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The Kyoto agreement and Technology Spillovers

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Abstract

A significant reduction in global greenhouse gas emissions will require development of new technologies if such reductions are to be achieved without excessive costs. An important question is whether an agreement of the Kyoto type, which does not include elements related to research and development (R&D) of new technologies, will give sufficient incentives to develop such new technologies. On the one hand, since greenhouse gas emissions will become costly for countries and private producers, countries and individual producers will have incentives to undertake effort and costs to develop new technologies. On the other hand, R&D in one country is not only advantageous for this country, but usually also for other countries. The reason for this is that producers in these countries in many cases will learn from the R&D project, for example, through (informal) networks, journals, and in some cases through the import of goods from the country where the new technology is developed. The purpose of the paper is to discuss properties of an international climate agreement of the Kyoto type when R&D investments undertaken in one country are beneficial also for other countries. We examine whether a Kyoto type of agreement can provide the correct social amount of aggregate emissions and R&D investments in new technologies. We argue that the outcome of a Kyoto type agreement will differ from the social optimum. In particular, for a given level of abatement a Kyoto type agreement provides too little R&D investments relative to the social optimum.

Key words: Climate policy, Kyoto, international environmental agreements, R&D, technology spillovers.

Introduction

In economics, a key challenge is to design mechanisms so that actions taken by individual agents (e.g. firms and households) lead to a social optimal outcome. If each agent bears all costs when taking an action (for example, purchasing a good), but also receives all benefits from the action, standard economic theory suggests that a market will provide the socially optimal amount of that good. If, however, each agent bears all costs but the benefits are shared with other agents, markets will typically give less of the good than what is socially optimal.

The latter case can be illustrated by the greenhouse gas problem, which is a global problem. It is the world wide sum of greenhouse gas (GHG) emissions that matters for the environment, and not the distribution of emissions between countries. If a country undertakes unilateral actions in order to reduce its emissions of GHG, that country bears all of the costs, whereas all countries benefit from the emission reduction. Typically, each country will compare its costs of abatement with its benefits of abatement, and hence neglect that also other countries benefit from the emission reduction. The discrepancy between what is individually rational for each country and what is collectively rational for the group of all countries, suggests that aggregate abatement will be too low relative to the social optimum. Hence, some kind of cooperation among countries is necessary in order to reach the socially optimal GHG emission reduction, or more generally, to obtain a significant reduction in GHG emissions, which, according to most scientists, is necessary if dramatic future climate changes are to be avoided.

Several types of international climate agreements have been suggested. The most well known is the Kyoto agreement, which will come into force in 2005, although with limited participation. The Kyoto agreement suggests the use of market based mechanisms that might reduce emissions in a cost effective way.

There is broad consensus among economists that a significant reduction in global greenhouse gas emissions will require development of new technologies if such reductions are to be achieved without excessive costs. An important question is whether an agreement of the Kyoto type will give sufficient incentives to develop such new technologies. On the one hand, since greenhouse gas emissions will become costly for countries and private producers, countries and individual producers will have incentives to undertake effort and costs, e.g. research and development (R&D) expenditures, to develop new technologies. For example, imposing a tax on GHG emissions will increase costs of fossil fuel-based electricity production, and hence tends to increase the price of electricity, thereby increasing the expected profitability of R&D in production of electricity based on renewable sources. On the other hand, R&D in one country is not only advantageous for this country, but usually also for other countries. The reason for this is that producers in these countries in many cases will learn from the R&D project, for example, through (informal) networks, journals, and in some cases through the import of goods from the country where the new technology is developed. Such technology spillovers imply that without any additional elements in a climate agreement (for example, the Kyoto agreement) there will be insufficient incentives to develop new technologies. An international climate agreement should therefore ideally include some elements making countries undertake more R&D than they would choose in the absence of such elements.

An obviouys question is why the Kyoto agreement does not include elements related to R&D of new technologies. One reason could be the problems of designing an agreement to include such elements, as the magnitude of R&D expenditures in a country is difficult to verify by other countries. If a country is required - through an international agreement - to have more R&D expenditures than what is individually rational for the country, it will be relatively easy for the country to have less R&D than required by the agreement, but to report other expenditures as R&D activities. The same problems apply with respect to including policy instruments that affect

R&D expenditures in an international agreement. In general, policies aimed at influencing R&D investments by private firms will be an integrated part of a country's tax system and to some extent other domestic policies. As tax systems and other policies vary significantly across countries, it will in practice hardly be feasible for a country (or some international agency) to verify all aspects of R&D policies of other countries.

For the reasons given above we shall in the present paper assume that climate agreements do not contain elements related to R&D expenditures. The purpose of the paper is to discuss properties of an international climate agreement of the Kyoto type when R&D investments undertaken in one country are beneficial also for other countries. A key issue will be to examine whether a Kyoto type of agreement can provide the correct social amount of aggregate emissions and R&D investments in new technologies. We argue that the outcome of a Kyoto type agreement will differ from the social optimum. In particular, for a given level of abatement a Kyoto type agreement provides too little R&D investments relative to the social optimum.

The model

In order to keep the analysis as simple as possible, we use a static framework, thus ignoring the fact that GHG emissions are stock pollutants and also neglecting the dynamic aspects of R&D. We also consider only one type of GHG, namely CO_2. None of our results are affected by this simplification. Moreover, all types of uncertainties – like the rate of return on R&D investments - are disregarded. Finally, all countries are assumed identical. While these assumptions of course are drastic simplifications, the analysis nevertheless gives insight that is relevant also in the real world.

There are n identical countries, and we assume that the technology level in a specific country depends on the amount invested in R&D in that country, x, and also the investments in R&D

undertaken in all other countries. However, technological diffusion is not perfect, only part of the R&D investments undertaken in one country ($0 < \gamma < 1$) is beneficial for other countries. Hence, the technology level of a particular country investing x in R&D is given by:

$$y = x + \gamma(n-1)x^* \tag{1}$$

assuming that the R&D investments in each of the other n-1 countries are x^*. In (1) we have assumed an additive structure of technology spillovers, that is, the technology level of a country depends on the sum of R&D investments undertaken in all countries, corrected by the technology diffusion parameter γ. This way of modeling spillovers can be found in a wide range of theoretical and empirical contributions, and goes back at least to Spence (1984). Although spillovers often are modeled as in (1), it is not obvious that this is the best way of modeling technology spillovers. Cohen and Levinthal (1989) have argued that the ability of a firm and a country to learn from other agents may depend on its own R&D effort. For an application of the ideas of Cohen and Levinthal on climate policy, see Golombek and Hoel (2004). We shall stick to the "standard" formulation (1).

In the absence of any explicit abatement activities, emissions in each country are assumed to be given, and we normalize this emission level to 1. Actual emissions from a country depend on the abatement activities in the country. Denoting abatement by a, actual emissions e from a country are thus

$$e = 1 - a \tag{2}$$

Abatement costs are assumed to depend both on the level of abatement and the technology level of the country, $c(a, y)$. Increased abatement is assumed to increase costs ($c_a > 0$), whereas an increased technology level is assumed to reduce costs ($c_y < 0$). We also assume that *c* is strictly convex in *a* and *y*.

In many cases an improvement in technology will reduce emissions even if there are no explicit abatement efforts. To simplify the analysis we have disregarded this in the present study, i.e. we assume that emissions are equal to 1 in each country if there are no explicit abatement activities, no matter what the technology level is. Modifying this assumption would have no consequence for the issues treated in the present study, see Golombek and Hoel (2005) for an example of an analysis where technology is important both for "business as usual" emissions and for abatement costs.

The reason why abatement is at all relevant is of course that emissions are considered harmful. We assume that countries have some monetary valuation of how harmful emissions are. This valuation is typically called an "environmental cost" by economists. Here we assume the simplest possible such environmental cost function, namely that the environmental cost is proportional to the total amount of emissions, i.e, given by $bne = bn(1-a)$ if all countries have the same abatement level.

The social optimum

The social optimum is defined as the outcome (given by abatement levels and R&D expenditures) that minimizes total costs aggregated over all countries. Because countries are identical, all countries must have the same levels of abatement (a) and R&D investments (x) in the social optimum. In general, total costs are given by total costs of abatement, R&D investments and environmental costs, that is,

$$n[c(a,y)+x+bn(1-a))] \quad (3)$$

Minimizing (3) subject to the relationship between technology level and R&D expenditures (relation (1)) gives the first order conditions

$$c_a(a,y)=nb \quad (4)$$

$$1=(1+(n-1)\gamma)(-c_y(a,y)) \quad (5)$$

Increased abatement is costly, but leads to lower emissions, and thus reduced environmental damage. According to (4), in the social optimum marginal costs of abatement (c_a) should equal the marginal benefit following from reduced emissions (nb). Suppose this was not the case, e.g., that marginal costs of abatement are lower than marginal benefit ($c_a < nb$). Increased abatement will then reduce total costs because the increase in costs of abatement is lower than the reduction in environmental damage costs. Abatement should therefore be increased until (4) is fulfilled.

According to (5) increased costs of one additional unit of R&D in a country (1) should at the margin be balanced against its total benefits. Since R&D expenditures are measured in money, the price of one unit of R&D is per definition equal to one. The benefits of increased R&D investments in a country are reduced abatement costs for the country ($-c_y$) and for other countries through technological diffusion ($-\gamma(n-1)c_y$). If (5) is not fulfilled, it is possible to adjust R&D expenditures such that total costs are decreased, see the discussion above with respect to the optimal level of abatement.

No international climate agreement

The social optimum can be interpreted as the outcome dictated by a benevolent social planner with perfect information. It assumes that the planer can implement the outcome that minimizes total social costs aggregated over all countries, under no other restrictions than the constraints (1) and (2).

In the real world, decisions are taken by countries, not by a benevolent social planer with jurisdiction over all countries. In this section we assume that there is no international climate agreement; the opposite case will be discussed in the next section. Each country chooses its abatement and R&D expenditures in order to minimize its costs

$$c(a,y) + x + b\left[(1-a)+(n-1)(1-a^*)\right] \tag{6}$$

subject to (1) and (2). Each country controls domestic R&D expenditures and domestic abatement. We assume that each country determines these two variables such that once the country observes the chosen values of the other countries, a (hypothetical) different choice of its R&D expenditures and/or abatement would have increased its costs (given by (6)). Technically, we find the non-cooperative equilibrium by assuming that each country takes R&D expenditures and abatement levels in all other countries as given (for each country equal to x^* and a^*, respectively). The first order conditions for this problem are given by:

$$c_a(a, y) = b \tag{7}$$

$$1 = -c_y(a, y) \tag{8}$$

Relations (7) and (8) determine abatement levels and R&D expenditures in all countries. Because countries are identical, they will choose identical amounts of abatement and R&D expenditures.

Comparing the case of no international agreement with the social optimum given by (4) and (5), we immediately see that there are two differences. First, in the case of no international agreement each country valuates changes in emissions only through its own marginal environmental cost *b* and not the total marginal environmental costs *nb* as in the social optimum. This tends to yield lower abatement in the case of no international agreement than in the social optimum.

The second difference is that in the case of no agreement each country ignores the impact of its R&D investment on abatement costs in other countries through technological diffusion ($-\gamma(n-1)c_y(a, y)$). This difference suggests that R&D expenditures will be lower in the case of no international agreement than in the social optimum.

An international climate agreement of the Kyoto type

We now examine the case in which all countries in the world sign an international climate agreement. The agreement specifies the initial distribution of emission quotas between countries, but allows countries to buy or sell quotas from/to other countries. The agreement imposes no restrictions on how a country sets its domestic policy, as long as its emissions does not exceed its quotas (i.e. initial endowment adjusted for quotas purchased or sold). Below this agreement is referred to as a Kyoto type of agreement although most countries have not signed the actual Kyoto agreement.

Consider a particular country and assume that it initially is given emission quotas equal to $\bar{e}$. Quotas can be traded in a competitive international market where the price of quotas is termed *p*.[c] The country faces costs of abatement, costs of R&D expenditures and costs of net purchase of quotas. The latter cost equals the price of quotas (*p*) times net purchase of quotas, which is the difference between gross purchase (1-*a*) and endowment ($\bar{e}$). The country therefore minimizes

$$c(a, y) + x_i + p[1 - a - \bar{e}] \qquad (9)$$

subject to (1). Notice that the environmental cost function does not appear in (9) since the sum of emissions is given from the climate agreement (equal to the sum of quotas initially allocated to all countries).

The first order conditions for the minimization problem are

$$c_a(a, y) = p \qquad (10)$$

and

$$1 = -c_y(a, y) \qquad (11)$$

[c] Assuming there are many countries, each country will be small, and hence each country will consider the market price as given, that is, neglects the minor impact of its decisions on the market price.

These conditions have a similar interpretation as the first order conditions in the case of no agreement; the only difference between the two sets of first order conditions is that marginal benefit of abatement (b) in the case of no agreement is replaced by the price of quotas. However, under a Kyoto agreement the price of quotas reflects the marginal benefit of abatement of a country; increased abatement by one unit will reduce purchase of quotas by one unit, and hence reduce costs by p.

The price of quotas is determined in the international market so that the total supply of quotas equals the total demand of quotas. The larger is the amount of quotas initially allocated, the lower is the equilibrium price of quotas. Hence, the group of all countries determines the price of quotas through the total number of quotas agreed upon. Whatever this sum is, it seems reasonable to assume that in our case of identical countries this sum will be divided equally between countries. When this is the case, there will be no trade of quotas in equilibrium.

A comparison of the Kyoto type agreement with the social optimum.

Let us compare the Kyoto case with the social optimum, given by (4) and (5). Notice that in the first-best optimum both abatement levels and R&D expenditures are uniquely determined. This is not the case for the Kyoto type agreement. For this agreement the outcome depends on the quota price p, which in turn depends on the total amount of emissions that the agreement specifies. There are therefore several ways one could compare these two cases. One alternative would be to compare them under the assumption that the total amount of quotas in the Kyoto type of agreement is set equal to the total amount of emissions that follows from the social optimum, which is often referred to as the first-best optimum by economists. A second alternative would be to set the total amount of quotas in the Kyoto agreement in order to minimize total social costs (given by (3)), subject to the constraints given by the behaviour of the individual countries, that is, (10) and (11). Such a minimization will give a second-best optimal outcome for abatement levels and R&D expenditures under the Kyoto agreement, which can be compared with the abatement levels and R&D expenditures in the first-best optimum .[d]

Consider the first of the alternatives above. When the variable a is the same in the two cases, one important difference between the Kyoto agreement and the first-best optimum is given by the difference between equations (5) and (11). Since a is given, it immediately follows from the properties of the abatement cost function and the fact that $\gamma > 0$ that the technology level y is lower under the quota agreement than in the first-best optimum. The reason for this is that the positive spillover effects of R&D expenditures to other countries are ignored under the Kyoto type of climate agreement. We can thus conclude that *there will be too little R&D expenditures in the Kyoto type agreement even if total emissions are set equal to what they are in the first-best optimum.*

Consider next a Kyoto type agreement where total quotas (which determines total emissions, and thus also determines abatement) are set in order to minimize total costs. Whatever this number of quotas is,, R&D expenditures will be set so that (11) is satisfied. This equation defines y as an increasing function of a; $y(a)$. The group of all countries takes into account the function $y(a)$ when choosing the optimal number of quotas. Moreover, the group takes into account that with identical countries, R&D expenditures will be the same in all countries. Inserting $y(a)$ and (1) for $x = x^*$ into the expression (3) for total costs aggregated over all countries, and minimizing with respect to a gives

[d] In a second-best optimum an optimization problem (minimizing total costs in the present paper) is solved by taking into account the behaviour of agents (relations (10) and (11)), which restricts the set of possible outcomes. In the first-best optimum, there are no behavioural restrictions.

$$c_a(a,y) = nb + \left[1 - \frac{1}{1+(n-1)\gamma}\right] y'(a) \qquad (12)$$

where we have used (11). Both $y'(a)$ and the term in square brackets are positive (for $\gamma > 0$), indicating the additional benefit from abatement that comes from inducing countries to spend more on R&D through a high quota price (that is, by choosing a low value of total number of quotas). *In the second-best optimum one should therefore set total emissions so low that the marginal abatement costs in equilibrium ($c_a(a,y)$) become higher than the marginal environmental costs (nb).*

Since marginal abatement costs are higher in the second-best Kyoto type agreement than in the first-best optimum, one might intuitively expect also total abatement to be higher in the second-best Kyoto type agreement. This is however not obvious, since R&D expenditures may be lower in the second-best optimum than in the first-best optimum. In the Appendix we show that total abatement may be higher or lower in the second-best optimum compared with the first-best. For the special case of a quadratic abatement cost function, abatement levels are the same in the two cases. For this case we also have lower R&D expenditures in the second-best optimum than in the first-best optimum. However, we cannot generally rule out the possibility that R&D expenditures are higher in the second-best optimum than in the first-best optimum, although we show in the Appendix that R&D expenditures are lower in the second-best optimum than in the first-best optimum if international technology spillovers are positive but sufficiently small.

Concluding remarks

We have shown that due to international technology spillovers, there is a social loss of not including R&D policies in an international climate agreement. A Kyoto type of agreement will not necessarily imply lower abatement levels than what is socially optimal, but there will be too little R&D activities relative to abatement efforts.

In the Introduction, we argued that one reason for not including R&D policies in an agreement is difficulties in monitoring compliance of this element of an agreement. However, even if it is difficult or impossible to design a first-best type of agreement, our results suggest that agreements where R&D policies are included in an imperfect manner may be superior to agreements that ignore R&D policies.

There is also another reason why it might be interesting to include elements related to technology development in an international climate agreement. Traditional agreements of the Kyoto type have an inherent weakness by providing large free rider incentives: Although a potential agreement may make all countries better off than a situation without any agreement, it will typically be the case that each county is even better off if it does not join the agreement but lets the other countries cooperate to reduce emissions. Since all countries have this free rider incentive, it is difficult to obtain voluntary participation. This may be one of the reasons why the present Kyoto agreement that regulates aggregate emissions for the period 2008-2012 only includes countries that totally stand for less than 30% of aggregate world emissions of greenhouse gases. The weakness of agreements focusing only on emission reductions has lead several economists to argue that agreements ought to have more focus on the development of new technology (see e.g. Barrett (2003), Buchner and Carraro (2004), Carraro and Marchiori (2003)). Such technology based agreements might have weaker free rider incentives than traditional agreements of the Kyoto type, and therefore be more likely to be successful.

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Appendix: The comparison between the first-best and second-best optimum

The first-best and second-best equilibria can be written in the following compact form

$$c_a(a,y) = nb + \lambda(1-h)H(a,y) \tag{13}$$

$$c_y(a,y) = -h + \lambda(h-1) \tag{14}$$

where

$$h = \frac{1}{1+(n-1)\gamma} \tag{15}$$

and

$$H(a,y) = \frac{-c_{ya}}{c_{yy}} = y'(a) \tag{16}$$

The case $\lambda = 0$ gives the first-best optimum defined by (4) and (5), while $\lambda = 1$ gives the second-best optimum defined by (11) and (12).

To se if we can find how the second-best optimum differs from the first-best optimum, we differentiate the system (13) and (14) with respect to λ. Straightforward calculations yield

$$\frac{da}{d\lambda} = \frac{1-h}{D}\left[Hc_{yy} + c_{ay} - \lambda(1-h)H_y\right] \tag{17}$$

and

$$\frac{dy}{d\lambda} = \frac{1-h}{D}\left[-Hc_{ya} - c_{aa} + \lambda(1-h)H_a\right] \tag{18}$$

where

$$D = c_{aa}c_{yy} - c_{ay}{}^2 + \lambda(1-h)(c_{ya}H_y - c_{yy}H_a) \tag{19}$$

We shall assume that *D* is positive. This is a weak assumption: From (12) and using the second order conditions of the second-best optimum it can be demonstrated that abatement *a* is increasing in marginal environmental costs *b*. It is then straightforward to verify that $D > 0$ for $\lambda = 1$ at the (*a,y*) combination of the second-best optimum. We assume that this holds for all relevant (*a,y*) combinations for $\lambda = 1$. It must then hold also for all $\lambda \in [0,1]$ since $c_{aa}c_{yy} - c_{ay}{}^2 > 0$ by assumption.

Inserting (16) into (17) gives

$$\frac{da}{d\lambda} = -\frac{(1-h)^2}{D}\lambda H_y \tag{20}$$

The sign of this expression is ambiguous, since the sign of H_y depends on third order derivatives of the abatement cost function. For the special case of a quadratic cost function these third order derivatives are zero, so in this case we have $H_y = 0$. Hence, for the special case of a quadratic cost abatement cost function total abatement (and thus total emissions) are identical in the first-best and second-best optimum.

Inserting (16) into (18) gives

$$\frac{dy}{d\lambda} = \frac{1-h}{Dc_{yy}} \left[c_{ya}^2 - c_{aa}c_{yy} + \lambda(1-h)c_{yy}H_a \right] \qquad (21)$$

The sum of the first two terms is negative, since the abatement cost function is assumed to be strictly convex. If this cost function is quadratic, then $H_a = 0$ and hence $\frac{dy}{d\lambda} < 0$. Thus, in the case of a quadratic cost function *y*, and thus R&D expenditures in all countries, is lower in the second-best optimum ($\lambda = 1$) than in the first-best optimum ($\lambda = 0$). For the general case we cannot rule out the possibility of the term in brackets being positive for sufficiently large values of λ. We can therefore generally not rule out the possibility that R&D expenditures are higher in the second-best optimum than in the first-best optimum. (If this is the case, it follows from a comparison of (4) with (12) that abatement will also be higher in the second-best optimum than in the first-best optimum.) However, if the variable *h* is sufficiently close to one, it is clear from (21) that the term in brackets will be negative for all values of λ. The variable *h* will be closer to 1 the smaller are technology spillovers between countries, measured by the parameter γ (cf. (15)). We can thus conclude that if international technology spillovers are positive but sufficiently small, R&D expenditures are lower in the second-best optimum ($\lambda = 1$) than in the first-best optimum ($\lambda = 0$).

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