the costs of abatement which the common instrument achieves' (Ekins and Barker 2001, 331). Accordingly, simulations like in Barker (1999) show that common regulation is preferable over unilateral regulation of pollution.[5] Since we have in mind mainly the case of fossil fuels, empirically, we have significant taxes in place at the same time where CO_2 trading schemes are heralded. We thus take the two instruments as given.

When it comes to taxing a resource, one important issue arises from the fact that the resource is a mobile factor of production. This can lead to horizontal tax competition between countries, whereby countries try to attract the tax base.. The possible delocalization of polluting and resource consuming activities makes it likely that countries act strategically (see e.g., Wildasin 1988). This is expected to lead to lower-than-efficient taxes as it has been shown for the cases of capital and commodity taxes. However, there is some important difference coming from the fact that revenue generation is not the premier aim of environmental taxation.

In order to analyze the different and combined effects of the two instruments, we first exhibit the optimal growth model. Thereafter, we study the different policies and cases and its effects.

[5]Trivially, when the impact of pollution differs between countries, this might call for national differing policies.

3. The model

The basic model is an optimal growth model with the two input factors labor L_{it} and the non-renewable resource R_{it} in two countries, A and B, i.e., $i = A, B$. Capital is omitted simply due to the fact that the model will be less tractable by adding another state variable. The technology of the economy is given by a Cobb-Douglas type production function so that the elasticity of substitution between the two inputs is equal to one:

$$Y_{it} = (A_{it} L_{it})^{\alpha} R_{it}^{1-\alpha}. \tag{1}$$

The labor supply is assumed to be constant over time while the technological level A_{it} expressed as labor-augmenting technical progress grows exogenously with the rate of x, i.e., $A_{it} = \phi_i A_o e^{xt}$. Allowing for different productivity ϕ_i in both countries, ϕ_A is normalized to one so that $\phi_B \equiv \phi$ stands for the technological level of country B as compared to country A. In the following, we omit the subscripts of time where it is clear in order to simplify the presentation.

The representative households in the two countries maximize intertemporal utility accruing from consumption C_i of the respective final goods and environmental quality E. Following the literature, we specify the utility function as being weakly separable between private consumption and environmental quality and with a constant intertemporal elasticity of substitution equal to one so that it can be written as

$$U_i = \int_0^{\infty} \log(\frac{C_i}{L_i} E^{\lambda}) e^{-\rho t} dt \tag{2}$$

where λ represents the relative weight of environmental quality. Note that at this point we assume the relative weight of the environment to be equal for the consumers in the two countries.

The stock of the resource at date zero, S_0, is known with certainty and the equation of motion for the resource is described as

$$\dot{S} = -(R_A + R_B) \tag{3}$$

The resource is depleted in finite time so that we have the following initial condition:

$$\int_0^\infty (R_A + R_B)dt = S_0 \tag{4}$$

The impact of resource usage on the environment is assumed to be linear leading to the following equation of motion for the environment

$$\dot{E} = -h(R_A + R_B), \tag{5}$$

where h denotes the flow of pollution generated by the combustion of one unit of the resource. We therefore abstract from the regenerating capacity of the environment. This might sound reasonable given that the regeneration effect is only of minor importance. In the context of classical optimal control partial equilibrium analyses, regeneration is usually included (see, e.g., Withagen 1994), but it would not change the qualitative results.

3.1. Optimal Allocation

From a global point of view, the optimal growth path is derived from the following optimization problem. The social planner maximizes the weighted sum of utilities of the two countries A and B:

$$\max_{C_A, C_B, R_A, R_B} \int_0^\infty \omega L_A \log(\frac{C_A}{L_A} E^\lambda) e^{-\rho t} + (1-\omega) L_B \log(\frac{C_B}{L_B} E^\lambda) e^{-\rho t} dt \tag{6}$$

subject to the two equations of motion (3) and (5), and the global budget constraint $C_A + C_B = Y_A + Y_B$. This problem with the four control variables and two state variables E and S has the following first order conditions (using the present-value Hamiltonian):

$$\omega L_A e^{-\rho t} \frac{1}{C_A} = \mu_Y \tag{7}$$

$$(1-\omega) L_B e^{-\rho t} \frac{1}{C_B} = \mu_Y \tag{8}$$

$$-h\mu_E - \mu_S + \mu_Y (A_0 e^{xt} L_A)^\alpha R_A^{-\alpha} (1-\alpha) = 0 \tag{9}$$

$$-h\mu_E - \mu_S + \mu_Y (A_0 e^{xt} L_A)^\alpha R_A^{-\alpha} (1-\alpha) = 0 \tag{10}$$

$$\omega L_A \lambda e^{-\rho t} \frac{1}{E} + (1-\omega) L_B \lambda e^{-\rho t} \frac{1}{E} = -\dot{\mu}_E \tag{11}$$

$$0 = -\dot{\mu}_S \tag{12}$$

From the first order conditions, we can compute the optimal allocation which is characterized by the following proposition.

Proposition 1. *The optimal path is described by the following conditions:*

$$g_{Y_A} = g_{Y_B} = g_Y = g_{C_A} = g_{C_B} = g_C \tag{13}$$

$$g_{R_A} = g_{R_B} = g_R \tag{14}$$

$$g_Y = \alpha x + (1-\alpha) g_R \tag{15}$$

$$\frac{Y_A}{Y_B} = \frac{R_A}{R_B} = \frac{L_A}{\phi L_B} \tag{16}$$

$$g_R = -\frac{\lambda g_E}{1-\alpha} - \rho \tag{17}$$

$$\frac{C_B/L_B}{C_A/L_A} = \frac{1-\omega}{\omega} \tag{18}$$

These condition determine the optimal growth path along with the initial conditions A_0, S_0, and E_0. The last FOC determines the distribution between the two countries given the (arbitrary) weights of the social planner.

Generally speaking, it can be said that the economy will be governed by the growth rates of E and R which is determined on the one hand by the log-differentiated version of (17), $\dot{g}_R = -\frac{\lambda}{1-\alpha}\dot{g}_E$, and the accumulation equation of pollution $\dot{E} = -hR$, which can be rewritten as

$$\dot{g}_E = g_E(g_R - g_E). \tag{19}$$

From this condition, using the optimal rate of extraction g_R, we find that the growth rate of g_E itself can be written as

$$\frac{\dot{g}_E}{g_E} = -g_E\left(\frac{\lambda}{1-\alpha} + 1\right) - \rho. \tag{20}$$

This term is negative for the relevant trajectory (see below).[6] From the phase diagram (Figure 2), we can analyze the dynamics of the system. It is governed by

[6] Analytically, the optimal trajectory of the growth rate of the environment can be derived by combining (17) and (19). This two equations yield a Riccatti differential equation $\dot{g}_E = -[(1-\alpha+\lambda)/(1-\alpha)]g_E^2 - \rho g_E$, which has the solution $g_{E_t} = \frac{-\rho}{[(1-\alpha+\lambda)/(1-\alpha)] - C1\cdot\rho\cdot e^{\rho t}}$. The starting point of the system identifies $C1 \in]-\infty, 0[$ since at time zero this implies $gE = -\rho/(K - C1\cdot\rho)$.

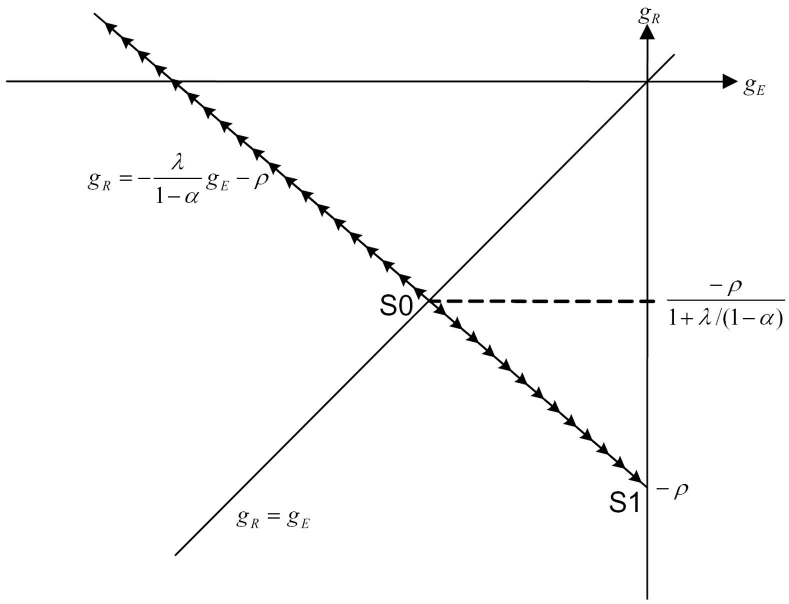

Figure 2: Phase diagram

the two equations (17) and (19). The dynamics are similar to the model studied in Daubanes and Grimaud (2006). The straight line through the points S0 and S1 represents the condition from equation (17). The condition (19) tells us how the growth rate of the environment changes if g_E is either larger or smaller than g_R. The only steady state is the point S0, but it is not stable. The trajectory at the left side from S0 finally yields a g_R greater than zero which implies that the resource is depleted in finite time which will never be optimal. So the only possible optimal trajectory is the one leading from S0 to S1. It can be shown that g_E will asymptotically increase to zero while g_R decreases over time with the limit of $-\rho$. Note that this limit is just the steady state in a model without the pollution externality. In the actual model, however, there is no steady state. The economy is on a transition path up to infinity. Figure (3) depicts the evolvement of g_E which is a central variable for the following analysis. For 'good' starting values, it declines slowly at the beginning and approaches zero as t tends to infinity.

From the modified Hotelling rule (17) we see that the optimal growth rate of resource extraction (which, of course, is negative) is larger due to the negative

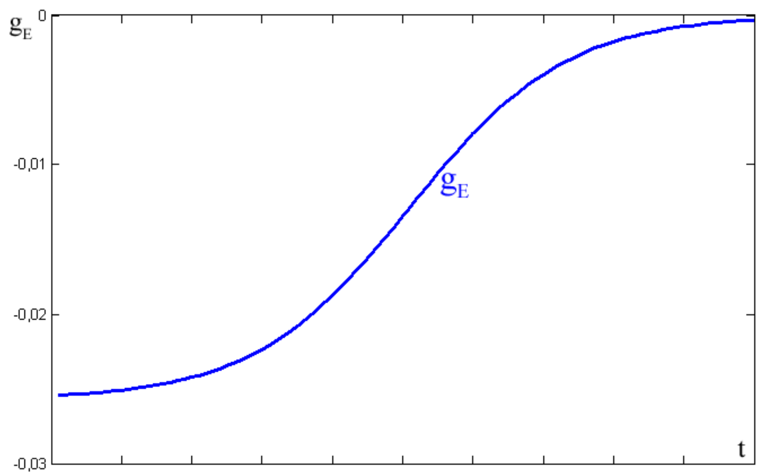

Figure 3: The optimal evolvement of the rate of change of the environment

effect of pollution (since g_E is negative). In other words, extraction is postponed to some extent. The lower level of extraction at the beginning necessarily implies a higher (negative) growth rate of extraction. This higher growth in resource extraction lead to higher output expansion at the beginning that ceases and finally converges to the level without pollution. This implies that the growth rate is higher than in the absence of pollution (see figure 4), while the initial level of output is lower due to the postponed extraction.

To see under what conditions long-run growth is possible, we just use (15) and the fact that g_R will converge towards $-\rho$. We find that sustainable growth of output is possible if the exogenous rate of technological progress is large enough:

$$x > \frac{1-\alpha}{\alpha}\rho \tag{21}$$

Or put it the other way round, this condition just states that the input share of the resource for production has to be low enough given the rate of technological progress and the discount rate. It is similar to previous results (see, e.g., Dasgupta and Heal (1979), Stiglitz (1974), or Garg and Sweeney (1978).

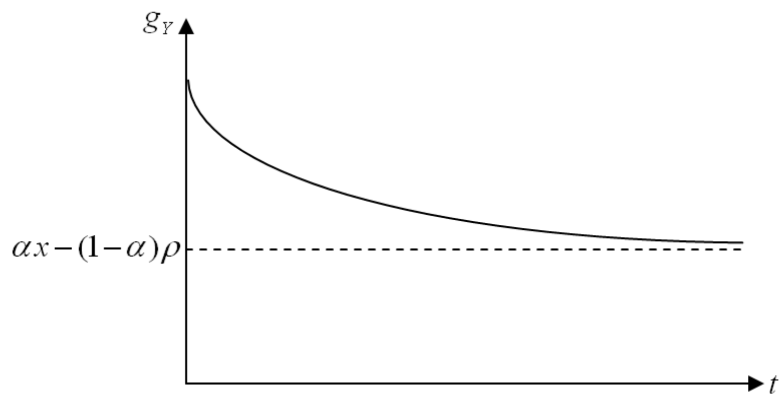

Figure 4: The optimal growth rate of output

3.2. Equilibrium with permits and resource taxes

In this chapter, we study the market equilibrium of the model. We assume that the markets for labor and the final goods are perfectly competitive. Labor is immobile while the final good and the resource are freely tradable. The financial market is also assumed to be perfectly open so that the interest rate is equal in the two countries. Regarding the resource, we assume that the property rights accrue entirely to country B and the extraction cost are assumed to be zero. This assumptions together with the assumption of $\phi < 1$ resembles a case where country A can be regarded as the typical industrialized country while country B stands for a resource abundant developing country.

3.2.1. The final good sectors

Both countries' final goods sectors consist in many identically firms using the resource and labor as their only inputs. Prices of the final goods are normalized to unity. Their problem consists therefore in

$$\max_{L_i,R_i} \int_0^\infty \left[(A_{it}L_i)^\alpha R_i^{1-\alpha} - w_i L_i - q\tau_i R_i - hPR_i\right] e^{-rt} dt \tag{22}$$

where q denotes the world market price of the resource and τ_i the national tax on the resource in country i defined as one plus the ad-valorem tax rate so that $\tau_i = 1 + t_i$. In order to simplify the notation, we denote by g_{τ_i} the growth rate of the tax which can be different at any point in time whereas τ_i refers to the initial level at time zero. Note also that, although we use a tax on the resource consumption here, it could be interpreted as well as a tax on pollution like a carbon tax due to the strictly linear relationship between the resource consumption and pollution and only one available technology. Nevertheless, we will refer to the tax as a tax on resource consumption aimed at reducing pollution.

Since the usage of R_i units of the resource leads to emissions of hR_i, the last term hPR_i denotes the cost of permits for the firm in country i where P is the price of the permits, e.g. for the right of emitting one ton of CO_2 equivalents. This policy resembles the policy where permits are auctioned of by the governing institution and no free allowances are given to the firms. A different policy, namely grandfathering where the firms are endowed with a certain amount of permits has different distributional implications only within a country. For efficiency considerations and the distribution between countries, it makes no difference.

The first-order conditions for the problem of country i's firm are given by

$$\frac{Y_i}{R_i}(1-\alpha) = q\tau_i + hP \tag{23}$$

$$\frac{Y_i}{L_i}\alpha = w_i \tag{24}$$

Note that due to the linear relationship between resource usage and pollution, the marginal product of the resource is in equilibrium just equal to the marginal cost which consists in the marginal price to be paid for the input and the marginal cost hP necessary to buy the permits equivalent to the emission of the resource. Note that if the firm were endowed with a sufficient number of permits, this condition would still hold since it then represents the opportunity cost of not selling the superfluous permits on the market.

From (23) we can further find the relative levels of production in the two countries as

$$\frac{Y_A}{Y_B} = \phi^{-\alpha}\left(\frac{L_A}{L_B}\right)^{\alpha}\left(\frac{R_B}{R_A}\right)^{\alpha} = \frac{q\tau_A + hP}{q\tau_B + hP}\frac{R_A}{R_B} \tag{25}$$

3.2.2. The extraction sector

The extraction sector is considered to be competitive and its intertemporal profit maximization problem can be stated as follows:

$$\max_{R_t} \int_0^\infty q_t R_t e^{\int_0^t r(t)du} dt \quad \text{s.t. } S(0) = \int_0^\infty R_t dt \tag{26}$$

This problem can be solved as a variations calculus problem with an isoperimetric constraint and yields the well-known Hotelling rule

$$\frac{\dot{q}_t}{q_t} = r(t). \tag{27}$$

The world market price of the resource -which here equals to the resource rent due to the abstraction of extraction costs- has to grow at the world interest rate. This is the only possible development of the resource price that allows for extraction at any point in time. It can also be interpreted as a no-arbitrage condition comparing the returns on capital and resource left in the ground.

3.2.3. The market for permits

On the market for permits, the fixed 'supply' z_t is determined by a global authority at any point in time. By z_i we denote the number of permits that are used in country i. The revenues are split between the two countries such that at any date t, a share $\vartheta_A < 1$ of the revenue is distributed to country A and the remaining part of $(1 - \vartheta_A)$ to country B. Note that for efficiency and international distributional considerations, it makes no difference if the permits are auctioned of (and possibly traded on a secondary market) and the revenues are distributed accordingly or if the permits are given away for free to the representative firms using the same relative shares ϑ_A and $1 - \vartheta_A$ respectively.

The exogenously given supply z_t and the demands for permits by the firms determine the price P for one permit such that the market clears at each date t, i.e., $z_t = h(R_A + R_B) = hR$. Due to the one to one relationship between permits and the resource, wen can use the demands for the natural resource from (23) to write the clearing condition for the permit market as

$$\sum_{i=A,B} R_i = \sum_{i=A,B} \frac{Y_i(1-\alpha)}{q\tau_i + hP} \stackrel{!}{=} \frac{z}{h}. \tag{28}$$

Note that this condition characterizes the equilibrium on both the resource and permit markets simultaneously.

3.2.4. Households' optimization problem

The representative household in each country maximizes his intertemporal utility subject to his budget constraint.

$$\max_{C_i t} \int_0^\infty \log(\frac{C_i}{L_i} E^\lambda) e^{-\rho t} dt \tag{29}$$

The budget constraints are different for the two countries and depends on the distribution of the endowments of both the resource and the pollution permits. Taking into account that the resource rent accrues only to country B, the instantaneous budget constraints for country A and B are given by the following equations:

$$C_A + \dot{B}_A = w_A L_A + r(t) B_A + [(\tau_A - 1) q R_A + \vartheta_A P z] \tag{30}$$

$$C_B + \dot{B}_B = w_B L_B + r(t) B_B + [(\tau_B - 1) q R_B + (1 - \vartheta_A) P z] + q(R_A + R_B) \tag{31}$$

The variable B_i represents the net holdings of financial assets in the two countries. The term in brackets thus represents the transfers to the households from the tax revenues and the respective shares of the permit revenues while the profits of the extraction are distributed to country B's consumers. In the final good sector, there are no profits due to constant returns to scales and therefore no transfers to the households.

The first-order conditions of these problems with B_i as the state variable yield the standard Ramsey-Keynes condition for both countries:

$$g_{C_A} = g_{C_B} = g_C = r(t) - \rho \tag{32}$$

In addition, the two transversality conditions, which can be interpreted as no Ponzi game conditions[7], have to be satisfied where $\mu_i(0)$ represents the value of

[7]While there is a debate on whether the Transversality conditions are in fact necessary conditions, in our case, we would otherwise need to impose this condition in order to rule out Ponzi games.

the costate variable to the state variable B_i at time t, which can be written as

$$\lim_{t\to\infty} B_i(t)\mu_i(0)e^{-\int_0^t r(s)ds} = 0. \tag{33}$$

The equilibrium of the model can now be derived. We develop four different cases and compare the results depending on which instruments are employed. We start by looking at the two cases where only one instrument, either a global system of pollution permits or national taxes are used.

3.3. Equilibrium with national taxes

First, we assume that there are only taxes used and no pollution permits ($P = 0$). We restrict our analysis to the case where the growth rate of both taxes is equal at equilibrium ($g_{\tau_A} = g_{\tau_B} = g_\tau$) Daubanes and Grimaud (2006) show that otherwise one of the no Ponzi conditions will be violated. The partitioning of world production depends on the level of the taxes. It is determined by the (34) derived from the first order conditions of the firms' maximization problems. From the Ramsey-Keynes condition we see that consumption in both countries grows at the same rate. Together with the global budget constraint (which implies $g_C = g_Y$) and (23) for the two countries, we get that both output and consumption in the two countries have the same growth rates at equilibrium.

Logdifferentiating (23) yields $g_Y - g_R = g_q + g_\tau$ and further by using the Ramsey-Keynes condition $g_R = -g_\tau - \rho$. The equilibrium can be characterized by the following conditions:

Proposition 2. *Equilibrium with national taxes*

$$\frac{Y_A}{Y_B} = \frac{\tau_A}{\tau_B}\frac{R_A}{R_B} = \left(\frac{\tau_B}{\tau_A}\right)^{\frac{1-\alpha}{\alpha}} \frac{L_A}{\phi L_B} \tag{34}$$

$$g_{Y_A} = g_{Y_B} = g_Y = g_C = g_{C_A} = g_{C_B} = \alpha x + (1-\alpha)g_R = r(t) - \rho \tag{35}$$

$$g_{R_A} = g_{R_B} = g_R \tag{36}$$

$$g_R = -g_\tau - \rho < 0 \tag{37}$$

$$r(t) = \alpha(x+\rho) - (1-\alpha)g_\tau \tag{38}$$

The level of the two countries' taxes determines the distribution of output between the two countries. However, economic growth is only influenced by the intertemporal change of the tax rates. A decreasing tax implies a slower extraction of the resource and therefore a higher (negative) growth rate of R. This leads to an increase in g_Y.

In order to determine the distribution of production and consumption between the two countries, one needs to find the initial values. First, we can compute the resource consumption at date zero from the condition

$$S_0 = R(0) \underbrace{\int_0^\infty e^{\int_0^t g_R(u)du} dt}_{\equiv D}. \tag{39}$$

Since the g_R is exogenously determined by the discount rate and the tax rates, we can actually compute $R(0) = S_0/D$. Here, D can be somewhat interpreted as the so-called reserves-to-production ratio. The higher its value, the slower will the resource be depleted. Since the growth rate of the tax influences the rate of change of the resource extraction, we can see immediately that it has an impact on the initial level or resource usage: A decreasing tax means that the initial level of resource consumption $R(0)$ is necessarily lower and therefore also the level of production, i.e. the tax has a negative level effect. However, since it increases the growth rates of production, on the long run, this effect is outweighed.

Now we turn to the distributional analysis between the two countries. Using (34), the usage of the resource in each country can be determined for $t = 0$. They are given as

$$R_A(0) = \frac{\frac{L_A}{\sqrt[\alpha]{\tau_A(0)}}}{\frac{L_A}{\sqrt[\alpha]{\tau_A(0)}} + \frac{\phi L_B}{\sqrt[\alpha]{\tau_B(0)}}} R(0) \text{ and } R_A(0) = \frac{\frac{\phi L_B}{\sqrt[\alpha]{\tau_B(0)}}}{\frac{L_A}{\sqrt[\alpha]{\tau_A(0)}} + \frac{\phi L_B}{\sqrt[\alpha]{\tau_B(0)}}} R(0) \tag{40}$$

Using the production functions, the values for $Y_A(0)$ and $Y_B(0)$ are straightforward to obtain.

In order to see the distribution of consumption, the budget constraint of the household are used. Since only the two representative households are borrowing or lending on the financial market, we must have at each point in time that $\dot{B}_A = -\dot{B}_B$ and $B_A = -B_B$. Using the first order conditions of the firm, we get from the budget constraint of country A the following differential equation: $C_A + \dot{B}_A = Y_A + rB_A - \frac{1-\alpha}{\tau_A} Y_A$. The solution of this non-homogenous first-order differential equation represents the instantaneous budget constraint at any date where $\Delta = \exp(\int_0^s -r(u)du)$:

$$B_A(t)e^{-\int_0^t r(u)du} = -\int_0^t C_A(s)\Delta ds + \int_0^t Y_A(s)\Delta ds - (1-\alpha)\int_0^t \frac{C_A(s)}{\tau_A(s)}\Delta ds + B_A(0) \tag{41}$$

When we take the limit for $t \to \infty$, the no Ponzi game condition (33) can be used to simplify the equation. Furthermore, using the conditions at equilibrium for the growth rates of all variables of (35), the solution can be written as

$$C_A(0) = Y_A(0) - (1-\alpha)\rho\frac{Y_A(0)}{\tau_A(0)}D + \rho B_A(0) \tag{42}$$

where D was defined in (39). Similarly, for country B we find

$$C_B(0) = Y_B(0) + (1-\alpha)\rho\frac{Y_A(0)}{\tau_A(0)}D - \rho B_A(0) \tag{43}$$

The second term on the right hand side stems from the fact that the resource is owned solely by country B. Note that the ratio of the tax rates determines the division of the resource usage and therefore production according to (40). When the tax rates are equal, a joint increase of the tax rates has no effect on welfare and the levels of production in each country. However, this policy decreases the resource rent as it can be seen from (43). In this case, the resource-scarce country captures a share of the rent of the resource abundant country B. So while the level of the taxes did not matter for efficiency, it has indeed strong implications for the distribution. Since the overall supply of the resource is fixed, the tax incidence falls solely on the owner of the resource. Here where only country B is endowed with the depletable resource, an increase of the tax level in both countries extracts a share from the resource rent to country A.

Another effect occurs when the national tax rates are not equal in the two countries. In this case, the equilibrium is not optimal. The different marginal costs of the resource will induce a relocation of production from the country with the higher tax to the one with the lower one. This relocation effect is captured by equation (34). In addition, the tax in country A has a distributional impact since it reduces resource consumption in country A and hence the rent payment to country B. The two effects and its distributional implications are in-depth studied in Daubanes and Grimaud (2006).

3.3.1. Optimal Taxation

In order to implement the global optimum, we compare the result of the previous section with the conditions for the optimal allocation. We find by comparing (34) and (16) that the tax rates have to be equal in the two countries ($\tau_A = \tau_B = \tau$). Implicitly, this follows from the fact that the marginal products of the resource should be equal between the two countries. Note that the level itself it not determined and thus arbitrary for optimality considerations. This is in accordance with the well-known result, that it is the time profile and not the level of a (decreasing) resource tax that makes it possible to implement the optimal extraction path (see e.g. Sinclair 1992). The level of the tax does not matter due to the exhaustible nature of the resource.[8] However, it has indeed distributional implications between the countries as discussed above. For the time profile of the taxes, we find the optimal growth rate of τ by comparing (17) and (37) as

$$g_{\tau_t} = \frac{\lambda g_{E_t}^{opt}}{1-\alpha} < 0 \tag{44}$$

The optimal tax rate is hence decreasing over time starting from an arbitrary level. Note that its growth rate is not constant but changes over time since g_E changes over time (see figure 3).

3.4. Equilibrium using pollution permits

Secondly, we compute the equilibrium allocation when only emission permits are used (i.e., setting $\tau_{it} = 1\ \forall i, t$) and the number of permits available z_t is determined globally. We first look for an equilibrium where the rate of growth for the use of permits in both countries is equal ($g_{z_A} = g_{z_B} = g_z$).[9] This implies for the market of permits

[8] Note that since τ is defined as one plus the tax rate, an decreasing τ implies that ultimately the tax becomes a subsidy. But since the initial level is not important for efficiency considerations, this is of no further relevance. In fact, we find that the tax rate converges to a certain value $\in]0, \tau_i[$ depending on the starting point of $(g_{R,}g_E)$ within the phase diagram.

[9] While this assumption would be crucial in a model with capital, we do not necessarily rely on it within this setting where the resource is the only variable production factor. This implies automatically that the resource consumption has to grow at the same pace in the two countries from the production functions and the first order conditions of the firm.

$$(Y_A + Y_B)(1-\alpha) = \frac{z_t}{h}(q + hP)^{10} \tag{45}$$

or written in growth rates $g_Y = g_z + g_{q+hP}$. Since the profile of permits is exogenously determined, the growth rate of R is equal to g_z. Moreover, we obtain as equilibrium conditions for both countries:

Proposition 3. *Equilibrium with a global system for pollution permits*

$$g_{R_A} = g_{R_B} = g_R = g_z \tag{46}$$

$$g_{Y_A} = g_{Y_B} = g_Y = g_C = g_{C_A} = g_{C_B} = \alpha x + (1-\alpha)g_z = r(t) - \rho \tag{47}$$

$$\frac{Y_A}{Y_B} = \frac{R_A}{R_B} = \frac{L_A}{\phi L_B} \tag{48}$$

$$g_{q+hP} = \alpha(x - g_z) > 0 \tag{49}$$

$$r(t) = g_q = \alpha x + (1-\alpha)g_z + \rho = g_{q+hP} + (\rho + g_z) \tag{50}$$

A faster reduction of available permits (g_z increases in absolute value), i.e. a tighter environmental policy, leads to a reduction of the growth rate since the resource is essential for production. While it increases the growth rate of the marginal cost of the resource $q + hP$, it depresses the growth rate of the resource price q. Thus, it leads to an increase of the growth rate of the permit price. As it can be seen from the last equation, the interest rate decreases when $|g_z|$ increases. This result is somewhat similar to the one of Grimaud (1999). Eventually, this reduces the growth rate of consumption and output (from the Ramsey-Keynes condition). From the analysis of the optimal allocation, we found that the growth rate of the resource has always to be greater than $-\rho$. Therefore we look only at policies which ensure that $g_z > -\rho$ at any point in time.

The implementation of the Pareto optimal allocation with permits is straightforward obtained by setting the profile of permit such that

$$g_{z_t} = -\frac{\lambda g_{E_t}^{opt}}{1-\alpha} - \rho. \tag{51}$$

[10] Note that we look only at the case where all permits are actually used by the firms ($R_t = z_t$). This implies that we concentrate on the case where z_t is chosen 'relatively' optimal. Otherwise the price of a permit would actually fall to zero and one could consider strategical behaviour of some countries with market power to gain some rents depending on the revenue sharing rule. (See Bernard et al. (2003) for an example).

As we have seen from the phase diagram, g_z, which equals g_R has to be negative. But since g_E was not constant, g_z is also varying over time. But we can compute its growth rate as $g_{g_z} = g_z - g_E$. This term is negative in the relevant case where the resource is not depleted in finite time, which implies that z is decreasing while its growth rate itself is converging to zero. This implies that the interest rate is also decreasing over time and approaches the value of $\alpha(x + \rho)$, which is the value that would prevail in the model without pollution. Intuitively, the (initially) higher interest rate compared to the equilibrium without pollution leads to a increased growth rate of consumption (from the Ramsey-Keynes condition) and thus to a lower initial consumption and resource exhaustion. This is precisely what is needed in order to take into account the externality of pollution by postponing resource extraction.

The same method as in the last chapter can be used to determine the initial value of the variables and therefore look at the level effects and distributional aspects. Now the difference is that the initial level of resource use $R(0)$ is exogenously determined by the initial supply of permits, $z(0)/h$, since we assume that all permits are actually used.[11] We get therefore the initial level of resource consumption and can compute the national ones as

$$R_A(0) = \frac{L_A}{L_A + \phi L_B}\frac{z(0)}{h} \text{ and } R_B(0) = \frac{\phi L_B}{L_A + \phi L_B}\frac{z(0)}{h} \tag{52}$$

The national production levels $Y_A(0)$ and $Y_B(0)$ can be simply derived by substituting this values into the production functions.

The determination of the consumption levels on the other hand is more difficult. From the budget constraints together with the closeness of the financial market we obtain again two differential equations which yield the following solutions for country A where $\Delta = \exp(\int_0^s -r(u)du)$:

[11] This assumption implies some restriction on the choice of either g_z or $z(0)$. This is due to the fact that a condition similar to (39), namely $hS_0 = z(0)\int_0^\infty \exp(\int_0^t g_z(u)du)dt$ must hold. We therefore assume that g_z is set by the intergovernmental agency and $z(0)$ is determined such that this condition is always satisfied. This implies that the market for permits is always cleared for a positive price.

$$B_A(t)e^{-\int_0^t r(u)du} = -\int_0^t C_A\Delta ds + \alpha\int_0^t Y_A\Delta ds + \vartheta_A(1-\alpha)\cdot \int_0^t Y\Delta ds + \vartheta_A\frac{1}{h}\int_0^t qz\Delta ds + B_A(0) \quad (53)$$

As t tends to infinity, the LHS goes to zero because of the no Ponzi condition (33). Furthermore, using the equilibrium growth rates of all the variables, we find for country A:

$$C_A(0) = \alpha Y_A(0) + \vartheta_A(1-\alpha)Y(0) - \vartheta_A\rho q_0 S_0 + \rho B_A(0) \quad (54)$$

and for country B we get similarly

$$C_B(0) = \alpha Y_B(0) + (1-\vartheta_A)(1-\alpha)Y(0) + \vartheta_A\rho q_0 S_0 - \rho B_A(0). \quad (55)$$

Note that the relative levels of consumption of the two countries depend still on the initial value of the resource price q_0 (alternatively, they could also be expressed in terms of the initial permit price P_0). This is because of some indetermination of the initial resource and permit prices, which is explored in the following.

3.4.1. A note on the determination of the permit and resource prices

The price for the resource and the price for pollution permits is simultaneously determined through the supply and demand for the resource from (45). The growth rates of these prices can be separately identified due to the determination of the growth rate of the resource through the Hotellings rule. The evolvement of the permit price cannot be solved explicitly but can be recovered from g_q and g_{q+hP} given some initial value q_0 or P_0.[12] Since we reduced the analysis to cases where $g_z > -\rho$ holds, it follows immediately that the resource price is growing at a higher rate than the entire marginal cost of the resource which is itself growing faster than the permit price. Along the equilibrium path, the growth rates of both the resource price g_q and the total marginal cost of the resource g_{q+hP} converge

[12] g_P is implicitly defined from $q_0\exp(\int_0^\infty g_q(s)ds) + hP_0\exp(\int_0^\infty g_P(s)ds) = (q_0 + hP_0)\exp(\int_0^\infty g_{q+hP}(s)ds)$

towards the value $\alpha(x+\rho)$ which implies that the permit price also approaches this value as t tends to infinity.

Regarding the initial values of the prices, the resource market clearing condition implies, that the sum of the initial prices $q_0 + hP_0$ can be identified. Together with the initial values for the national production levels, we get

$$q_0 + hP_0 = \frac{[A_0(L_A + \phi L_B)]^\alpha}{(z(0)/h)^\alpha}(1-\alpha). \tag{56}$$

However, one is not able to determine both prices separately. There is an infinite number of combinations of q_0 and P_0 that can prevail at equilibrium. The only restrictions are that both prices have to be positive and have to satisfy jointly (56). However, the impact of the introduction of a permit system on resource prices is highly relevant for distributional considerations. For the case of oil and CO_2 permits, there has been several studies concluding that a permit system can have an huge impact on the resource rent depending mainly on market power in the resource market and the demand elasticity. For instance, Rosendahl (1996) find in a competitive setting that a CO_2 permit price of 10 US-\$ would reduce the resource rent by one third for relatively low elasticities of demand. Still the figures estimated vary significantly from almost zero to almost 100 per cent (Berg et al. 1997). So the question how the two prices could be determined, is of utmost importance.

One possibility to determine them in the present model would be, to assume that the economy was at the steady state already before the introduction of the permit scheme according to the same model just without pollution. In fact, this could mean either that the market equilibrium was sustained without a correction for the externality or that simply the externality was not yet perceived by the households (i.e., $\lambda = 0$). Formally, we say that the economy started at date $-T$ as described in the model without permits (i.e., $P = 0$). Then, at time 0, the permit system is introduced without having been anticipated by the agents. One could argue that the permit price just adds up to the resource cost thus leading to the necessary postponement of extraction while the resource price itself is not directly affected immediately while its growth rate changes evidently. One argument supporting this view would be a no-arbitrage condition à la Hotelling around date zero assuming that the introduction of the permit system is becoming public shortly before its actual introduction. If we impose this restriction, one can show that the initial permit price will be determined as

$$P_0 = (1-\alpha)\frac{[A_0(L_A+\phi L_B)]^\alpha}{S_0^\alpha}\left[\left(\int_0^\infty e^{\int_0^t g_z ds}dt\right)^\alpha - \left(\frac{1}{\rho}\right)^\alpha\right]. \tag{57}$$

Proof. For the period $[-T, 0[$, we have the same model with a permit price equal to zero. From (56) applied to time $-T$ together with the growth rate of the price which is $g_q = r(t) = \alpha(x+\rho)$, we can compute the price at date zero which will prevail at the date the permit system is introduced. Here, $z(0)/h$ in (56) is replaced by $R(-T)$ which can be computed using the fact that $g_R = -\rho$ and hence $R(-T) = \rho S_{-T}$. Then we equalize the value for $q(0)$ with the initial condition for the equilibrium with permits given by (56). This condition yields $q(0) = (1-\alpha)\frac{[A_{-T}(L_A+\phi L_B)]^\alpha}{\rho S_{-T}^\alpha}e^{\alpha(x+\rho)} \overset{!}{=} (1-\alpha)\frac{[A_0(L_A+\phi L_B)]^\alpha}{(z(0)/h)^\alpha} - hP_0$. Using the fact that $S_0 = S_{-T}e^{-\rho T}$ and $A_0 = A_{-T}e^{xT}$ and (39), we obtain (57). This completes the proof. ■

Note that using (39), it can be shown that the term in the square brackets is positive if the initial number of permits z_0 is smaller than the optimal initial resource consumption level in the case without externality. This intuitive result means that the permit price is strictly greater than zero if the permit system effectively postpones extraction. This gives rise to another interpretation of the (possible) initial permit price given by (57): While it might well be the case that the resource price actually drops at the introduction of the permit system, it will at least most likely not rise. The minimum permit price will therefore be the one given by (57). A reduction of the resource rent would only further increase the permit price. The situation where the resource price is not altered at the introduction of the permit system is depicted in figure 5.

When we look at the case where the resource price is indeed altered by the introduction of the permits, we could fix one of these prices at an arbitrary value given that the remaining price will be non-negative (and the permit price is at least as large as given by (57)). The distributional effects can then be studied using the values for consumption given by (54) and (55). A marginal increase of q_0 (which is equivalent to a decrease of hP_0 since $dq_0 + hdP_0 = 0$) leads to a higher resource rent net of reduced permit revenues in the resource-rich country B. Its consumption level increases by the amount of $\vartheta_A \rho S_0$:

$$\frac{dC_B(0)}{dq_0} = \vartheta_A \rho S_0 \tag{58}$$

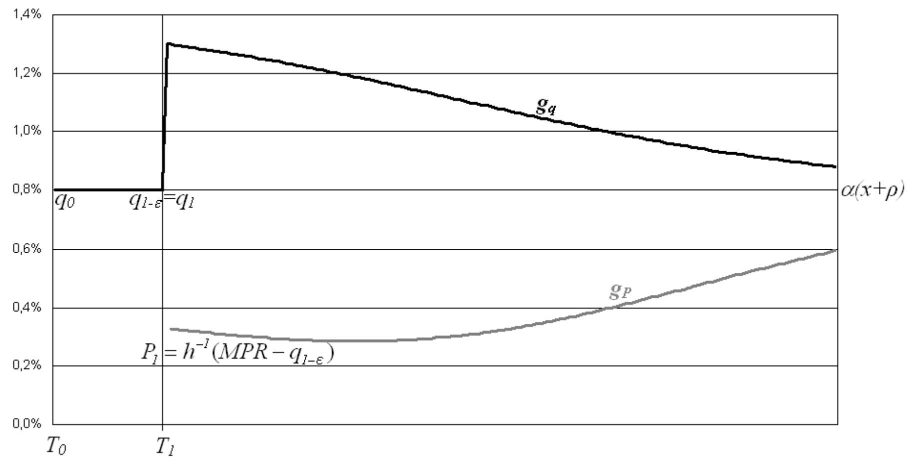

Figure 5: Determination of the initial resource and permit price

An interesting example for this effect of higher permit prices on the resource rent comes from the debate about Russia's role within the Kyoto protocol: Bernard et al. (2003) show that while resource-rich Russia has an interest in relatively high permit prices given its favorable endowment with permits, on the other hand, higher permit prices will reduce prices for fossil fuels and hence decrease its rents. This shows the basic trade-off between higher resource rents when a country is also entitled to a large share of permit revenues.

4. Simultaneous taxes and permit system

So far we have shown that either pollution permits or resource taxes can reduce the distortion from pollution. Now we study the possible interaction effect when both instruments are used at the same time. The main question arising is therefore, what is the optimal allocation of permits given there are already possibly different national resource taxes in place?

4.1. Equal national taxes

First, we analyze the situation where the taxes are equal in the two countries at any point in time ($\tau_A = \tau_B \ \forall t$). This implies that the marginal costs of the resource are equal between the two countries. In this case, we get basically the same equilibrium as in the case where only permits are used. So the equilibrium conditions hold apart from equation (49) which is replaced by $g_{q\tau+hP} = \alpha(x - g_z)$. Intuitively, since the resource consumption is determined by the permits available on the market, the marginal cost of the resource is determined and any tax will only affect the permit and resource prices such that $q\tau + hP$ remains unchanged. As it was mentioned before that the relative size of resource and permit prices is not defined, similarly we cannot determine whether an increased tax rate lowers the resource or permit price. So while the level of the marginal cost is the same as in the case with only permits, the prices of the resource and/or permits are affected by the tax rate and its growth rate. While the intertemporal allocation of the resource and hence production is unchanged, this has a distributional impact between the different countries. We therefore compute the initial consumption level for the resource importing country A[13] in order to study the effect of a change in taxation.

$$\begin{aligned} C_A(0) &= \alpha Y_A(0) + \vartheta_A(1-\alpha)Y(0) + \rho q_0 \tau_0 \int_0^\infty e^{\int_0^t g_\tau + g_z ds} dt \left(R_A(0) - \vartheta_A \frac{z(0)}{h} \right) \\ &\quad - \rho q_0 R_A(0) \int_0^\infty e^{\int_0^t g_z ds} dt + \rho B_A(0) \end{aligned} \tag{59}$$

First we look at a impact of the growth rate of the tax, g_τ. In a world without permits, it was needed in order to implement the optimal allocation. In the presence of a permit system however, the extraction path is fully determined by the profile of permits. The growth rate of the tax thus has no effect on the resource consumption path and therefore on global optimality. However, it has distributional consequences for the two countries: It directly affects the growth rate of the permit price and leaves the resource price unchanged.[14] The effect on the consumption between the two countries thus depends again on the relation between the actual emissions and the share of the proceeds of permits that is being distributed to the country. If a country is a net buyer of permits, a faster

[13] Due to the simple financial market between the two countries, the case for country B is omitted here since it is just the same effect with the opposite sign.

[14] This can be seen from the fact that the initial level of $q_0\tau_0 + hP_0$ still determined by (56). Since the growth rate of the resource price is determined by the interest rate which is not affected by g_τ, g_P has to adjust such that the total marginal cost of the resource is not altered.

reduction of the tax rate which implies a higher growth rate of the permit price, its consumption is being reduced due to the higher expenditures for permits.

In order to study the effect of the initial tax level, we focus on the case where the taxes are constant over time ($g_\tau = 0$). In that case, consumption of country A simplifies to

$$C_A(0) = \alpha Y_A(0) + \vartheta_A(1-\alpha)Y(0) - \vartheta_A \rho q_0 \tau_0 S_0 + \rho q_0 S_0^A(\tau_0 - 1) + \rho B_A(0), \quad (60)$$

where S_0^A is the share of the total stock of the resource that will eventually be consumed in country A. From this expression, we can study the effect of an increase in both countries' tax rate. Since the tax rate can have an impact on both the permit and the resource prices (due to the identification problem discussed earlier), we study the two extreme cases. First, if q remains unchanged (which might be the more realistic case, as discussed before), we find that

$$\left.\frac{dC_A(0)}{d\tau_0}\right|_{q_0=const} = \rho q_0 \left[S_0^A - \vartheta_A S_0\right]. \quad (61)$$

The sign of this expression depends on the relation between the resource consumption and the share of the revenue of permits each country gets. A net buyer country of permits will gain from this policy due to lower expenditures for permits. If the revenues are distributed accordingly to the actual consumption in each country, there is no distributive effect of taxation since the tax revenues are exactly compensated by lower transfers coming from permit sales.

On the other hand, if we consider the situation where the tax does not alter the permit price but only influences q_0, we get a different result. We look at a marginal increase of the tax rate that is accompanied by a decline of the resource price such that $q_0\tau_0$ remains constant, i.e., $d\tau_0/\tau_0 \approx dq_0/q_0$.[15] Since all other variables are not affected by this tax raise, we get from the total differential the following effect on consumption:

$$\left.\frac{dC_A(0)}{d\tau_0}\right|_{P_0=const} = \rho \frac{q_0}{\tau_0} S_0^A \quad (62)$$

This effect is always positive and reflects the fact that the resource rent to be paid to country B is reduced through taxation. This implies that the resource-rich country B is worse off due to the reduced resource rent.

[15] More precisely, we need that $(q_0 + dq_0)(\tau_0 + d\tau_0) = q_0\tau_0$ holds. However since, the cross product $dq_0 d\tau_0$ is very small compared to the other terms, we can use this approximation.

Different from the model with no permits, the overall effect is somewhat ambiguous. It depends on the revenue sharing rule of the permit scheme and on the impact ot the tax on the resource and permit prices. When we assume that both prices are affected by the tax rate, we obtain the distributive effects as a weighted average of the two extreme cases.[16] So there is a continuum of effects depending on the relative change of the two prices that are induced by the tax.

Summing up, we find that when the taxes are equal in the two countries, global optimality is not affected. However, the distributional implications depend on the tax rate and its growth rate, the specification of the permit scheme (in particular its distributional aspects), and the effect of the tax on both the prices for permits and the resource.

4.2. Different national tax rates

When we allow the national taxes to differ, things become more difficult but also more realistic as it has been pointed out in the introduction. In this case, we have necessarily different marginal cost of the resource in the two countries, namely $q\tau_B + hP_0 \neq q\tau_A + hP$. This implies that the growth rates of resource usage and thus output differ between the two countries. Therefore, the optimum can never be achieved since (13) and (14) never hold at an equilibrium (if it exists). This stems from the fact that an international permit system implying an identical permit price. Together with the fact that the resource price is also determined globally, the national different taxes create a distortion due to different marginal costs of the resource usage which cannot be eliminated through trade or delocalization of production. Hence, the country with the lower tax will attract more of the resource. This leads to a suboptimal allocation due to the diminishing marginal productivity of the resource.

Note that the argument used frequently in favor of international permit systems that it equalizes costs a pollutant globally does not hold here. In that we introduce the link between resource consumption and pollution, we find that in a second best world with pre-existing (non-optimal) taxes, a global permit trading system creates an additional distortion.

While the exact solution of the equilibrium is not feasible in this model, we know at least that a global permit system can never be optimal in the presence of national different taxes. Therefore we look at the case of national permit systems

[16]In this case we take $dq_0 = -\xi \frac{q_0}{\tau_0} d\tau_0$ where $\xi \in [0, 1]$ denotes the relative share of the change of τ_0 that is undone by a change of q_0.

which might be the preferred solution in this case.

4.3. National permit trading systems

We now look at the case where the profile of permits available $\{z_t\}$ is still determined globally and individual levels are assigned to each country. But now, no transactions between the national permit markets are allowed. The prices for permits are thus allowed to differ between countries. We denote by z_A and z_B the allowances assigned to each country such that $z = z_A + z_B$ and by P_A and P_B the respective permit prices at any point in time.[17] We look at the case, where the global profile of permits is set optimally. Additionally, in order to make it possible to implement the global optimum, we assume that the national permit profiles are determined such that they allow for equal growth rates of production in the two countries. Note that this setting is comparable to the situation under the Kyoto protocol without the International Emissions Trading (IET) mechanism (as proposed in article 17 to be put in place in 2008), but with national permit systems in place as they already exist in several countries (Kitamori 2002). Since the reduction obligations are set globally, countries can decide which instrument to use in order to reach their individual targets. As we assume that tax levels are set non necessarily optimally, national permit systems are the instrument of choice.

The tax rates are exogenously set for both countries and differ between the two. Now, the marginal cost of the resource can be equalized at equilibrium. This will happen due to the international markets for the resource and the final good. Moreover, the equilibrium for each country i is straightforward to obtain and can be characterized by the following proposition:[18]

Proposition 4. *The equilibrium with national pollution permit systems for both countries $i \in \{A, B\}$ is characterized by the following conditions:*

$$g_{R_i} = g_z \tag{63}$$

$$g_{Y_i} = g_{C_i} = \alpha x + (1 - \alpha) g_z = r(t) - \rho \tag{64}$$

[17] We look here only at the case where $g_{z_A} = g_{z_B}$ since otherwise the optimum can never implemented. Therefore, if this were the case, the allocation would never be optimal (straightforward to see from Proposition 1).

[18] We imposed the condition that the number of permits available in each contry grows at the same rate g_z since otherwise one of the no Ponzi conditions would not hold at equilibrium.

$$g_{q\tau_i + hP_i} = \alpha(x - g_z) > 0 \tag{65}$$

$$r(t) = g_q = \alpha x + (1-\alpha) g_z + \rho \tag{66}$$

Note that the growth rates of output, consumption, and resource usage are equal for the two countries. Additionally we find the following initial values for consumption at equilibrium:

$$C_A(0) = Y_A(0) - \rho q_0 S_0^A + \rho B_A(0) \text{ and } C_B(0) = Y_B(0) + \rho q_0 S_0^A - \rho B_A(0) \tag{67}$$

Note that now the taxes and permits do not at all affect the distribution of consumption (and production). Also note that the partitioning of the permit allowances is determined by the relative productivities[19] as

$$z_A(0) = z(0) \frac{L_A}{L_A + \phi L_B} \text{ and } z_B(0) = z(0) \frac{\phi L_B}{L_A + \phi L_B} \tag{68}$$

This initial values for resource usage together with the conditions for both countries' equilibria imply that the global optimum can be implemented simply by setting the optimal growth rate of permits (globally and in both countries) according to (51). As it has already been said, optimality requires also the partitioning of the permits as given by (68). While a global permit trading system is not able to restore optimality in the presence of national taxes, permit systems on the national level are indeed able to do so.

Looking at the prices for permits between the two countries, the equal marginal costs of the resource imply directly

$$P_A - P_B = -\frac{q}{h}(\tau_A - \tau_B) \ \forall t. \tag{69}$$

Evidently, the permit prices' discrepancy reflects just the differences in the national taxes. Note that as in the case without taxes, the absolute levels of the permit and resource prices are not identified by the model. In this case, while the difference between the two permit prices is determined, the absolute levels compared to the resource price are somewhat free to choose at is was argued before.

[19] This is due to the fact that substitution betwen production factors is limited to (fixed) labor and the resource. The conditions follow from the initial values of production and the fact that the marginal costs will be equalized.

So far we assumed that the permits available globally were chosen according to the optimal solution presented in chapter three. This requires determination on the global level due to the nature of the environment as a public good. If the countries set their respective optimal extraction path for the resource, their criterion would not be the optimal g_R given by (17). When we look at the national optimum individually, the optimal solution yields an equivalent of this condition given by

$$g_{R_i} = -\frac{\lambda g_E}{1-\alpha}\left[\frac{R_i}{R_A + R_B}\right] - \rho \tag{70}$$

which becomes for the symmetric[20] equilibrium:

$$g_R = -\frac{1}{2}\frac{\lambda g_E}{(1-\alpha)} - \rho \tag{71}$$

Comparing this condition with (17) and taking into account that $g_E < 0$, this implies that the resource is exhausted faster than in the global optimum. This stems precisely from the public good nature of the environment. This result accentuates the necessity that the optimal extraction path (or equivalently, the optimal time path of the environment) has to be set at a global level considering the global impact of e.g., burning fossil fuels.

5. Conclusion

The basic results including the distributional effects of the different regimes described above can be summarized as shown in the following table:

[20] In this model, non-symmetric equilibria do most probably not exist, however, we did not check this explicitly since we are only interested in the role of the public good.

policy	optimality	determination	distributional effects
g_τ^{opt}, $\tau_A = \tau_B = \tau_0$	optimal,	τ_0 not determined	$\tau_0 \uparrow \Rightarrow q_0 \downarrow \Rightarrow$ resource scarce country gains
g_τ^{opt}, $\tau_A \neq \tau_B$	not optimal		delocalisation to the country with lower taxes
$\{z_t^{opt}\}$	optimal	q and P only jointly determined	$P_0 \uparrow \Rightarrow q_0 \downarrow \Rightarrow$ resource scarce country gains
$\{z_t^{opt}\}$, g_τ, $\tau_A = \tau_B = \tau_0$	optimal		$g_\tau \downarrow \Rightarrow g_P \uparrow \Rightarrow$ net seller of permits gains $\tau_0 \uparrow \Rightarrow$ resource scarce country gains if $q_0 \downarrow$, net buyer of permits gains if $P_0 \downarrow$
$\{z_t^{opt}\}$, $\tau_A \neq \tau_B$	not optimal		
$\{z_t^{opt}\}$, $\tau_A \neq \tau_B$, national permit markets	optimal	q and $\{P_A, P_B\}$ only jointly determined	$\tau_i \uparrow \Rightarrow P_i \downarrow$ (no effect), but $q_0 \downarrow \Rightarrow$ resource scarce country gains

We have studied second-best equilibria in a model that integrates a non-renewable resource and pollution. First we studied several policies, which, while all being optimal, have important distributional impacts. The effect depend mainly on the design of the permit scheme (in particular, its revenue sharing rule) and the determination of the initial prices of the resource and permits. In particular, the indetermination of the initial prices in this model leaves room for very different distributional consequences.

We then look at the case where different national taxes on resource consumption are in place and study the optimal pollution permit system. The results suggest that a global permit trading scheme is not always optimal. This comes from the fact that in a model with non-renewable resources like fossil fuels, it is not the cost of the pollutant but the total marginal cost of using the resource which has to be equal between countries. The presence of varying national resource taxes thus asks for national permit markets in order to obtain an international unique 'total price' of the resource. Note however that this result does not stand against the idea of international actions against pollution like the Kyoto protocol. It suggests that while the quota and reduction goals should be agreed upon on a global level, the measures to achieve them should take into account heterogeneity of the tax systems between countries. Supranational permit trading makes perfectly sense for a region with more homogenized taxes like Europe, which points in favor of the European Trading System. On the other hand, between countries with very different taxes on non-renewable resources, national permit markets are preferable. It therefore suggests that the International Emissions Trading (IET) might create a distortion due to the little harmonization of taxes on exhaustible resources.

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