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Abstract

The theoretical justification for a greenhouse gas (GHG) cap and trade system is that participants will trade emission permits until their marginal cost of abatement equals the equilibrium price of emission permits. However, for fiscally constrained governments this logic does not apply, as they have a fiscal incentive to let welfare concerns, rather than industrial cost efficiency, guide their abatement policy. Then, global cost efficiency will fail even if just a (small) subset of governments are fiscally constrained. Finally, we argue that any institutional change which breaks the connection between a government's abatement policy and its budget will increase welfare.

Keywords: environmental policy, fiscal incentive, fiscal constraints, GHG cap and trade, welfare.

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1 Introduction

The UN Framework Convention on Climate Change (UNFCCC) has as its ultimate objective to stabilize concentrations of greenhouse gasses (GHGs) in the atmosphere at a level that *prevents dangerous anthropogenic inferences with earth's climate system.* In order to meet this objective, international climate negotiations have proceeded along the following track: First, set a global cap for emissions, then allocate the global cap to nations, and, lastly, allow nations to trade in emission permits. The cap and trade mechanism is said to be characterized by two favorable features. First, it minimizes global pollution abatement costs for any given global cap, a result which dates back to the literature on the optimal regulation of environmental pollutants (Dales, 1968). Second, the national caps can be allocated according to the principle of common but differentiated responsibilities (UNFCC's Article 3.1) – implying a compensation to countries whose histories leave them with particularly high burdens from emission trading – without impeding efficiency (Montgomery, 1972).

We demonstrate, however, that global GHG cap and trade across countries introduces a *fiscal incentive* which may hamper the simple text book notion of cost efficiency. Crucial to our argument is that national governments may be *fiscally constrained* – that is, they are unable to tax the private sector sufficiently to finance their first-best levels of public spending. A fiscally constrained government will have the incentive to close its fiscal gap through the use of any available instrument, including emission trading. We show that if one or more countries are fiscally constrained, greenhouse gas (GHG) abatement costs will no longer be minimized even if a global permit market is established. Moreover, the permit price will be below the cost efficient permit price. Finally, the initial allocation, or a reallocation, of emission permits will affect both the price on emission permits and the global distribution of GHG abatement effort.

As long as abatement costs are not minimized, there are potential gains that possibly can be exploited by changing the cap and trade institution. First, we show that a restriction on permit sales, as advocated by the supplementary principle in the Kyoto treaty, does not lead to lower abatement costs. In order to improve on the permit market equilibrium the institutional change must break the direct connection between a national government's abatement policy and its budget. One candidate solution could be global auctioning of emission permits directly to firms, and transfers of the revenues from the auctioning to nations by a predetermined scheme. We show that this improves global welfare in our static setup, and in fact this is the way in which the EU ETS heading.[1]

As an extension, we also discuss how a cap and trade system carries with it adverse dynamic effects. First, since access to the permit market effectively equips fiscally constrained countries with a powerful fiscal instrument, their incentive to invest in improving their ability to collect taxes will be weakened. Then, if different dimensions of state capacities act as strategic complements (as in, e.g., Besley and Persson, 2011), economic development may be hampered. Second, the permit price in fiscally unconstrained countries will be lower than marginal environmental damage which, in turn, provides too weak incentives for research and development of new pollution abatement technology. Thus, the cost of abatement in future periods may be higher compared to a situation in which the price on emissions is equal to marginal environmental damage in all countries.

That countries may be *fiscally constrained* is not new to the economics literature. Cukierman, Edwards and Tabellini (1992) differentiate between a tax reform and fiscal policy. Fiscal policy is the choice of tax rates and level of government spending. A tax reform is the broad design of a tax

[1] See http://ec.europa.eu/clima/policies/ets/index_en.htm.

system which involves both the available tax base and technology for collecting taxes. While fiscal policy can be changed from year to year, a tax reform takes several years, and thus, fiscal policy can be constrained in the short run. Besley and Persson (2011) formalizes the distinction between fiscal policy and tax reforms by assuming that the government cannot collect more than a given share of private income as taxes in a given year. We say that the country is *fiscally constrained*, if the government could have improved welfare by collecting a higher share of private income,

The fiscal stance in many developing countries may serve as examples of fiscal constrainedness. It is well documented that the lack of an effective technology for collecting taxes prevents several developing country governments from raising the amount of government funds needed for the financing of a socially desirable level public goods spending, such as spending on basic health and schooling services, or on economically sound public infrastructure investments.[2] Additionally, the use of advanced transfer pricing techniques by large multinational companies, and organizational issues at the lower bureaucratic level, including corrupt practices, severely limits the fiscal capacity in many of these countries. According to a joint report by the IMF, OECD, UN and WB, "[...] half of sub Saharan African countries still mobilize less than 17% of their GDP in tax revenues [...]".[3]

Countries may also be occasionally fiscally constrained. Generally, this can happen for two different sets of reasons. First, a government's capacity to raise funds may temporally shift down below the capacity needed to finance a given level of socially optimal level of public goods. This may occur if the economy is hit by a negative shock to productivity or to aggregate demand (an economic depression), if there is a sudden increase in the price of government funding due to, e.g., international financial stress, or if the economy experiences a massive migration of parts of the tax base.[4] Second, at any given level of fiscal capacity, a government may become temporarily fiscally constrained if there is a positive shock to the marginal social benefit of public funds. Economists and economic historians have extensively analyzed how both intrastate and interstate conflicts, or wars, suddenly and significantly increases the fiscal needs of countries, often beyond their current fiscal capacities.[5] Notice that both of these sources of fiscal constrainedness may be exacerbated by political frictions, such as the political deadlock recently seen in U.S. politics, which may temporarily hinder or delay necessary fiscal adjustments.

The technical point of departure for our model setup is a standard cap and trade model where we assume the existence of an international agreement on the overall cap on global GHG emissions. Emission permits can be traded costlessly among the countries. Subject to the allocation of emission caps, the governments can freely set their national abatement targets. The benevolent governments in our model ultimately care about household welfare, which derives from the households' consumption of both private and public goods. Households, in turn, derive income from industrial production with GHG as a by-product, and the national governments finance public goods provision

[2] For a broad documentation of the weak fiscal capacity among developing countries, see UNDP (2011, Ch. 7). Indeed, Besley and Persson (2013) lists as a stylized fact that, due to lack of effective tax technology and widespread tax evasion: "Rich countries collect much higher tax revenue than poor countries despite comparable statutory rates."

[3] The full reference reads: International Monetary Fund, Organization for Economic Cooperation and Development, United Nations, and World Bank (2011). This report states that (2011, p.9) the identification of "ways to help developing countries' tax Multinational Enterprises (MNEs) through effective transfer pricing" is one of five requests asked by the G-20 to help raise the fiscal capacity in developing countries. Khan (2006) discusses the relationship between fiscal capacity and corruption in developing countries.

[4] Notice that financial crises is even more critical for the ability to raise public funds and, hence, the ability to optimally adjust fiscal policy among those developing countries with the lowest level of fiscal capacity (World Bank, 2009).

[5] See, e.g., Dincecco and Prado (2012), Dincecco and Katz (2012), Gennaioli and Voth (2011), Hintze (1906), Tilly (1975; 1990).

through the taxation of household income. Additionally, however, the governments can also collect funds from trading in emission permits.

If governments are free to raise whatever amount of funds they desire through taxation, fiscal policy, on one hand, and the abatement policy, on the other hand, are effectively separated in the governments' welfare maximization problem. Then, the equilibrium level of public spending coincides with the first-best preferred level and the government optimally sets the national emission level such that the marginal industrial cost of abatement is equal to the equilibrium price of emission quotas. If some of the governments are fiscally constrained, however, the optimally chosen levels of emissions in these countries are also influenced by their respective marginal utilities of public goods provision. In market equilibrium, the fiscal incentive of those countries that are fiscally constrained will be transmitted to *all* participating countries through the equilibrium price of emission permits. Hence, also the abatement levels of fiscally unconstrained countries will be affected, and the global market equilibrium is no longer cost efficient.

One fundamental assumption that we make is that governments are always fully capable of setting a national emission target, and enforce this in a cost efficient way. We consider this to be a natural benchmark, which also underlines the robustness of our results. Our analysis demonstrates that even with perfectly effective market institutions, and even if national governments are fully benevolent social welfare maximizers, the occasional event of fiscal stress will generally render the permit market cost inefficient. Alternatively, one could imagine that a fiscally constrained government regulates emissions through brute force; the most straightforward way would simply be to force those polluting industries that contribute the least to social welfare to shut down. Such a country would likely not be abating its emissions efficiently, however, the fiscal incentive created by the permit market would still apply and probably amplify the loss from the inefficient regulation of emissions.

Our paper relates to a larger literature on how inefficiencies in the organization of the market for emission permits and different structural characteristics in local markets may induce a suboptimal market allocation of abatement. Hagem and Westskog (1998) analyze the effect of imperfect competition in the permit market, and shows that introducing durable permits – e.g., permits that last for more than one period – can limit the problem with market power. Moreover, Hagem and Westskog (2009) shows that a dominant player in the permit market can behave competitively if the allocation of permits in period $t + 1$ depends on the price observed in period t. Babiker et al. (2004) analyze how pre-existing distortions in the economy of the countries participating in permit trade may erode the gains from this trade. This happens because there is a difference between private marginal abatement costs and social marginal abatement cost. We note that these types of inefficiencies will come on top of the inefficiencies associated with the fiscal incentive that we study here. Finally, there is a large literature on the Kyoto protocol discussing and analyzing how its flexible mechanisms (permit trade in various forms) may lead to inefficiencies, as in, e.g., Barrett (1998), Weyant (1999) and Springer (2003).

Also other and less formal contributions have warned that trading in emissions permits among nations might lead to undesired outcomes. Lohmann (2006) argues that it (p.18): *"encourages the industries most addicted to coal, oil and gas to carry on as before"*. Victor and Cullenward (2007) are sceptical to cap and trade for several reasons, one being that it *"might impede wise planning due to volatile prices"*. The EU has also been hesitant to fully accept the efficiency properties of cap and trade, and during the Kyoto negotiations they insisted on the "supplementary principle" in order to ensure that permit trading should not lead to too little abatement in the Kyoto Annex

1 countries (UN, 2000).[6]

Finally, our paper relates to the so-called "resource curse" literature which informs us that when a country is endowed with a valuable and tradable resource, political incentives may distort economic policies and outcomes. In particular, this may happen when democratic institutions are weak, or when there is a high degree of political instability (Robinson et al., 2006).[7] Translated into the context of cap and trade, insights from this literature suggest that a non-democratic government may choose to abate more than the technically cost effective level of abatement, in order for the political elite enrich themselves or their partisans through the sale of emission permits at the world market. We show, however, that one need not resort to political economy distortions of any kind for the fiscal incentive to hamper economic efficiency.

The remaining of the paper is organized as follows. Section 2 describes the model and the economic environment. In Section 3, we analyze the incentives of fiscally unconstrained and fiscally constrained countries, and derive the comparative statics. The market equilibrium is analyzed in Section 4, and this is illustrated with a numerical model in Section 5. Section 6 includes a number of extensions including a discussion of a global emission tax regime instead of a global permit trade regime. Finally, Section 7 concludes.

2 The model

2.1 The world

We consider a world consisting of n heterogenous countries. Each country is populated by a large number of identical households, and their economies are administered by national, welfare maximizing governments. We assume that n is sufficiently large, and each single country i, $i = 1, ..., n$, sufficiently small, such that all countries and their respective governments behave as price takers on the world market.

World aggregate emissions E lead to global environmental damages $D(E)$. We assume that there exists a global climate agreement that puts a cap on global emissions $\bar{E}$, and that allocates emission quotas to countries. The treaty also ensures that each country's level of emissions does not exceed the country's holding of emission quotas. The global emission target, $\bar{E}$, is strictly lower than the historical level of emission, $\bar{E} < \sum_n e_{i0}$, where e_{i0} is the historical level of emission in country i. Moreover, the target is distributed to the countries according to $\bar{e}_i = \vartheta_i e_{i0}$, $\vartheta_i \leq 1$.

Finally, let $C^G(E)$ denote global abatement cost e.g. the minimum global cost of reaching a global emission target $E < \sum_n e_{i0}$. We assume that the target, $\bar{E}$, is optimal in the sense that it minimizes the sum of environmental costs $D(E)$ and pollution abatement costs $C^G(E)$.

[6] Supplementarity refers to the concept that internal abatement of emissions should take precedent before external participation in flexible mechanisms. These mechanisms include emissions trading, Clean Development Mechanism (CDM), and Joint Implementation (JI). The supplementarity principle is found in three articles of the Kyoto Protocol: article 6 and 17 with regards to trading, and article 12 with regards to the clean development mechanism.

[7] See, e.g., van der Ploeg (2011) for a broad review of the resource curse literature, and Morrison (2010) on foreign aid and its parallels with the "resource curse".

2.2 Households

Households derive income from industrial production with GHG emissions as a necessary by-product. The level of industrial income in country i can be represented as

$$\pi^i(e_i) = \bar{\pi}^i - C^i(e_i), \tag{1}$$

where e_i is the level of emission in country i and the abatement technology $C^i(e_i)$ reflects the country's industrial characteristics, and where $C^i_e(e_i) \leq 0$ and $C^i_{ee}(e_i) \geq 0$ for $e_i \leq e_{i0}$. The marginal cost of abatement in country i is then given by $-C^i_e(e_i)$, as in, e.g., Rubin (1996).

The income of households from production, $\pi^i(e_i)$, is taxed at the flat rate t_i. Assuming that households derive utility from consuming their net income, y^i, and that they also value public goods consumption, G^i, we can write the preferences of the households as

$$u^i\left(y^i(t_i, e_i), G^i\right) = w^i\left(y^i(t_i, e_i)\right) + h^i\left(G^i\right), \tag{2}$$

where

$$y^i(t_i, e_i) = (1 - t_i)\,\pi^i(e_i), \tag{3}$$

and where the Inada conditions apply to both $w^i(\cdot)$ and $h^i(\cdot)$.[8]

2.3 Governments and GHG emissions

Governments are free to determine their respective national levels of GHG emissions. For instance, the national governments may allocate permits among the national emitters and monitor emissions themselves, or they may delegate this to a separate body; anyway, we assume that the emission level set by the national governments will be respected. To the extent that the governments set their national levels of GHG emissions different from their national quotas, they may trade their respective residual emission permits on an international market. When deciding on its preferred level of emissions, the government in each country will take into account the equilibrium price of emission permits in the market, as well as the social costs and benefits to the country of emission trading.

Country i's net revenue from trading emission permits, which may be positive or negative, is given by $p^{eq}(\bar{e}_i - e_i)$, where $p^{eq.}$ is the equilibrium permit price on the world market. How this net revenue is allocated between the government and the households depends on the fiscal and environmental institutions in the country. In the following, we assume that the entire net revenue from emissions trading accrues to the government, however, this constraint can easily be relaxed.

[8] The Inada conditions imply: $w^i_y(y_i) > 0$; $w^i_{yy}(y_i) < 0$; $\lim_{y \longrightarrow 0} w^i_y(y_i) = \infty$; $\lim_{y \longrightarrow \infty} w^i_y(y_i) = 0$; $h^i_G(G_i) > 0$; $h^i_{GG}(G_i) < 0$; $\lim_{G \longrightarrow 0} h^i_G(G_i) = \infty$; $\lim_{G \longrightarrow \infty} h^i_G(G_i) = 0$. Notice that welfare is an implicit function of the level of abatement. This setup covers a broad range of abatement cost structures, such as, e.g., $C(c_i, e_i) = c_i f(e_i)$, $c_i > 0$, where $f(\cdot)$ is continuously differentiable and satisfies the (inverse Inada) conditions: $f(e_i) > 0$ for any $e_i \geq 0$; $f_e(e_i) < 0$; $f_{ee}(e_i) > 0$; $\lim_{e_i \longrightarrow 0} f_e(e_i) = \infty$; $\lim_{e_i \longrightarrow \infty} f_e(e_i) = 0$. If $w^i = w(C(c_i, e_i)) > 0$, $w_C < 0$, and $w_{CC} = 0$, then welfare will be increasing (decreasing) at a decreasing (increasing) rate in the level of emission (abatement) and decreasing in c_i: $w^i_e(e_i|c_i) \equiv w_C c_i f_e(e_i) > 0$; $w^i_{ee}(e_i|c_i) \equiv w_C c_i f_{ee} < 0$; $w^i_c(e_i|c_i) \equiv w_C f(e_i) < 0$. The restriction $w_{CC} = 0$ simplifies the expressions, but could easily be replaced by other and more general assumptions on the shape of $w(\cdot)$ for which $w^i_{ee} < 0$.

We also assume that the national emission target is grandfathered to the private sector, and hence, that the government does not use a permit auction.[9]

In addition to regulating the levels of emission in their respective countries, the countries' governments are responsible for the provision of public goods. We assume that the governments freely decide on a tax rate t_i on private income, and a level of public goods provision G^i, so as to maximize social welfare. The tax rate in any country i is, however, potentially constrained by the country's fiscal capacity, $\tau^i \in (0,1)$ implying

$$t_i \leq \tau^i. \tag{4}$$

The fiscal capacity parameter τ can be interpreted as in Besley and Persson (2010): *"In concrete terms, τ represents fiscal infrastructure such as a set of competent tax auditors, or the institutions necessary to tax income at the source or to impose a value-added tax"*. For some countries, the fiscal capacity constraint may (occasionally) be binding, while for others it may not. The governments budget constraints can then be stated as

$$G^i\left(t_i, e_i\right) \leq t_i \pi^i\left(e_i\right) + p^{eq\cdot}\left(\bar{e}_i - e_i\right). \tag{5}$$

The governments maximize welfare with respect to the tax rate and the level of emissions,

$$\max_{t_i, e_i} u^i\left(y^i\left(t_i, e_i\right), G^i\left(t_i, e_i\right)\right) = \max_{t_i, e_i}\left[w^i\left(y^i\left(t_i, e_i\right)\right) + h^i\left(G^i\left(t_i, e_i\right)\right)\right], \tag{6}$$

subject to the constraints given by inequalities (4) and (5).

Notice that our assumptions about the properties of $w^i(\cdot)$ and $h^i(\cdot)$ imply that the budget constraint, but not necessarily the fiscal constraint, holds with equality.

3 Taxation, public goods provision and emissions

3.1 Optimal policy when the fiscal constraint is not binding

In the continuation, we drop the country indexation i until we consider the market equilibrium in Section 4. In order to save notation, we denote $\pi^i(e_i)$ and $u^i\left(y^i\left(t_i, e_i\right), G^i\left(t_i, e_i\right)\right)$ by π^i and u^i, respectively, and denote the first derivatives of $w(\cdot)$, $h(\cdot)$, and $C(\cdot)$ by w_y, h_G, and C_e, respectively, noting that all of these are functions of all of the exogenous variables and the parameters of the model (i.e., of $\bar{e}$, τ, and $\bar{\pi}$).

Given that each country is too small to take into account its own impact on the equilibrium price, $p^{eq\cdot}$, a respective government's objective function can be restated as

$$\max_{t,e}\left[\begin{array}{c} w\left((1-t)\left(\bar{\pi}^i - C(e)\right)\right) \\ +h\left(t\left(\bar{\pi} - C(e)\right) + p^{eq\cdot}\left(\bar{e} - e\right)\right) \end{array}\right], \tag{7}$$

which is solved subject to Eq. (4). If the fiscal constraint is not binding, the two first order conditions simplify, after rearranging, to:

$$h_G = w_y; \tag{8}$$

[9] In the Appendix we extend the model in two ways: (A1) We allow the government to obatin additional income from auctioning of permits nationally; (A2) we allow the proceeds from emission trading to be split among the government and the households. All of our main results regarding the inefficiency of cap and trade remain invariant to these extensions, however, some of the comparative statics change.

$$-C_e = p^{eq\cdot}. \tag{9}$$

Hence, when the fiscal constraint is not binding, the decisions on taxation and public spending on the one hand, and which emission level to implement on the other hand, are effectively separated. Fiscal policy, t and G, should then be set such that the marginal utility from private consumption, w_y, is equal to the marginal utility from consumption of the public good, h_G, and the level of emission should be such that the marginal abatement cost, $-C_e$ is equal to the equilibrium price of emission permits, $p^{eq\cdot}$.

Optimal policy can be derived from the first order conditions. From Eq. (8) we have that the optimal level of public goods provision is given by

$$G^* = h_G^{-1}(w_y), \tag{10}$$

where $h_G^{-1}(\cdot)$ is the inverse of h_G, and the superscript * indicates that the allocation is consistent with the first-best fiscal policy vector of the welfare maximizing government. By Eq. (9), the optimal level of emission of the country is given by

$$e^* = C_e^{-1}(p^{eq\cdot}). \tag{11}$$

where $C_e^{-1}(\cdot)$ is the inverse of $-C_e$.

Finally, the welfare maximizing tax rate is found by inserting from equations (10) and (11) into the government budget constraint in Eq. (5),

$$t^* = \frac{G^* - p^{eq\cdot}[\bar{e} - e^*]}{\bar{\pi} - C(e^*)}. \tag{12}$$

The expression in Eq. (12) implies that the optimal tax rate in a fiscally unconstrained country, t^*, can be negative if the amount of quotas allocated to the country, $\bar{e}$, is sufficiently high. A negative tax rate can be interpreted as the government redistributing to the households the residual of its proceeds from trading in emission permits, subject to providing the optimal amount of public goods provision.

3.2 Optimal policy in fiscally constrained countries

In the event that the fiscal constraint, given by Eq. (4), is binding, the government optimally sets $t^c = \tau$, and maximizes its objective function, Eq. (7), with respect to e_i. Notice that a fiscally constrained government ideally would like to set t even higher, but that the fiscal capacity of the country renders such a policy not feasible. The associated first order condition of a fiscally constrained country is then given by

$$[p^{eq} - \tau(-C_e)]\, h_G = (1-\tau)(-C_e)\, w_y. \tag{13}$$

On the left hand side of (13) we have the marginal effect of more abatement on the utility from public spending. As long as p^{eq} is higher than $\tau(-C_e)$, the government can increase its public spending by demanding more abatement from the private sector in exchange with more permit sales, which has a value of h_G. On the right hand side of (13) we have the marginal effect of more abatement on the utility from private income.

Reorganizing Eq. (13), the first order condition for the fiscally constrained country can be stated as

$$-C_e \frac{\tau h_G + (1-\tau)\, w_y}{h_G} = p^{eq\cdot}. \tag{14}$$

Note that the government no longer equates marginal abatement cost with the permit price. In Eq. (14), the left hand side represents the marginal *social* cost of abatement, including how abatement affects the provision of public goods in the country. Interpreting Eq. (14), and comparing with the cost efficient allocation in Eq. (9), we obtain the following result for the optimal level of emissions, e^c, in a fiscally constrained country:

Proposition 1 *If a country goes from being fiscally unconstrained to being fiscally constrained, its level of emissions will decrease, i.e., $e^c < e^*$.*

Proof. Comparing equations (9) and (14), notice that $\frac{\tau h_G+(1-\tau)w_y}{h_G} < 1$ since, for any fiscally constrained country, $\tau \in (0,1)$ *and* $h_G > w_y$. This implies that $-C_e > p^{eq}$, and hence that $e^c < e^*$. ■

Global abatement costs $C^G(\bar{E})$ is given by $\sum_i C^i(e_i)$. We know that e_i^*, $i = 1, ..., n$, minimizes C^G for any global cap $\bar{E}$. It then follows from Proposition 1 that global abatement costs will not be minimized in a permit market equilibrium in which one or more countries are fiscally constrained.

Note that in Eq. (14), $p^{eq\cdot}$ and e_i enter h_G^i through G_i, and that e_i enters w_y^i through C_i. Thus, without further assumptions about the shape of $w(\cdot)$, $h(\cdot)$, and $C(\cdot)$ we cannot solve for an explicit expression for the level of emission by the constrained country, $e^c(p^{eq})$. However, we can still evaluate the comparative statics on e^c with respect to the variables $p^{eq\cdot}$, $\bar{e}$, and τ, noting that $p^{eq\cdot}$ is considered exogenous to the single country.

3.3 Comparative statics

From equations (11) and (14), and taking into account that $w(\cdot)$, $h(\cdot)$, and $C(\cdot)$ are implicit functions of all variables and parameters that are exogenous to the single country, it is clear that both e^* and e^c generally depends on $\bar{e}$ and $p^{eq\cdot}$. The comparative statics of e^* and e^c can be found by implicit derivation of equations (11) and (14). We begin with the case when the government is fiscally unconstrained and then move on to the case when the fiscal constraint is binding.

If fiscal capacity is not binding, implicit derivation of Eq. (11) with respect to e^* and the three parameters $p^{eq\cdot}$, τ, and $\bar{e}$ gives:

$$\frac{de^*}{dp^{eq\cdot}} = -\frac{1}{C_{ee}} < 0; \tag{15}$$

$$\frac{de^*}{d\bar{e}} = 0; \tag{16}$$

$$\frac{de^*}{d\tau} = 0. \tag{17}$$

Hence, a fiscally unconstrained country's level of emissions depends exclusively on the equilibrium price of emission permits, and not on the quota allocation or the fiscal capacity. An increase in the permit price induces the government to decrease the level of emission since the increased price of permits makes selling emission permits more valuable than producing at the margin. The results in equations (15) to (17) are standard results in the literature on emissions trading.

If a country is fiscally constrained, however, both τ and $\bar{e}$ may matter for the government's optimal level of emission. We differ between countries that are net sellers of permits, i.e., $\bar{e} - e^c > 0$, and countries that are net buyers, i.e., $\bar{e} - e^c < 0$. The comparative statics on the level of emission, e^c, can be found by implicit derivation of the first order condition in Eq. (13), and we summarize the results for a fiscally constrained country in the following propositions:

Proposition 2 *For a fiscally constrained country which is a net buyer of emission permits we have* $\frac{de^c}{dp^{eq\cdot}} < 0$*, while for a fiscally constrained country which is a net seller of emission permits we have* $\frac{de^c}{dp^{eq\cdot}} \gtreqless 0$.

Proof. First, implicit derivation of Eq. (13) with respect to e^c and $p^{eq\cdot}$ gives

$$\frac{de^c}{dp^{eq\cdot}} = \left[-\left(h_G - w_y\right) - h_{GG}\left[p^{eq} - \tau\left(-C_e\right)\right]\left(\bar{e} - e^c\right)\right]/D_s, \tag{18}$$

where

$$D_s = -\left[\left[w_y + \left(h_G - w_y\right)\tau\right]\left(-C_{ee}\right) + h_{GG}\left[\tau\left(-C_e\right) - p^{eq\cdot}\right]^2 + w_{yy}\left[\left(1-\tau\right)\left(-C_e\right)\right]^2\right] > 0. \tag{19}$$

We have $-\left(h_G - w_y\right) < 0$ and $-h_{GG}\left[p^{eq} - \tau\left(-C_e\right)\right] > 0$. Hence, $\frac{de^c}{dp^{eq\cdot}} < 0$ if $\bar{e} - e^c < 0$, and ambiguous if $\bar{e} - e^c > 0$. ■

In the "net seller" case, there are two effects pulling in different directions: On the one hand, a higher permit price makes it more valuable on the margin to do abatement. Thus, the government substitutes income from taxing the real economy with income from permit sales. On the other hand, the income from permit sales increases which makes it less necessary to do extra abatement to finance public goods. It it easy to see that the income effect might dominate the substitution effect, for instance if the difference $\bar{e} - e^c$ is large, and we then have the counter-intuitive result that a higher permit price leads to less supply of emission permits from the constrained country in question, $\frac{de^c}{dp^{eq\cdot}} > 0$.

In case a fiscally constrained country receives a higher quota, the effect of emissions is unambiguous:

Proposition 3 *For a fiscally constrained country we have* $\frac{de^c}{d\bar{e}} > 0$ *independent of whether the country is a net buyer or a net seller of emission permits.*

Proof. Differentiation of Eq. (13) with respect to $\bar{e}$ gives

$$\frac{de^c}{d\bar{e}} = -h_{GG}\left[p^{eq\cdot} - \tau\left(-C_e\right)\right]p^{eq\cdot}/D_s > 0. \tag{20}$$

■

In this case there is only an income effect: For a given level of emissions, setting a higher quota reduces the money spent on permit acquisitions or increases the income from permit sales. Hence, the country finds it less necessary to do abatement to finance public goods. Finally, we take a look at the effect of an increase in fiscal capacity:

Proposition 4 *For a fiscally constrained country we have* $\frac{de^c}{d\tau} > 0$ *independent of whether the country is a net buyer or a net seller of emission permits.*

Proof. Differentiating Eq. (13) with respect to e^c and τ gives: ■

$$\frac{de^c}{d\tau} = \left[\left(h_G - w_y\right)\left(-C_e\right) - \left(1-\tau\right)\left(-C_e\right)w_{yy}\pi - \left[p^{eq} - \tau\left(-C_e\right)\right]h_{GG}\pi\right]/D_s > 0. \tag{21}$$

Again we have a substitution effect and an income effect, but this time pulling in the same direction. First, a higher income tax makes it more costly on the margin to do abatement since the loss in fiscal income becomes higher when real output decreases. Thus, the government substitutes income from permit sales with income from taxing the real economy by increasing emissions. Second, for a given level of abatement fiscal income increases, which makes it less necessary to do extra abatement to finance public goods.

Comparing with the comparative statics for a fiscally unconstrained country it is clear from Proposition 2-4 that a fiscally constrained country has different incentives when participating in a global market for emission permits than do a fiscally unconstrained country. Notice in particular that the allocation of emission quotas $\bar{e}$ may have real effects since countries change their supply in response to changes in emission quota allocations.

4 Market equilibrium

In this section, we analyze the market equilibrium in the permit market. The condition for market clearing is given by:

$$\bar{E} = \sum_n e_i. \tag{22}$$

The market clearing condition in Eq. (22) implicitly pins down the equilibrium price $p^{eq \cdot}$. Denote fiscally unconstrained countries by j, and constrained countries by k. The equilibrium price is then given implicitly from the following equation:

$$\sum_j e_j^* \left(p^{eq}\right) + \sum_k e_k^c \left(p^{eq}\right) = \bar{E} \tag{23}$$

The following proposition then follows:

Proposition 5 *The equilibrium price in the case in which all countries are fiscally unconstrained must be higher than the equilibrium price in the case in which one or more countries are fiscally constrained as long as* $\left(h_G^k - w_y^k\right) \geq h_{GG}^k \left[p^{eq} - \tau_k \left(-C_e^k\right)\right] \left(\bar{e}_k - e_k^c\right)$, $\forall k$.

When a country goes from being fiscally unconstrained to being constrained, its equilibrium level of emissions decreases (Proposition 1). Thus, we will have $\sum_j e_j^* \left(p^{eq}\right) + \sum_k e_k^c \left(p^{eq}\right) < \bar{E}$. In order to restore equilibrium in the permit market, the price has to fall such that both unconstrained and constrained countries increase their emissions. Note that all constrained countries will react in this way as long as the substitution effect dominates the income effect from a decline in the equilibrium price p^{eq} e.g. $(h_G - w_y) > h_{GG} \left[p^{eq} - \tau \left(-C_e\right)\right] \left(\bar{e} - e^c\right)$ (Proposition 2).

If $(h_G - w_y) < h_{GG} \left[p^{eq} - \tau \left(-C_e\right)\right] \left(\bar{e} - e^c\right)$ for one or more countries k, these countries will respond to a decreasing permit price by decreasing their emissions even more (Proposition 2). Moreover, if this effect dominates the increase in emissions from both unconstrained and constrained countries for which $(h_G - w_y) \geq h_{GG} \left[p^{eq} - \tau \left(-C_e\right)\right] \left(\bar{e} - e^c\right)$ still holds, the equilibrium price may rise. As this seems unlikely, we will in the following assume that:

Assumption A1 $\left(h_G^k - w_y^k\right) > h_{GG}^k \left[p^{eq} - \tau_k \left(-C_e^k\right)\right] \left(\bar{e}_k - e_k^c\right)$, $\forall k$.

Notice that in the symmetric case where all countries are initially identical, we have $\bar{e}_i - e_i^* = 0$. Then, if one or more countries k become fiscally constrained, for example due to a sudden jump in h_G^k, Assumption A1 will hold. More generally, Assumption A1 holds as long as the curvature of $h^j(\cdot)$ is relatively moderate, i.e., if the value $\left|h_{GG}^j\right|$ is relatively low.

Since the global cap is optimally set, the unconstrained market equilibrium must imply $D'(\bar{E}) = C'(e_i^*) \forall i$. We then also have:

Proposition 6 *Given Assumption A1, the permit market equilibrium price in the case in which one or more countries are fiscally constrained must be lower than marginal environmental damage.*

On the other hand, in countries that are fiscally constrained, we may have $C'(e_i^c) > D'(\bar{E})$.

A change in the quota allocation could also have implications for the market equilibrium, as given in Eq. (23). If a constrained country receives a higher emission quota, the country will increase its emissions (Proposition 3). Thus, we will have $\sum_j e_j^* (p^{eq}) + \sum_k e_k^c (p^{eq}) > \bar{E}$, and by A1 the quota price has to increase. We then have the following proposition:

Proposition 7 *In the case in which one or more countries are fiscally constrained, a change in the quota allocation has real effects, that is, it changes the equilibrium permit price, and hence also the levels of abatement in both fiscally constrained and fiscally unconstrained countries.*

This result has some resemblance with Hahn's (1984) result, that when some country may obtain market power in a global quota market, the market power problem can be removed by changing the quota allocation. In our case it might be possible to allocate the quotas such that no country is constrained in the permit market equilibrium. On the other hand, this may involve politically infeasible allocations.

Note finally that, a change in fiscal capacity for any of the fiscally constrained countries will have real effects. Having established the properties of the permit market equilibrium with fiscally constrained countries, we can move on to look at welfare effects.

5 Welfare

5.1 Welfare with GHG cap-and-trade

How does the existence of a fiscal constraint in one or more countries affect the welfare of fiscally unconstrained countries? Fiscally unconstrained countries are only affected through the permit price. Subject to constraints (4) and (5), using the envelope theorem on Eq. (6) gives:

$$\frac{\partial u^i}{\partial p_i^{eq}} = h_G^i \left(\bar{e}_i - e_i\right).$$

The permit price is lower in a fiscally constrained market equilibrium, and we therefore have the following proposition:

Proposition 8 *If one or more countries become fiscally constrained, fiscally unconstrained countries will gain if they are net buyers of emission permits before and after the change in the permit price, and loose if they are net sellers of emission permits before and after the change in the permit price.*

For countries that change from being net sellers to become net buyers, we cannot say in what direction their welfare changes.

One may wonder whether the existence of fiscal constraints constitutes an argument against permit trade. In order to discuss global welfare further, we assume that the marginal utility from income is equal to unity, $w_y^i = 1 \forall i$, and that the marginal utility of public goods is given by

$h_G^i = 1 + \alpha_i$, where $\alpha_i \geq 0 \forall i$.[10] Note that fiscally unconstrained countries, by definition, have $w_y^i = h_G^i$, and hence $\alpha_i = 0$. Welfare of the individual countries can then be written:

$$u^i = \begin{cases} \bar{\pi}^i - C^i(e_i) + p^{eq}(\bar{e}_i - e_i) & \text{if} \quad \alpha_i = 0 \\ \bar{\pi}^i - C^i(e_i) + p^{eq}(\bar{e}_i - e_i) + \alpha_i \left[\tau^i(\bar{\pi}^i - C^i(e_i)) + p^{eq}(\bar{e}_i - e_i)\right] & \text{if} \quad \alpha_i > 0 \end{cases}$$

Adding the welfare of the individual countries we obtain:

$$U^C = \sum_i \left[\bar{\pi}^i - C^i(e_i)\right] + \sum_k \alpha_k \left[\tau^k(\bar{\pi}^k - C^k(e_k)) + p^{eq}(\bar{e}_k - e_k)\right] \tag{24}$$

where $U^C = \sum_i u^i$, k denote the additional terms due to the participation of fiscally constrained countries, and i denote "all" countries, i.e., it denotes terms that are common to all (constrained and unconstrained) countries. Maximizing welfare, as given by Eq. (24), with respect to the levels of emission e_j and e_k under the constraint:

$$\sum_j e_j + \sum_k e_k = \bar{E}$$

we obtain:

$$\begin{aligned} -C_{je} &= \lambda \forall j \\ -C_{ke} + \alpha_k \tau^k(-C_{ke}) - \alpha_k p^{eq} &= \lambda \forall k \end{aligned} \tag{25}$$

where λ is the shadow cost of the global emission constraint. Thus, we have:

Proposition 9 *Given $w_y = 1$ and $h_G^i = 1+\alpha_i$, the emission levels in any permit market equilibrium maximizes global welfare irrespective of countries being fiscally constrained or not.*

Proof. In the permit market equilibrium we have $p^{eq} = \lambda$. The conditions stated in (25) are then identical to the conditions stated in the first order conditions of the individual countries, conditions (9) and (14). ■

The result should not be surprising. Although the permit market does not minimize global abatement costs, it minimizes total cost from forgone public goods and abatement costs. On the other hand, the levels of public goods in one, more or all countries are not optimal due to the fiscal constraint. Thus, if we could find some mechanism that ensured equal marginal abatement costs across countries, and at the same time provided income such that the level of public goods in all countries stayed the same or increased, welfare would improve. We will look at this in the next section.

We also have:

Proposition 10 *Any restriction in the freedom of countries to buy and sell quotas, such as the supplementary principle in the Kyoto treaty, must reduce global welfare.*

[10] With concave utility from both private and public goods, all redistribution of income from high income countries to low income countries will improve global welfare. To isolate the effect on global welfare of the allocation of abatement effort, we have to assume w_g and h_G constant.

The proposition follows directly from Proposition 9. The intuition is that the supplementary principle will reduce demand for permits in the market. Consequently, the permit price has to fall in order to reduce supply to the same extent. As noted in Proposition 8, the countries that sell permits will then loose. Moreover, buyers may also loose since they are restrained from trading, and in sum global welfare is reduced.[11]

5.2 Welfare with global auctioning of permits

Since global abatement costs are not minimized, there are potential gains to be exploited. There are at least two ways in which this can be done: Either the global treaty could fix a global GHG tax which is levied on all fossil fuels, or all permits could be auctioned by some supra-national authority directly to the private sector in each country. Moreover, the income from the auction (tax) could be redistributed to the countries by some predetermined scheme such that the link between national emission levels and the amount of funds for public spending is taken away.[12]

We will look at a global auctioning system here. The total number of permits sums to $\bar{E}$. Denote the equilibrium price on permits in the global auctioning system by θ. Since all emitters face this price, we will obtain the cost minimizing levels of emissions e_i^*. The different participating countries' levels of welfare are then given by:

$$u^i = \begin{cases} \bar{\pi}^i - C^i(e_i^*) - \theta e_i^* + \varphi_i \theta \bar{E} & \text{if} \quad \alpha_i = 0 \\ (1-\tau^i)(\bar{\pi}^i - C^i(e_i^*) - \theta e_i^*) + (1+\alpha_i)\left[\tau^i(\bar{\pi}^i - C^i(e_i^*) - \theta e_i^*) + \vartheta_i \theta \bar{E}\right] & \text{if} \quad \alpha_i > 0 \end{cases}$$

where φ_i is the predetermined level of redistribution of the income from the auction to the individual countries. Adding the individual welfare levels we obtain:

$$U^\theta = \sum_i \left[\bar{\pi}^i - C^i(e_i^*)\right] + \sum_k \alpha_k \left[\tau^k(\bar{\pi}^k - C^k(e_k^*) - \theta e_k^*) + \varphi_k \theta \bar{E}\right] \tag{26}$$

where $U^\theta = \sum_i u^i$, i.e., global welfare in the global auction case and k denotes the fiscally constrained countries. The difference in global welfare between the global auction case and the cap and trade case, i.e., Eq. (26) subtracted Eq. (24) is, after some rearranging, given by:

$$\begin{aligned} U^\theta - U^c &= \sum_i \left[C^i(e_i^C) - C^i(e_i^*)\right] + \sum_k \alpha_k \tau^k \left[C^k(e_k^C) + \theta e_k^C - C^k(e_k^*) - \theta e_k^*\right] \\ &\quad + \sum_k \alpha_k \left[\varphi_k \theta \bar{E} - p^{eq}(\bar{e}_k - e_k^C) - \tau^k \theta e_k^C\right] \end{aligned} \tag{27}$$

The first term in Eq. (27) is clearly positive since abatement costs are minimized when $e_i = e_i^* \forall i$. The second term is also positive since, given the emission tax θ, e_j^* is the optimal level of emissions, and thus the sum of permit aquisitions and abatement costs must be lower for e_j^* than for e_j^C. Finally, the third term is positive. This is more easy to see if we assume $\sum_k \varphi_k = 1$ and $\sum_k \bar{e}_k = \bar{E}$, i.e., the

[11] Notice, however, that more abatement is carried out in buyer countries, which may be good for dynamic efficiency since their "internal" price on emissions must have increased. We discuss dynamic efficiency in more detail in sections 7.2 and 7.3.

[12] This is the way in which the EU now has organized its permit trading system. That is, the commision auctions permits to firms, and the proceedings is paid back to the member states by a predetermined scheme.

fiscally constrained countries get all the income from the auction; alternatively, they get the whole emission cap. The term $\sum_k p^{eq}(\bar{e}_j - e_j^C)$ must then be positive, and we can insert $p^{eq} = \theta$ without risking changing the sign from negative to positive. The last term in Eq. (27) is then reduced to: $\sum_j \alpha_j(1-\tau^j)\theta e_j^C$ which is positive. Hence, we have:

Proposition 11 *Global welfare W^G can be increased if all permits are auctioned to the private sector in each country by some supra-national authority, and the income from the tax is redistributed to the countries in a predetermined way.*

Not all redistribution schemes will increase global welfare. The distribution scheme must take into account that countries have different marginal utilities from public goods, α's (or, alternatively, that they are to different extents fiscally constrained) and different allocations, $\bar{e}_i$, such that an improvement in total welfare results. The proposition also holds for a global tax.

Notice that for a global auction system to be consistent with a cost-effective distribution of a given level of global abatement across industries and countries, there must be a system for controlling and enforcing emission levels in the private sector in each country.

6 A numerical illustration

In order to illustrate our analytical results, and also to get a feel for the potential magnitude of the effects we have found, we present results from a simple numerical simulation. Our global model has seven regions: The EU, the US, China, Japan, India, Russia and "the rest of the world" (RoW). Carbon emissions and GDP data for these seven regions are taken directly from the business as usual (BaU) RICE model (Regional Integrated model of Climate and the Economy) scenario for the year 2035.[13] As our "climate treaty", we use the Copenhagen Accord with full permit trade. The Copenhagen Accord will, according to Nordhaus (2010), lead to a 17% reduction in global carbon emissions from BaU by 2035, and a global price on emission permits of USD 72 (per tonne of carbon).

For GHG abatement costs, we use the cost function $C^i(e_i) = c_i(e_{i0} - e_i)^2$. We calibrate the parameter c_i such that our model gives precicely the same emission reduction per region as the RICE model for the global optimum in 2035. Moreover, Nordhaus (2010) translated the Copenhagen Accord pledges into national emission caps for 2035 which we use in our model runs (see Appendix). Assuming that no country is fiscally constrained, we can then replicate the RICE results for the year 2035, Copenhagen Accord, full trade scenario.

For the social value of public funds, we use the function $H_i(\cdot) = \eta_i G_i - \frac{\eta_{ii}}{2}(G_i)^2$, where η_i and η_{ii} are parameters to be calibrated and G_i is the level of public spending. We approximate the level of public spending across regions and countries using data on total public spending as a share of GDP, collected from CIA (2014). We then assume that the levels of public spending in the EU, the US and Japan is socially optimal and, hence, that the marginal utility of public funds is equal to unity in these regions and countries. In our *baseline* scenario, we let China, India and Russia be fiscally constrained, and in the *alternative* scenario we also let RoW be fiscally constrained. For the fiscally constrained countries/regions, we calibrate the model such that their marginal utility of public funds $H_G^i = \eta_i - \eta_{ii}G_i$ is greater than unity.[14] When interpreting the values of the

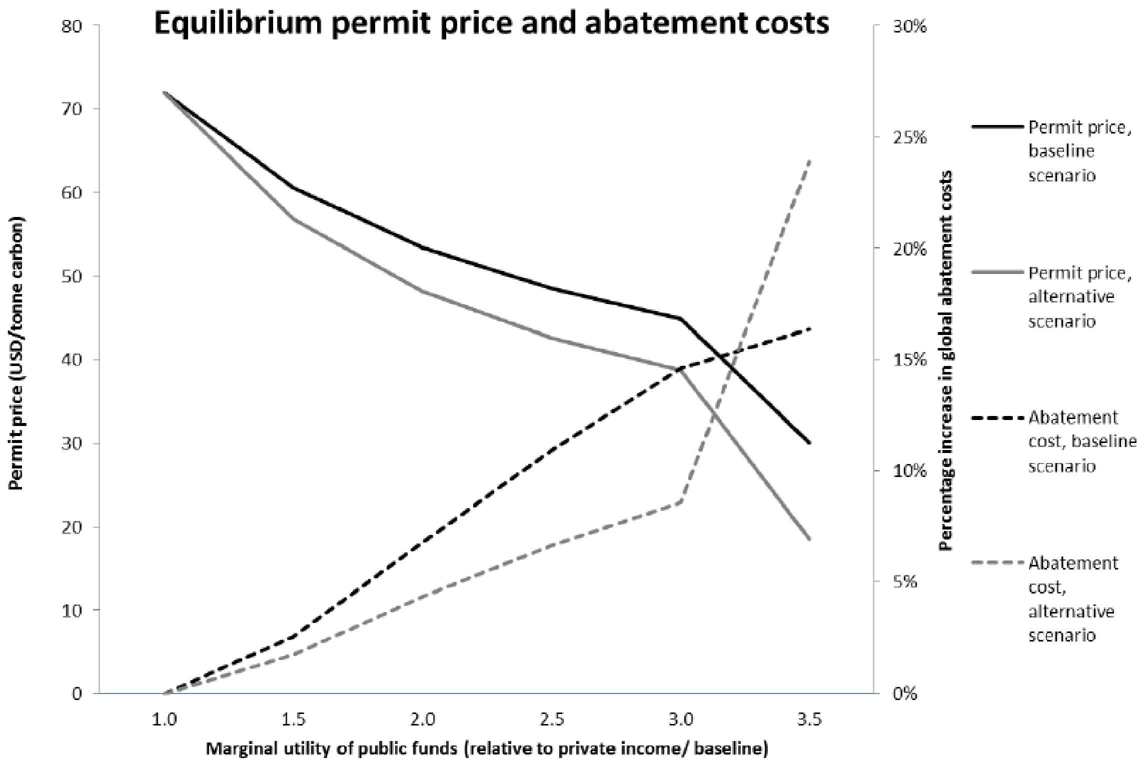
[13] For scenarioes and model documentation of the RICE model, see http://www.econ.yale.edu/~nordhaus/homepage/RICEmodels.htm

[14] See the Appendix for more on the calibration.

marginal utility of public funds, notice that this value is equal to one in countries that are fiscally unconstrained which, in turn, is equal to the marginal utility of private goods (which is pinned down to unity in our model). The marginal utility of public funds, hence, reflects the marginal utility of publicly provided goods relative to private goods *and* the marginal utility of public funds in a fiscally constrained country relative to that in a fiscally unconstrained country.

Figure 1 displays how, in our simulations, both the equilibrium permit price and the global abatement costs depend on the marginal utility of public funds in the fiscally constrained countries:

Figure 1: Permit price and abatement costs



Notes: The solid lines show the equilibrium permit price from cap and trade in the baseline (black) and alternative (grey) scenarios, as a function of the extent of fiscal constrainedness (measured according to the marginal value of public funds) among the fiscally constrained countries in our model simulations. The dotted lines show the associated percentage welfare gains in the socially optimal RICE scenario for year 2035 (Nordhaus, 2010) relative to the two alternative scenarios of fiscal constrainedness.

Figure 1 shows both the *baseline* scenario (where only China, India and Russia are fiscally constrained) and the *alternative* scenario (where all other countries but the EU, the US and Japan are fiscally constrained. In the figure, the market equilibrium permit price is measured on the on the left vertical axis, and the percentage increase in global abatement costs relative to the optimal RICE scenario on the right vertical axis. The extent of fiscal constrainedness among the fiscally constrained countries is measured along the horizontal axis, measured as the marginal utility of public funds.

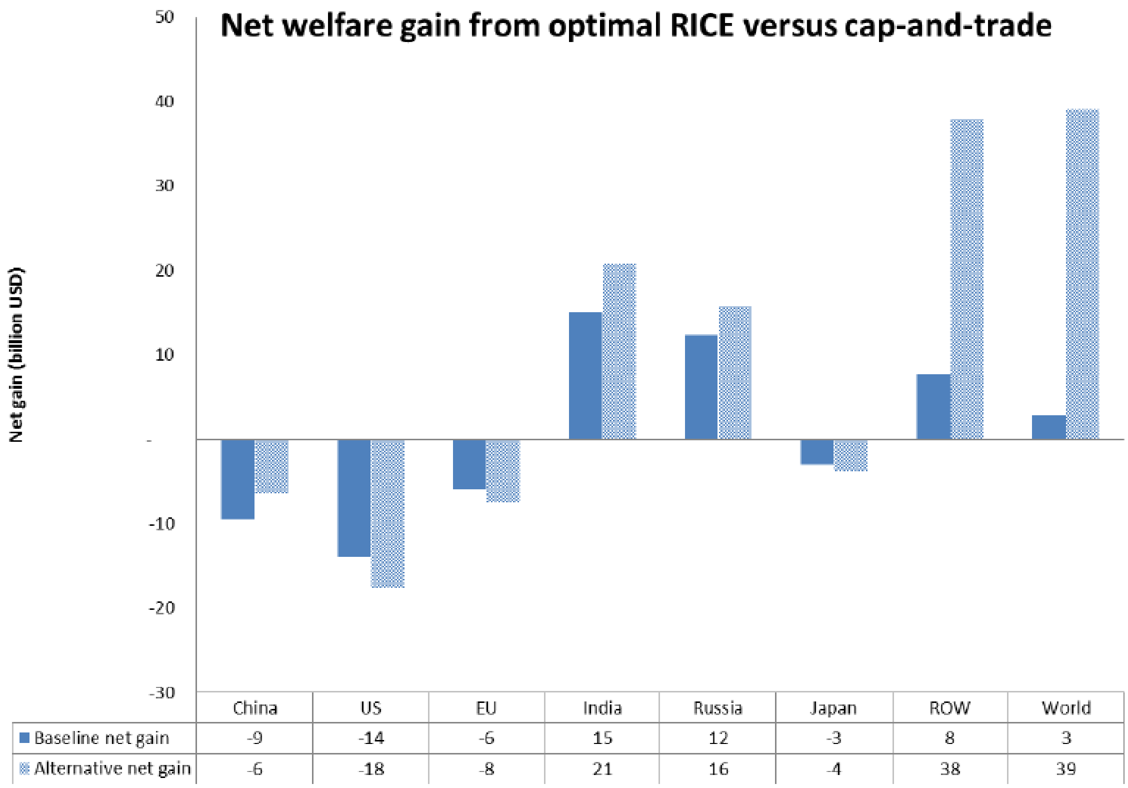
Note, first, that the equilibrium permit price decreases rapidly with the level of fiscal constrainedness in China, India and Russia in the baseline case. For example, if the marginal utility from public funds is 50 percent higher than in social optimum in these three countries, the equilibrium price of emission permits is simulated to fall by some 20 percent (from USD 72 to about

USD 60). Moreover, in the alternative scenario the equilibrium price falls by another some five percentage points.

The low permit price leads to an inefficient allocation of GHG abatement across the countries, that is, the fiscally constrained countries abate too much and the other countries too little. This leads to higher global costs of abatement than necessary. In particular, if all RoW and China, Russia and India is fiscally constrained, our simulations suggests that global abatement cost may increase with as much as 25 percent. Note that the increase in global abatement cost is less in the alternative scenario than in the baseline scenario for some levels of the marginal utility of public funds in the fiscally constrained countries. The reason is that RoW has low abatement cost and when RoW increases its abatement, this replaces some costly abatement in the other fiscally constrained countries.

The fiscally constrained countries hamper their possibilities to raise money for public spending through the permit market by offering too many permits. If some global regulator would set the permit price to USD 72 (that is, the economically efficient price), and all countries would adjust their emissions such that their marginal abatement cost equated this price, world welfare would increase. This can be seen from the next figure. In Figure 2 we show the difference in welfare between "the fixed USD 72 price equilibrium" and the realized permit market equilibrium in which fiscal incentives drive fiscally constrained countries to sell too many permits.

Figure 2: Welfare comparison



Notes: The graph shows the simulated difference in welfare across regions/countries, and for the world, in the baseline and the alternative fiscal constrainedness scenarios, relative to the socially optimal the RICE scenario for year 2035 (Nordhaus, 2010).

As can be seen from the figure, all countries/regions except the China, US, EU and Japan would gain on a fixed, economically efficient, price on permits. The reason that these countries loose is that they are permit buyers in both the unconstrained and the constrained equilibrium. As expected, world welfare also increases if the price is fixed to the economically efficient price. Note that the higher welfare levels could also be obtained by a global tax combined with a redistribution scheme that resembles the permit allocations in the Copenhagen accord.

The incentive to offer too many permits is not taken away by restricting quota trade. In our numerical example, we find that limiting the market by not allowing any country to buy more permits than their own reductions in emissions (from BaU), hampers global welfare. The permit price decreases further, and all countries tend to loose – also those that are net buyers since they must abate more.

7 Extensions and discussion

7.1 Letting the private sector trade emission permits

In our benchmark model, we assume that the net proceeds from emission trading flow directly into (or out of) the governments' funds. Perhaps more realistically, the trade in emission permits, and the associated financial flows, will be shared between the government and the private sector. The effects of splitting the revenue between the public and the private sector—in our model the households, which owns and are the recipients of the income from industrial production—can be studied by assuming that a share γ (where we, for simplicity, ignore the country notation, i) of the net revenue from emission trading accrues to the government, and the remaining share $1-\gamma$ enters into the budgets of households, where $\gamma \in [0,1]$. We present this analysis and the associated results, including comparative statics and the market equilibrium, in Appendix A2.

The main results from this extension is that GHG cap and trade still fails to be cost efficient. Intuitively, if only a small share of the revenues are directed towards the private sector, the fiscally constrained governments faces a similar trade-off as in the benchmark case. Specifically, this happens as long as $\gamma > \tau$, implying that emission trading is fiscally more important (at the margin) than income from private sector production for the funding of public goods among the fiscally constrained governments. In the case when $\gamma < \tau$, however, this effect is reversed; now, private sector production is more important at the margin than emission trading. Hence, when only a minor share of the proceeds from emission trading can be used directly for the financing of public goods, the fiscally constrained governments have the incentive to increase, rather than decrease, their respective national levels of emission beyond the level which is consistent with global cost efficiency. In the special case when $\gamma = 0$, the only source of government funding is through the national tax base, hence, a fiscally constrained country has a strong incentive to increase the value of this tax base by allowing for a higher level of national emissions, even if this means that the private costs of abatement are higher than the cost efficient level. The only case where the market generally is cost efficient, is in the case where $\gamma^i = \tau^i$, $\forall i$.

Our model and analysis, hence, suggests that the fiscal incentives of fiscally constrained governments hinders a globally cost efficient distribution of abatement independent of the internal, national organization of the split of revenues from emission trading between the public and the private sector (except in the special, and very unlikely, case where $\gamma^i = \tau^i$, $\forall i$). Whether the latter case, of small γ^i's and a policy of underabatement, is relevant, is an open empirical question. This, generally, depends on the extent to which the fiscally constrained governments can incentivize, or force, private industries to expand their level of emission beyond the globally cost efficient level through the private purchase of emission permits at the international market. This, in turn, depends on the policy instruments available to the fiscally constrained governments. One such potential instrument could be a policy that decreases the effective, national private price on emissions, for example via a government subsidy of private sector emission permit purchases at the international market.

7.2 Fiscal capacity dynamics

The fiscal capacities of countries are endogenous and will, hence, change over time. Notice, however, that while the model we analyze is static, extending it to a dynamic framework is straightforward. In such a framework, the fiscally constrained countries would optimally invest in expanding their fiscal capacities subject to their rational expectations of future outcomes. These expectations include the expected chance, and the associated social cost, of being fiscally constrained in the future, and expectations about the nature of a future climate treaty.

If the cost for the government of adjusting fiscal capacity through investments is convex, as in, e.g., Besley and Persson (2011), and future outcomes are uncertain, the optimal government investment in fiscal capacity would be nonnegative, in any period. However, as long as governments are not too risk averse and/or that they discount future welfare by a factor strictly smaller than one, the optimal investment path for fiscal capacity will never be so steep that it completely eliminates the chance of ever being fiscally constrained in the future. Hence, one can easily extend the model to a dynamic framework where countries will occasionally be fiscally constrained (according to some stochastic process), and all of our results thus remain robust to endogenizing fiscal capacity.

Interestingly, an additional conjecture in this type of dynamic setting is that the incentives for fiscally constrained governments to invest in fiscal capacity will be weakened by the introduction of international cap and trade, the intuition being that cap and trade endows governments with a fiscal instrument to partly alleviate their fiscal constrainedness.[15] Hence, in addition to the observation that the results from the static model also carry over to a dynamic setting, there would be an additional effect arising from the weakened incentives of fiscally constrained governments to invest in future fiscal capacities. Notably, this latter effect will slow down the pace at which the most fiscally constrained countries gradually become less fiscally constrained over time, potentially lowering the development prospects of these countries.[16]

7.3 R&D and dynamic efficiency

Private investors spending resources on research and development (R&D) for developing better pollution abatement techniques will look to the value of a potential patent when deciding how much to invest (see e.g. Laffont and Tirole, 1996). Generally, the higher the price on emissions, the higher is the value of a patent, and only as long as $p^{eq.} = D(\bar{E})$ can we expect the incentives for R&D on pollution abatement techniques to be sufficient to compete with the incentives for R&D on normal market goods. Proposition 6 suggests that $p^{eq.} < D(\bar{E})$ in the market equilibrium in which one or more countries are fiscally constrained. Thus, if the bulk of global R&D on GHG pollution abatement techniques happens in fiscally unconstrained countries based on the price on emissions in these countries, we conjecture that cap and trade could hamper dynamic efficiency.

8 Conclusion

A largely ignored side-effect of a cross-national cap and trade system for pollution control is that it endows all participating governments with the opportunity to trade a valuable resource, the right to emit GHG, in a liquid market. A fiscally constrained government should optimally take advantage of this source of government funds to narrow its fiscal gap. Specifically, a fiscally constrained government should cut emissions until the real marginal social, rather than industrial, cost of abatement equates the market price of emission permits. Consequently, if some (one or more)

[15] Besley and Persson (2013) discusses this type of dynamics in the case of aid and natural resources. As (potentially large) caps to developing countries represent (potentially large) pure wealth transfers, their analysis straightforwardly extends to the case of a Kyoto-type cap and trade system.

[16] Specifically, economic development may be depressed if fiscal and other growth promoting state capacities (e.g., legal capacity) act as strategic complements, as in Besley and Persson (2011). Jensen (2011) presents evidence suggesting that resource windfalls retards state capacity development, including fiscal capacity.

countries are fiscally constrained, the efficiency properties of a global GHG permit market are hampered. First, marginal abatement costs will differ between countries, and GHG abatement costs strictly defined will not be minimized. Second, the allocation of the global cap on GHG will affect the distribution of GHG abatement activities across the globe, and, hence, the level of global welfare. This happens even if governments act as benevolent welfare maximizers. Finally, we demonstrate our main results in a simple, numerical example. The numerical example also demonstrates that an international emission tax regime that fixes the carbon price may greatly outperform cap and trade, the intuition being that a system where polluting activities are taxed directly eliminates the fiscal incentive to abate.

Connecting fiscal policy and permit trade, as we do in our model, seems appropriate. Estimates of the expected market value of GHG emissions trading range from about 15 to 900 billion USD.[17] Hence, all participating countries in such a system will be endowed with a scarce and valuable resource—the permission to emit GHG gases—which may be traded freely in a global market. Consequently, governments will have the incentive to take into account the fiscal and social effects of such trade.

While this paper focuses on a specific source of inefficiency in an international cap and trade system, there may also be other, and potentially even more severe, problems with cap and trade. The fact that developing countries are likely to have comparably lower GHG abatement costs than developed countries implies that developing countries will be net sellers of emission permits. A recent study by the IISD (2009) estimates that revenues from permit sales to developing countries could reach $ 300 billion already in 2020. Such a large transfer to developing countries has close resemblance with the discovery of a highly valuable renewable resource, or foreign aid. Might revenues from emission trading also have negative "resource curse" effects, as have been claimed to be the case for natural resource income and aid? Given the evidence on the natural resource curse (see van der Ploeg (2011) for an overview of this literature), and aid (Djankov, Montalvo and Reynal-Querol, 2008) this possibility must be taken seriously. Natural resources and foreign aid share several common characteristic: they can be appropriated by corrupt politicians without having to resort to unpopular, and normally less profitable, measures like taxation; the money from aid and resource revenue often go directly into the hands of state leaders; the amount of revenues from aid and resource income is not always transparent to the public; they produce foreign currency earnings that, if not neutralized by monetary policy, will raise the real exchange rate, undermining the competitiveness of other sectors. All of these characteristic could also be linked to revenues from emission trading. This is another avenue by which permit trade can hamper the efficiency properties of permit markets through fiscal incentives which should be a topic of future research.

[17] According to a survey by Springer (2003), estimates of the average market volume is approximately 17 and 33 billion USD under global trading and Annex B trading, respectively. The International Institute for Sustainable Development (IISD, 2009) estimates the development world revenue with 50 per cent of developed country demand met by developing country credits to range from approximately 30 to 300 billion USD in 2020, and 90 to 900 billion USD in 2050.

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Appendix

A1. Income from national permit market

In A1 we look at the situation in which the national government sets up its own national permit market and auctions all national permits. The government still sets e_i, but its budget constraint is given by:

$$G^i(t_i, e_i) \leq t_i \left[\bar{\pi}^i - C^i(e_i) - p_i(e_i)e_i\right] + p_i(e_i)e_i + p^{eq\cdot}(\bar{e}_i - e_i)$$

where $p_i(e_i)$ is the national price on emission quotas. It is easy to show that we must have $p_i' < 0$.

The welfare expression is now given by:

$$u^i = w^i\left((1-t_i)\left[\bar{\pi}^i - C^i(e_i) - p_i e_i\right]\right) + h^i\left(t_i\left[\bar{\pi}^i - C^i(e_i) - p_i e_i\right] + p_i e_i + p^{eq\cdot}(\bar{e}_i - e_i)\right)$$

where $p_i = p_i(e_i)$. As above the government maximizes u^i with respect to e_i and t_i. The first order condition with respect to the optimal national emission level writes:

$$\frac{du^i}{de_i} = w_y(1-t_i)\left[-C_e - p_i - p_i' e_i\right] + h_G(t_i\left[-C_e - p_i - p_i' e_i\right] + p_i + p_i' e_i - p^{eq\cdot}) = 0$$

Note that the government behaves as a monopolist, that is, takes into account that the national price of permits depends on the national emission level. The private sector sets $-C_e = p_i$. The first-order condition can thus be simplified to:

$$\frac{du^i}{de_i} = (h_G - w_y)(1-t_i)p_i' e_i + h_G(p_i - p^{eq\cdot}) = 0 \tag{28}$$

For the optimal tax t_i^* we have as before:

$$\frac{du^i}{dt_i} = (h_G - w_y)\left[\bar{\pi}^i - C^i(e_i) - p_i e_i\right] = 0.$$

Hence, a fiscally unconstrained government sets e_i such that $h_G = w_y$ and Eq. (28) can then only hold if $p_i = p^{eq\cdot}$. Hence, e_i is set such that $p_i(e_i) = p^{eq\cdot}$ and the cost efficient outcome is reached.

On the other hand, the government might be fiscally constrained, that is $t_i^* > \tau_i$. The government will then set $t_i = \tau_i$, and we have $h_G > w_y$ in equilibrium. From Eq. (28), note that $(h_G - w_y)(1-t_i)p_i' e_i < 0$. Consequently, we must have $h_G(p_i - p^{eq\cdot}) > 0$, which implies $p_i > p^{eq\cdot}$ and excessive abatement in fiscally constrained countries.

Thus, if the government can increase its public spending by auctioning quotas at home and the government is fiscally constrained, the fiscal incentive still ruins the efficiency properties of the global permit market.

A2. Revenue sharing

Our baseline model implicitly assumes that a country's net revenue from trading emission permits accrues exclusively to the government of the country. Of course, this may not be the case, and the exact revenue sharing between the government and the private sector will generally depend on the fiscal and environmental institutions of the country. Here, we extend our model by introducing a parameter, γ^i, which characterizes how large share of the net revenue in country i which accrues to the government, hence, $\left(1-\gamma^i\right)$ is the share that is transferred to the households. The parameter γ^i can take any value between 0 and 1, i.e., $\gamma^i \in [0,1]$.

As a result of this extension, a number of the baseline equations change. Below, we list the modified equations, where we use the marker "′" to indicate that the equation has been modified. All the remaining equations remain unchanged.

The modified equations are:

$$y^i = (1-t_i)\,\pi^i + r_i, \tag{3'}$$

where

$$r_i = \left(1-\gamma^i\right) p^{eq\cdot}\left(\bar{e}_i - e_i\right);$$

$$G^i \leq t_i \pi^i + \gamma^i p^{eq\cdot}\left(\bar{e}_i - e_i\right); \tag{5'}$$

$$\max_{t_i, e_i}\left[\begin{array}{c} w^i\left((1-t_i)\left(\bar{\pi}^i - C^i(e_i)\right) + \left(1-\gamma^i\right)p^{eq\cdot}\left(\bar{e}_i - e_i\right)\right) \\ +h^i\left(t_i\left(\bar{\pi}^i - C^i(e_i)\right) + \gamma^i p^{eq\cdot}\left(\bar{e}_i - e_i\right)\right)\end{array}\right]; \tag{7'}$$

$$t^* = \frac{G^* - \gamma p^{eq\cdot}\left[\bar{e} - e^*\right]}{\bar{\pi} - C(e^*)}, \tag{12'}$$

where the accompanying (unnecessary) restriction on $\bar{e}$ is

$$\bar{e} < G^*/\gamma p^{eq\cdot} - C_e^{-1}\left(p^{eq\cdot}\right);$$

$$\left[\tau\left(-C_e\right) - \gamma p^{eq\cdot}\right] h_G = (1-\gamma)\,p^{eq\cdot} - (1-\tau)\left(-C_e\right) w_y; \tag{13'}$$

$$-C_e = \frac{\gamma h_G + (1-\gamma)\,w_y}{\tau h_G + (1-\tau)\,w_y} p^{eq\cdot}. \tag{14'}$$

As a result of these changes, optimal policy and the efficiency properties of the model will be modified. First, the results in Proposition 1 changes to the following: (*i*) If $\tau \neq \gamma$, the level of emission in a constrained country, e^c, will not be cost efficient; (*ii*) if $\tau < \gamma$, then $-C_e > p^{eq}$ and $e^c < e^*$; (*iii*) if $\tau > \gamma$, then $-C_e < p^{eq}$ and $e^c > e^*$. The proof goes as follows. Comparing equations (13′) and (14′), first notice that cost efficiency requires $\frac{\gamma h_G + (1-\gamma)w_y}{\tau h_G + (1-\tau)w_y} = 1$, which is impossible if $\gamma \neq \tau$. Second, replacing $\gamma = \tau + \varepsilon$ in Eq. (14′), and noticing that a constrained country is characterized by $h_G - w_y > 0$, we have that $-C_e \gtreqless p^{eq}$ if $1 + \frac{\varepsilon(h_G - w_y)}{\tau h_G + (1-\tau)w_y} \gtreqless 1 \Longleftrightarrow \varepsilon \gtreqless 0$. Hence, $-C_e \gtreqless p^{eq}$ if $\tau \lesseqgtr \gamma$.

Notice that the main result concerning the cost inefficiency if the level of emissions is robust to this extension. Moreover, as long as the government's share of the net revenue from emissions trading, γ, is larger than its share of production income, τ, the fiscally constrained country will implement a lower level of emissions than the cost efficient level, $e^c < e^*$. However, if the government's share of the net revenue from emissions trading is lower than its share of production income, the country will have higher emissions than what is cost efficient, and the some of qualitative results from the comparative statics change.

Comparative statics

Proposition 2 is modified as follows. A fiscally constrained country is characterized by $h_G > w_y$ and therefore optimally sets $t^c = \tau$. Then:

$$\frac{de^c}{dp^{eq\cdot}} \gtreqless 0 \quad if \quad \left[-\left(h_G - w_y\right)\gamma + \left[\frac{w_{yy}}{w_y}(1-\gamma) + \frac{h_{GG}}{h_G}\gamma\right] h_G\left[\tau\left(-C_e\right) - \gamma p^{eq\cdot}\right]\left(\bar{e} - e^c\right)\right] \gtreqless 0; \tag{18'}$$

$$\frac{de^c}{d\bar{e}} \gtreqless 0 \quad if \quad -\left[\frac{w_{yy}}{w_y}(1-\gamma) - \frac{h_{GG}}{h_G}\gamma\right] h_G \left[\tau(-C_e) - \gamma p^{eq\cdot}\right] p^{eq\cdot} \gtreqless 0. \tag{20'}$$

$$\frac{de^c}{d\tau} \gtreqless 0 \quad if \quad \left[(h_G - w_y)(-C_e) - \left(\frac{w_{yy}}{w_y} - \frac{h_{GG}}{h_G}\right) h_G \left[\tau(-C_e) - \gamma p^{eq\cdot}\right]\pi\right] \gtreqless 0 \tag{21'}$$

$$\frac{de^c}{d\gamma} \gtreqless 0 \quad if \quad \left[-(h_G - w_y) - \left(\frac{w_{yy}}{w_y} - \frac{h_{GG}}{h_G}\right) h_G \left[\tau(-C_e) - \gamma p^{eq\cdot}\right](\bar{e} - e)\right] p^{eq\cdot} \gtreqless 0 \tag{A1}$$

The modified proof for Proposition 2 becomes: First, implicit derivation of Eq. (13) with respect to e^c and $p^{eq\cdot}$ gives

$$\frac{de^c}{dp^{eq\cdot}} = \left[-(h_G - w_y)\gamma + \left[\left[(1-\tau)(-C_e) - (1-\gamma)p^{eq\cdot}\right] w_{yy}(1-\gamma) + \left[\tau(-C_e) - \gamma p^{eq\cdot}\right] h_{GG}\gamma\right](\bar{e} - e)\right]/D_s,$$

where

$$D_s = -\left[\left[w_y + (h_G - w_y)\tau\right](-C_{ee}) + h_{GG}\left[\tau(-C_e) - \gamma p^{eq\cdot}\right]^2 + w_{yy}\left[(1-\tau)(-C_e) - (1-\gamma)p^{eq\cdot}\right]^2\right] > 0. \tag{19'}$$

Eq. (13) implies that $\left[(1-\gamma)p^{eq\cdot} - (1-\tau)(-C_e)\right] = \left[\tau(-C_e) - \gamma p^{eq\cdot}\right]\frac{h_G}{w_y}$, which proves (18$'$. Second, differentiation of Eq. (13) with respect to e^c and $\bar{e}$, and substituting back from Eq. (13), gives

$$\frac{de^c}{d\bar{e}} = -\left[\frac{w_{yy}}{w_y}(1-\gamma) - \frac{h_{GG}}{h_G}\gamma\right] h_G \left[\tau(-C_e) - \gamma p^{eq\cdot}\right] p^{eq\cdot}/D_s,$$

which proves (20$'$. Third, differentiating (13) with respect to e^c and τ, and substituting back from Eq. (13), gives

$$\frac{de^c}{d\tau} = \left[(h_G - w_y)(-C_e) - \left(\frac{w_{yy}}{w_y} - \frac{h_{GG}}{h_G}\right) h_G \left[\tau(-C_e) - \gamma p^{eq\cdot}\right]\pi\right]/D_s$$

which proves (21$'$. Finally, differentiation of (13) with respect to e^c and γ, and substituting back from Eq. (13), gives

$$\frac{de^c}{d\gamma} = \left[-(h_G - w_y) - \left(\frac{w_{yy}}{w_y} - \frac{h_{GG}}{h_G}\right) h_G \left[\tau(-C_e) - \gamma p^{eq\cdot}\right](\bar{e} - e)\right] p^{eq\cdot}/D_s,$$

which proves ($A1$).

A3. The numerical model

The parameters η_i and η_{ii} for the US, the EU, Japan and RoW are calibrated by assuming i) $\eta_i = 2$ and ii) that their level of taxation is optimal, e.g., $\eta_i - \eta_{ii}G^i = 1$. The parameter values are kept constant in all simulations. In the alternative scenario, we treat RoW the same way as China, Russia and India.

For China, Russia and India, we assume that in BaU they would have liked to set the tax rate to 0.34, e.g., the average of the US, the EU and Japan. Moreover, we run simulations in which we fix the marginal utility of public funds to a given number α_i. This yields:

$$\begin{aligned} \eta_i &= 1 + 0.34\eta_{ii}\bar{\pi}_i \\ \eta_{ii} &= \frac{\alpha_i - 1}{0.34\bar{\pi}_i - G_i} \end{aligned}$$

where $\bar{\pi}_i$ is BaU GDP, and $0.34\bar{\pi}_i$ is the preferred level of public spending in country i.

In Table A1 we show the key data for our model countries.

Table A1 Data for the model countries

	BaU emission (Mill. tonn carb.)	Share world emissions	GDP (Billion USD)	Share world GDP	Tax revenue (Percent of GDP)	Public spending (Reference)	Allowance (Mill. tonn carb.)	Allocation (Percent of BAU)
World	14000	100.00 %	141043	100.00 %	30 %	42 736	11618	83 %
China	3426	24.47 %	22276	15.79 %	19 %	4 322	2530	74 %
US	1915	13.68 %	26732	18.95 %	22 %	5 881	1070	56 %
EU	1189	8.49 %	26390	18.71 %	45 %	11 876	810	68 %
India	1173	8.38 %	4932	3.50 %	10 %	508	1170	100 %
Russia	449	3.21 %	3111	2.21 %	21 %	644	490	109 %
Japan	372	2.66 %	6190	4.39 %	35 %	2 148	210	56 %
ROW	5476	39.11 %	51412	36.45 %	20 %	10 282	5338	97 %

Note: The table lists the input data that we use in our simulations. All data is taken directly from the 2035 RICE scenario (Nordhaus, 2010), except data for public spending which is from CIA (2014).

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