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Paolo Buonanno, Carlo Carraro,
Efrem Castelnuovo and Marzio Galeotti

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Paolo Buonanno, Fondazione ENI Enrico Mattei
Carlo Carraro, Università di Venezia and CEPR
Efrem Castelnuovo, Fondazione ENI Enrico Mattei
Marzio Galeotti, Università degli Studi Di Bergamo

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Centre for Economic Policy Research
90–98 Goswell Rd, London EC1V 7RR, UK
Tel: (44 20) 7878 2900, Fax: (44 20) 7878 2999
Email: cepr@cepr.org, Website: http://www.cepr.org

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ABSTRACT

Emission Trading Restrictions with Endogenous Technological Change*

In this Paper we use a simple climate model with endogenous environmental technical change in order to analyse the effects on equity and efficiency of different degrees of restrictions on trade in the market for pollution permits. The model is obtained by incorporating in Nordhaus and Yang (1996)'s RICE model and the notion of induced technical change as proposed in Goulder and Mathai (1998). With the help of such a model we aim at assessing the pros and cons of the introduction of ceilings on emission trading. In particular, we analyse the implications of restrictions on trading both in terms of their cost effectiveness and in terms of their distributional effects. The analysis takes into account the role of environmental technical change that could be enhanced by the presence of ceilings on trading. However, this effect is shown to be offset by the increased abatement cost induced by the larger than optimal adoption of domestic policy measures when ceilings are binding. Hence, our analysis provides little support in favour of quantitative restrictions on emission trading even when these restrictions actually have a positive impact on technical change. Even in terms of equity, ceilings find no justification within our theoretical and modelling framework. Indeed, we find that flexibility mechanisms in the presence of endogenous technical change increase equity and that the highest equity levels are achieved without ceilings, both in the short and in the long run.

JEL Classification: H00, H20 and H30
Keywords: ceilings, climate policy, emission trading, environmental modelling and technical change

Paolo Buonanno
Fondazione ENI Enrico Mattei
Corso Magenta 63
20123 Milano
ITALY
Tel: (39 02) 520 36949
Fax: (39 02) 520 6946
Email: buonanno.paolo@feem.it

Efrem Castelnuovo
Fondazione ENI Enrico Mattei
Corso Magenta 63
20123 Milano
ITALY
Tel: (39 02) 520 36949
Fax: (39 02) 520 6946
Email: efrem.castelnuovo@econ.upf.es

Carlo Carraro
Dipartimento di Scienze Economiche
Università di Venezia
San Giobbe 873
30121 Venezia
ITALY
Tel: (39 041) 257 4166
Fax: (39 041) 257 4176
Email: ccarraro@unive.it

Marzio Galeotti
Dipertimento di Scienze Economiche
Università degli Studi di Bergamo
Piazza Rosate 2
I-24129 Bergamo
ITALY
Tel: (39 035) 277 540
Fax: (39 035) 249 975
Email: galeotti@unibg.it

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NON-TECHNICAL SUMMARY

In the recent debate on the cost and benefits of different climate policies the role of restrictions in the market for GHGs emission permits is an issue which has been increasingly discussed in the policy arena. These restrictions are often advocated for equity reasons: in particular, developed countries should not be allowed to trade freely in the permit market, in order to be induced to abate their own emissions through domestic policy and measures, rather than by 'exploiting' the lower abatement costs of developing countries. But restrictions on emission trading are also advocated on efficiency grounds, because they would stimulate environmental innovation and the adoption of environmentally friendly technologies, thus reducing abatement costs, at least in the long run

The efficiency argument seems to be in contrast with the basic economic result which says that the equalization of marginal abatement costs across countries (achieved through free trading) minimizes overall abatement costs. Indeed, Chander, Tulkens, Van Ypersele, and Willems (1999) show that the application of simple economic principles is sufficient to prove that: (i) flexibility mechanisms reduce total compliance costs; (ii) the largest cost reduction is achieved when no constraint is imposed on the trading system (e.g. no ceilings); (iii) there exists a system of transfers such that this cost reduction benefits all countries.

However, the theoretical conclusions by Chander *et al*. (1999) are achieved within the framework of a static model, and it is not *a priori* clear whether they can be generalized to the case in which investment, stock pollution, R&D and technical change are accounted for. This is why several empirical models have been used to assess the role of ceilings within a dynamic framework where the most relevant variables are taken into account. For example, Manne and Richels (1999) state that 'losses in 2010 are two and one-half times higher with the constraint on the purchase of carbon emission rights; international co-operation through trade is essential if we are to reduce mitigation costs'.

Still, most of these models do not satisfactorily specify the role of technical progress and, above all, are unable to take into account the link between the presence of ceilings and the path of environmental innovation and diffusion. Indeed, the issue of technical change is very controversial and not yet sufficiently studied in that context. As stated, arguments offered in support of the introduction of ceilings on emission trading are based on the view that the widespread adoption of flexibility mechanisms reduces the incentives to carry out environmental R&D, thereby reducing the effectiveness and increasing the costs of abatement options in the long run. Moreover, the incentives to R&D induced by the presence of ceilings on the use of flexibility mechanisms may spill over onto other sectors, thus speeding up the 'engine of growth', and reducing the impact of climate change control on long run *per capita* income and welfare.

This is why it is important to study the problem of ceilings with a model which on the one hand endogenizes the process of adoption and diffusion of environmental technical change, and on the other hand captures the link between this process and the introduction of ceilings on emission trading. This is the goal of this Paper, in which we take the well-known RICE model of integrated assessment (Nordhaus and Yang, 1996) and incorporate in it a modified version of the endogenous environmental technical change (ETC) model proposed by Goulder and Mathai (1998). In the model, which we label 'ETC-RICE', the agent chooses the optimal R&D effort that increases the stock of technological knowledge. This stock in turn enters the production function as one of the production factors and, at the same time, affects the emission-output ratio. R&D is thus a policy variable, the idea being that more knowledge helps to increase a firm's productivity and reduce the negative impact on the environment. The model so obtained is also extended to include a market for pollution permits. Using our ETC-RICE model, we solve the game played by the six regions in which the world is divided when deciding the optimal level of four instruments: fixed investments, R&D expenditures, rate of emission control, and amount of permits which each country wants to buy or sell. The game is played under some regulatory constraints: with or without ceilings on trading, with the possibility to trade only among Annex 1 countries or under global trade.

Our analysis provides little support to quantitative restrictions on emission trading. Even if the introduction of ceilings increases the R&D efforts of buyer countries and fosters technological innovation, the overall effect on abatement costs and economic growth is negative. The reason is that the benefits from technological innovation are lower, even in the long run, than the costs of adopting a more costly approach to climate change control. In other words, firms benefit more from a low impact of climate policies on their costs than from the stimulus to innovation that these policies induce.

Even equity is not positively affected by ceilings. We find that flexibility mechanisms in the presence of endogenous technical change increase equity and that the highest equity levels are achieved without ceilings, both in the short and long run.

EMISSION TRADING RESTRICTIONS
WITH ENDOGENOUS TECHNOLOGICAL CHANGE

1. Introduction

In the recent debate on the costs and benefits of different climate policies (OECD, 1998; Carraro, 1999, 2000) the role of restrictions in the market for greenhouse gases (GHGs) emission permits is an issue which has been increasingly discussed in the policy arena. These restrictions are often advocated for equity reasons: in particular, developed countries should not be allowed to trade freely in the permit market, in order to be induced to abate their own emissions through domestic policy and measures, rather than by "exploiting" the lower abatement costs of developing countries. But restrictions on emission trading are also advocated on the basis of efficiency reasons, because they would stimulate environmental innovation and the adoption of environmental friendly technologies, thus reducing abatement costs, at least in the long run (see for instance Hourcade and Le Pesant, 2000; Grubb, Brack, and Vrolijk, 1999; Schleicher, Buchner, and Kratena, 2000).

The efficiency argument seems to be in contrast with the basic economic result which says that the equalisation of marginal abatement costs across countries (achieved through free-trading) minimises overall abatement costs. Indeed, Chander, Tulkens, Van Ypersele, and Willems (1999) show that the application of simple economic principles is sufficient to prove that: (i) flexibility mechanisms reduce total compliance costs; (ii) the largest cost reduction is achieved when no constraint is imposed on the trading system (e.g. no ceilings); (iii) there exists a system of transfers such that this cost reduction benefits all countries. [1]

However, the theoretical conclusions by Chander *et al*. (1999) are achieved within the framework of a static model, and it is not a priori clear whether they can be generalised to the case in which investment, stock pollution, R&D and technical change are accounted for. This is why several empirical models have been used to assess the role of ceilings within a dynamic framework where the most relevant variables are taken into account. For example, Manne and Richels (2000) state that "losses in 2010 are two and one-half times higher with the constraint on the purchase of

[1] Article 17 of the Kyoto Protocol calls for emissions trading to be only "supplemental to domestic actions for the purpose of meeting quantified emissions limitation and reduction commitments under Article 3". To make this provision operational, it has been suggested that quantitative constraints (ceilings) on imports of emissions permits be introduced.

carbon emission rights; international co-operation through trade is essential if we are to reduce mitigation costs”.[2]

Still, most of these models do not satisfactorily specify the role of technical progress and, above all, are unable to take into account the link between the presence of ceilings and the path of environmental innovation and diffusion. Indeed, the issue of technical change is very controversial and not yet sufficiently studied in that context. As said above, arguments offered in support of the introduction of ceilings on emission trading are based on the view that the widespread adoption of flexibility mechanisms reduces the incentives to carry out environmental R&D, thereby reducing the effectiveness and increasing the costs of abatement options in the long run. Moreover, the incentives to R&D induced by the presence of ceilings on the use of flexibility mechanisms may spill over onto other sectors, thus speeding up the “engine of growth”, and reducing the impact of climate change control on long run per capita income and welfare.

This is why it is important to study the problem of ceilings with a model which, on the one hand endogenises the process of adoption and diffusion of environmental technical change, and on the other hand captures the link between this process and the introduction of ceilings on emission trading. This is precisely the goal of this paper, which uses an extended version of Nordhaus and Yang (1996)’s RICE model to propose an answer the following questions:

- Is R&D a complement or a substitute with respect to emissions trading, i.e. do countries reduce their R&D efforts when trading is allowed for? Do ceilings increase R&D expenditure?
- When ceilings on emissions trading foster R&D expenditures and increase R&D efforts, do they also reduce abatement costs? What is the overall effect on economic growth?
- What is the impact on equity of different degrees of restrictions on trading? In particular, is it true that emission trading will favour developing countries, thus increasing equity, as argued in Nordhaus and Boyer (1999), or does emission trading favour mainly Annex 1 countries, because it reduces their abatement costs, thus reducing equity? [3] In this context, do ceilings increase or reduce equity?

In order to answer these questions, we take the well-known RICE model of integrated assessment (Nordhaus and Yang, 1996) and incorporate in it a modified version of the endogenous environmental technical change (ETC) model proposed by Goulder and Mathai (1998) (see also Nordhaus, 1997). In the model, which we label “ETC-RICE”, the agent chooses the optimal R&D effort which increases the stock of technological knowledge. This stock in turn enters the production function as one of the production factors and, at the same time, affects the emission-

[2] Similar conclusions are achieved by Shogren (2000), Rose and Stevens (2000), Bosello and Roson (2000), Tol (2000), and several others.

output ratio. R&D is thus a strategic variable, the idea being that more knowledge helps increasing a firm's productivity and reducing the negative impact on the environment. The model so obtained is also extended to include a market for pollution permits. Using our ETC-RICE model, we solve the game played by the six regions in which the world is divided when deciding the optimal level of four instruments: fixed investments, R&D expenditures, rate of emission control, and amount of permits which each country wants to buy or sell. The game is played under some regulatory constraints: with or without ceilings on trading, with the possibility to trade only among Annex 1 countries or under global trade.

In order to compare our analysis with a benchmark, the ETC-RICE model is calibrated in such a way as to reproduce the same Business As Usual (BAU) scenario as that of Nordhaus and Yang (1996)'s RICE model where technical change is present, but follows an exogenously given path.

Our simulations provide little support for quantitative restrictions on emission trading. Even if the introduction of ceilings increases the R&D efforts of buyer countries and fosters technological innovation, the overall effect on abatement costs and economic growth is negative. Finally, even equity is not positively affected by ceilings. We find that flexibility mechanisms in the presence of endogenous technical change increase equity, and that the highest equity levels are achieved without ceilings, both in the short and in the long run.

The structure of the paper is as follows. Section 2 presents the modelling framework that will be used for simulating different degrees of restrictions in the market for emission permits. Section 3 discusses the main simulation results. Finally, section 4 provides some policy conclusions and describes directions of future research.

2. The Model

We tackle the issue of endogenous technical change inspired by the ideas contained in both Nordhaus (1997) and Goulder and Mathai (1998) and accordingly we modify Nordhaus and Yang (1996)'s regional RICE model. Doing so requires the input of a few new parameter values, some of which we try to estimate using information provided by Coe and Helpman (1995), while the remaining parameters are calibrated so as to reproduce the BAU scenario generated by the RICE model with exogenous technical change. We then extend the integrated assessment model thus

[3] Nordhaus and Boyer (1999) actually claim that the Kyoto protocol, even if implemented through emission trading, will be excessively costly to the U.S.A. and extremely beneficial to developing countries.

obtained to allow for trading of emission permits and we analyse several policy options looking at their efficiency and equity implications.

In Goulder and Mathai (1998)'s partial equilibrium model of knowledge accumulation, a firm chooses time paths of abatement and R&D efforts to minimise the present value of the costs of abating emissions and of R&D expenditures subject to an emission target. The abatement cost function depends both on abatement and on the stock of knowledge, which increases over time via R&D investment.[4] In a similar vein, Nordhaus (1997) lays out a model of induced innovation brought about by R&D efforts. In particular, technological change displays its effects through changes in the emissions-output ratio. This aspect is then embedded in the non-regional version of the author's RICE model for climate change policy analysis, called DICE (Nordhaus, 1993).

Our model of integrated assessment is an extended version of the RICE model, which is one of the most popular and manageable integrated assessment tools for the study of climate change (see, for instance, Eyckmans and Tulkens, 1999). It is basically a single sector optimal growth model suitably extended to incorporate the interactions between economic activities and climate. There is one such model for each macro region into which the world is divided (U.S.A., Japan, Europe, China, Former Soviet Union, Rest of the World). Within each region a central planner chooses the optimal paths of fixed investment and emission abatement that maximise the present value of per capita consumption. Output (net of climate change) is used for investment and consumption and is produced according to a constant returns Cobb-Douglas technology, which combines the inputs from capital and labour with the level of technology. Population (taken to be equal to full employment) and technology levels grow over time in an exogenous fashion, whereas capital accumulation is governed by the optimal rate of investment. There is a wedge between output gross and net of climate change effects, which depends upon the amount of abatement (rate of emission reduction) as well as the change in global temperature. The model is completed by three equations respectively representing emissions (which are related to output and abatement), carbon cycle (which relates concentrations to emissions), and climate module (which relates the change in temperature relative to 1990 levels to carbon concentrations).

In our extension, each country plays a non-cooperative Nash game in a dynamic setting, which yields an Open Loop Nash equilibrium (see Eyckmans and Tulkens, 1999, for an explicit derivation of first order conditions of the optimum problem).[5] This is a situation where in each

[4] A second model studied by Goulder and Mathai (1998) assumes that the rate of change of the knowledge stock is governed by abatement efforts themselves. This form of technological change is termed learning by doing. The analysis we conduct in the present paper can be easily adapted to this case as well, although we have selected R&D-driven technological change as it appears to be more popular in the literature and because it provides an additional policy variable relative to the case of abatement driven knowledge accumulation.

[5] A more complete description of the ETC-RICE model can be found in Buonanno, Carraro, Castelnuovo, and Galeotti (2000).

region the planner maximises its utility subject to the individual resource and capital constraints and the climate module for a given emission (i.e. abatement) strategy of all the other players.[6]

Let us now focus on the technical change extension of the RICE model. As said above, we assume that innovation is brought about by R&D spending which contributes to the accumulation of the stock of existing knowledge. Following an approach pioneered by Griliches (1979, 1984), we assume that the stock of knowledge is a factor of production, which therefore enhances the rate of productivity (see also Weyant, 1997). Besides this channel, however, knowledge also serves the purpose of reducing, *ceteris paribus*, the level of carbon emissions. Thus, in our formulation, R&D efforts prompt both environmental and non-environmental technical progress, although with different modes and elasticities.[7] More precisely, we modify the RICE production function and the emission-output relationship as follows:

$$Q(n,t) = A(n,t)K_R(n,t)^{\beta_n}[L(n,t)^{\gamma}K_F(n,t)^{1-\gamma}] \quad (1)$$

and:

$$E(n,t) = [\sigma_n + \chi_n \exp(-\alpha_n K_R(n,t))][1-\mu(n,t)]Q(n,t) \quad (2)$$

where Q is output (gross of climate change effects), A the exogenously given level of technology and K_R, L, and K_F are respectively the inputs from knowledge capital, labour, and physical capital. In addition, E stands for emissions and μ for the rate of abatement effort.

In (1), the stock of knowledge has a region-specific elasticity equal to β_n *(n=1,…6)*. Note that, to the extent that this coefficient is positive, the output production process is characterised by increasing returns to scale, in line with current theories of endogenous growth. Also, note that, while allowing for R&D-driven technological progress, we maintain the possibility that technical improvements can also be determined exogenously (the path of A is the same as that specified in the original RICE model). In (2) knowledge reduces the emissions-output ratio with an elasticity of α_n, which also is region-specific; the parameter χ_n is a scaling coefficient, whereas σ_n is the value to which the emission-output ratio tends asymptotically as the stock of knowledge increases without limit. The stock accumulates in the usual fashion:

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[6] As there is no international trade in the model, regions are interdependent through climate variables.

[7] Obviously, we could have introduced two different types of R&D efforts, respectively contributing to the growth of an environmental knowledge stock and a production knowledge stock. Such undertaking however is made difficult by the need of specifying variables and calibrating parameters for which there is no immediately available and sound information in the literature.

$$K_R(n,t+1) = R\&D(n,t) + (1-\delta_R)K_R(n,t) \quad (3)$$

where *R&D* is the expenditure in research and development and δ_R is the rate of knowledge depreciation. We finally recognise that some resources are absorbed by R&D spending. That is:

$$Y(n,t) = C(n,t) + I(n,t) + R\&D(n,t) \quad (4)$$

where *Y* is output net of climate change effects (specified just as in the RICE model), *C* is consumption and *I* gross fixed capital formation.

In summary, our formulation introduces R&D as a further strategic variable of the model which, on the one hand, contributes to output productivity and, on the other hand, affects the emission-output ratio, and therefore the overall level of pollution emissions.

As for parameter calibration and data requirements for the newly introduced variables, we proceed as follows. Firstly, coefficients already present in the original RICE model are left unchanged. Next, for each region we calibrate the coefficient β_n in the production function (1) so as to obtain in the initial year a value of the R&D-output ratio equal to the actual one. R&D figures for 1990 are taken from Coe and Helpman (1995), while the 1990 stock of knowledge for the U.S.A., Japan, and Europe comes from Helpman's Web page. [8] For the remaining three macro-regions 1990 values of the knowledge stock are constructed by taking the ratio knowledge/physical capital of the three industrialised regions and multiplying it by the 1990 physical capital stock of the other regions as given in the RICE model. The regional parameters α_n and χ_n in equation (2) are OLS estimated using time series of the emissions-output ratio and of the stock of knowledge (the sample runs from years 1990 to 2120, i.e. it consists of ten years of data). The data for the former variable are those used by Nordhaus and Yang (1996), while those for the latter variable are recovered from a BAU simulation conducted using the original emissions-output ratio $\sigma(n,t)$ of the RICE model.[9] The asymptotic values σ_n are computed by simulating the pattern of the exogenous emissions-output ratio considered by Nordhaus and Yang (1996) for 1,000 periods: the values of the last period are then taken as asymptotes. Finally, the rate of knowledge depreciation is set at 5%, following a suggestion contained in Griliches (1979).

[8] Helpman's Web page is at the URL http://www.economics.harvard.edu/faculty/helpman/data.html.

[9] More specifically, for each region we regress $ln[\sigma(n,t)-\sigma_n]$ against an intercept and $-K_R(n,t)$. The antilog of the intercept provides an estimate of χ_n, while the slope coefficient produces an estimate of α_n.

When simulating the model in the presence of emission trading, two additional equations are considered:

$$Y(n,t) = C(n,t) + I(n,t) + R\&D(n,t) + p(t)NIP(n,t) \qquad (4')$$

which replaces equation (4) and

$$E(n,t) = Kyoto(n) + NIP(n,t) \qquad (5)$$

where *NIP(n,t)* is the net demand for permits and *Kyoto(n)* are the emission targets set in the Kyoto protocol for the signatory countries and the BAU levels for the non-signatory ones. According to (4'), resources produced by the economy must be devoted, in addition to consumption, investment, and research and development, to net purchases of emission permits. Equation (5) states that a region's emissions may exceed the limit set in Kyoto if permits are bought, and vice versa in the case of sales of permits. Note that *p(t)* is the price of a unit of tradable emission permits expressed in terms of the numéraire output price. Moreover, there is an additional policy variable to be considered in this case, i.e. net demands for permits *NIP*.

Under the possibility of emission trading, the sequence whereby a Nash equilibrium is reached must be revised as follows. Each region maximises its utility subject to the individual resource and capital constraints, now including the Kyoto constraint, and the climate module for a given emission (i.e. abatement) strategy of all the other players and a given price of permits *p(0)* (in the first round this is set at an arbitrary level). When all regions have made their optimal choices, the overall net demand for permits is computed at the given price. If the sum of net demands in each period is approximately zero, a Nash equilibrium is obtained; otherwise the price is revised in proportion to the market disequilibrium and each region's decision process starts again.

Finally, when the model is used to simulate the effects of restrictions on emission trading, an additional constraint has to be introduced. Namely:

$$NIP(n,t) = CEIL(n,t)[E_{BAU}(n,t) - Kyoto(n)] \qquad (6)$$

where E_{BAU} is the level of regional emissions obtained from the BAU simulation of the model and *CEIL* is the percentage ceiling to participation in emission trading. In the present paper we consider three restricted ET (Emission Trading) policy options, setting the ceilings to either 0% (no trading), 15% or 33% and having either only Annex 1 or All countries exchanging pollution rights.

A final important feature of this paper is its focus both on efficiency and on equity of the different policy options described above. Efficiency is measured in terms of abatement costs and total costs of complying with Kyoto, the latter including both the costs of abatement and the costs (benefits) from buying (selling) permits. We also consider impacts on GNP growth, R&D efforts, emission control, and emission price. Equity is measured by an equity index *IE* which, following Bosello and Roson (2000), compares an "equally distributed level of consumption" *EINC* with the actual average consumption per head. More precisely, the equity index is:

$$IE(t) = EINC(t) / \left[\sum_{n} s(n,t) PVC(n,t) \right] \qquad (7)$$

where:

$$EINC(t) = \exp\left[\sum_{n} s(n,t) \ln PVC(n,t) \right] \qquad (8)$$

and where *s* is the region's share in the world population and *PVC* is the present discounted value of regional consumption. This is the maximised value of the objective functions generated by the model simulations. The index *EI* ranges between zero and one: the closer to unity, the more equitable the distribution.

3. Efficiency and Equity Effects of Ceilings with Induced Technical Change

With the help of the ETC-RICE model just summarised, we analyse the following eight policy options: Business as Usual, trade among Annex 1 countries (Et-A1 hereafter), trade among all countries (Et-All hereafter) and six additional policy options where trading is restricted. In these simulation experiments, only a share of emission reductions can be achieved through emission trading. The remaining abatement must be achieved by controlling the other variables, i.e. domestic abatement and R&D, which also reduces the emission-output ratio. The share of emission abatement that can be achieved through trading ranges from 0% to 33%. Higher values were not considered because often not binding. From the optimisation runs we derive the optimal time paths of the control variables and their impacts on the endogenous variables over the period 2010-2100.

As mentioned in the Introduction, the first set of question to which we seek an answer concerns whether R&D is a complement or a substitute with respect to emissions trading, i.e. do countries reduce their R&D efforts when trading is allowed for? Hence, do ceilings increase R&D expenditure?

A first answer is provided by Table 1, which shows a strong negative correlation between the demand for permits and R&D, thus supporting the conclusion that these two control variables are substitutes. Table 1 is computed by simulating the model in the absence of ceilings, but in the presence of the optimally chosen R&D expenditures which determine the dynamic path of technical change through time.

Table 1: Correlation between R&D Expenditures and Net Demand of Pollution Permits

	Correlation Index
USA	-0,999
JPN	-0,974
EU	-0,995

Let us now see whether all countries increase their R&D effort in the presence of ceilings. This is indeed the situation shown by our numerical analysis as far as developed countries are concerned, but the behaviour of the other world regions appears to be quite different. As shown in Table 2, in the U.S.A., Japan and the EU the lowest R&D effort, as measured by the percentage ratio between R&D expenditure and GNP, is made in the Business-As-Usual scenario and when all countries are allowed to trade without any restrictions. The ratio then increases when Annex 1 countries are allowed to trade without ceilings, and further increases in the presence of ceilings. The R&D effort is highest in the Kyoto scenario, which corresponds to a 0% ceiling (all abatement is carried out through domestic measures). Hence, these results support the conjecture of those who are in favour of ceilings, namely that these would stimulate R&D expenditure. The implications for costs and growth are however another matter and are discussed shortly.[10]

[10] Note that those countries for which the ceiling is not binding purchase more permits at a cheaper price and undertake less domestic abatement as well as less R&D effort. This is the case for instance of the U.S.A. in the Et-A1 (33%) policy option. On the other hand, Japan and Europe have to make more domestic efforts and R&D investment when ceilings are imposed as these are always binding. These results are consistent with those presented in Ellerman, Jacoby, and Decaux (1998).

Table 2: Percentage Ratio between R&D and GNP

	Bau	*Kyoto*	*Et-A1(15%)*	*Et-A1(33%)*	*Et-A1*	*Et-All(15%)*	*Et-All(33%)*	*Et-All*
USA	2,57	3,02	2,95	2,97	2,98	2,95	2,85	2,60
JPN	2,62	2,73	2,72	2,70	2,68	2,71	2,69	2,62
EU	1,88	2,05	2,03	2,00	2,00	2,03	1,99	1,89
CHN	0,72	0,72	0,72	0,72	0,72	0,75	0,79	0,92
FSU	1,02	1,71	2,34	2,72	2,78	1,54	1,38	1,24
ROW	0,62	0,62	0,62	0,62	0,62	0,63	0,64	0,67

Note: figures are averages for the 2010-2100 period. “Kyoto” indicates the no-trade case.

In the other world regions, the R&D effort depends on the role of these regions in the permit markets. For example, the FSU carries out the largest R&D effort in the case in which Annex 1 countries trade without ceilings. The reason is that this is the most favourable situation for the FSU, because the demand for permits is high and the FSU is the only seller. Hence, it increases R&D to reduce its own emission levels, thus increasing the amount of permits that can be sold in the market. When ceilings are introduced, the demand for permits is lower and the FSU’s R&D effort is consequently reduced. It becomes even lower when all countries are allowed to trade. In this case, the FSU is no longer the unique seller, nor the one with the lowest abatement costs. Hence, China and the Rest of the World sharply increase their R&D effort to exploit the benefits arising from selling permits. This R&D effort is obviously reduced in the presence of ceilings. The conclusion is that, in general, ceilings are likely to increase R&D expenditures (relative to GNP) in OECD countries, i.e. in countries which are going to buy permits, but they reduce them in the FSU, China, and other developing countries – the seller countries -- where the greatest stimulus to carry out R&D comes from the possibility to trade emission permits without restrictions.

The evidence just presented notwithstanding, what matters are the effects produced by trading restrictions on abatement costs and economic growth. This aspect refers to the second set of questions we asked in the introduction: namely, when ceilings on emissions trading foster R&D expenditures and increase R&D efforts, do they also reduce abatement costs? What is the overall effect on economic growth?

Table 3 shows whether the increased R&D effort in the presence of ceilings reduces the total cost of complying with the Kyoto commitments. In all OECD regions the highest cost is achieved when all abatement is carried out domestically and there is no trade (the Kyoto scenario), whereas the lowest cost is achieved when all world countries are allowed to trade without restrictions (the U.S.A. is a partial exception). Ceilings generally increase costs, with the exception of the U.S.A. where a 33% ceiling in the case of global trade may be slightly beneficial (but the ceiling is binding only in the first decade). The situation of the U.S.A. is again explained by the fact that, for countries where the ceiling is not binding, its introduction is beneficial because it reduces the equilibrium prices of permits, without affecting the quantity demanded in that country. In the developing countries the cost is lowest when they can fully exploit the benefits of emission trading: for China and the Rest of the World in the case of global trade, for the FSU in the case of Annex 1 trade.

Table 3: Percentage Ratio between Total Compliance Cost and GNP

		Bau	***Kyoto***	***Et-A1(15%)***	***Et-A1(33%)***	***Et-A1***	***Et-All(15%)***	***Et-All(33%)***	***Et-All***
USA	*short run*	0,00024	0,12574	0,08342	0,04630	0,07477	0,08346	0,04630	0,00761
	long run	0,00015	0,86298	0,53697	0,26825	0,77999	0,53406	0,26825	0,00348
JPN	*short run*	0,00003	0,21065	0,13410	0,06959	0,02491	0,13430	0,06959	0,00231
	long run	0,00002	1,34816	0,83808	0,42529	0,36924	0,84498	0,42529	0,00138
EU	*short run*	0,00017	0,13042	0,08534	0,04628	0,03515	0,08535	0,04628	0,00362
	long run	0,00015	1,20075	0,75922	0,38762	0,47935	0,75877	0,38762	0,00214
CHN	*short run*	0,00028	0,00029	0,00029	0,01816	0,00029	0,00416	0,01816	0,07787
	long run	0,00095	0,00099	0,00099	0,00576	0,00100	0,00261	0,00576	0,01903
FSU	*short run*	0,00008	0,06844	0,15029	0,02995	0,30214	0,04870	0,02995	0,03925
	long run	0,00006	0,06067	0,32969	0,02295	0,58834	0,03938	0,02295	0,00838
ROW	*short run*	0,00012	0,00012	0,00012	0,00299	0,00012	0,00079	0,00299	0,01212
	long run	0,00027	0,00029	0,00029	0,00146	0,00029	0,00068	0,00146	0,00543

Note: short run refers to averages over the 2010-2030 period, long run refers to averages over the 2080-2100 period.

To deepen our analysis, the next goal is to see whether the long run effects of the increased R&D effort can stimulate economic growth, thus providing an economic benefit that could compensate the cost of complying with the Kyoto protocol. The argument is closed to the so called Porter Hypothesis: environmental regulation, and the related costs, induces firms to undertake R&D and innovate, thus achieving a competitive advantage that increases profits in the long run.

Table 4: GNP Differences

		Kyoto vs. Bau	***Et-A1 vs. Bau***	***Et-A1(15%) vs. Bau***	***Et-A1(33%) vs. Bau***	***Et-All vs. Bau***	***Et-All(15%) vs. Bau***	***Et-All(33%) vs. Bau***
USA	*Short run*	0,033	4,200	2,900	4,733	2,533	2,067	0,003
	Long run	-191,167	-168,333	-92,233	-163,567	25,167	-99,700	-0,026
JPN	*Short run*	-18,800	-1,500	-12,533	-6,400	0,000	-12,833	-0,007
	Long run	-264,500	-86,500	-181,133	-99,000	10,633	-185,400	-0,107
EU	*Short run*	-19,367	-2,333	-11,933	-4,633	0,400	-12,533	-0,007
	Long run	-502,067	-207,433	-329,900	-203,967	35,533	-338,500	-0,183
CHN	*Short run*	0,033	0,033	0,033	0,033	-5,567	-0,567	-0,002
	Long run	22,267	22,200	22,300	22,233	52,000	26,333	0,032
FSU	*Short run*	1,967	-0,967	1,633	-0,067	0,867	1,533	0,001
	Long run	49,533	16,667	29,900	14,533	20,233	42,333	0,033
ROW	*Short run*	0,033	0,033	0,033	0,033	-15,600	-1,733	-0,005
	Long run	26,667	26,833	25,967	25,933	55,967	30,600	0,037

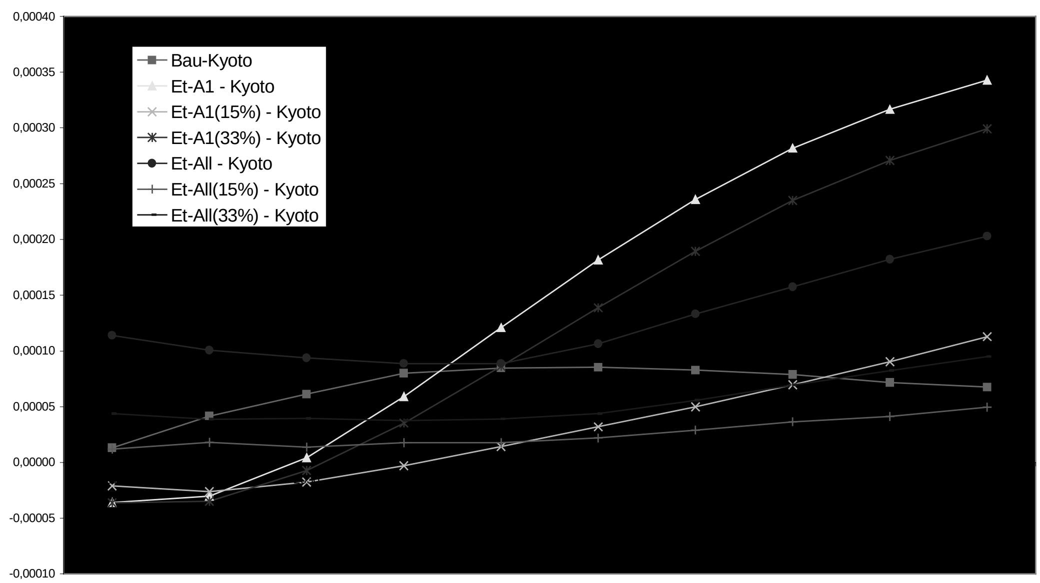
Note: figures are expressed in 1990 US$ billions.

Our model is able provide a partial assessment of this argument, but, as it emerges from Table 4, it unfortunately gives little support to it. Indeed, for the OECD regions, the only policy scenario in which the long run GNP is above its BAU value is the Et-All scenario, where all countries trade permits without restrictions. In all other cases GNP is below the BAU values and achieves the lowest value in the Kyoto scenario, where all abatement is carried out domestically. However, there are cases in which ceilings are beneficial. Consider the U.S.A.. If trade is allowed only among Annex 1 countries, ceilings have a beneficial impact on long run GNP, particularly the stricter 15% ceiling. But in the case of global trade, ceilings have a negative impact on long run GNP. The situation is different for Japan and the EU, for which ceilings reduce long run GNP both in the case of trade among Annex 1 countries and in the case of global trade. In China and in the Rest of the World, the highest long run GNP is also achieved when all countries trade without restrictions. In these regions, ceilings reduce long run GNP, but they may be beneficial in the short run. The situation of the FSU is more complicated. The reason is that the FSU largely benefits from being the only seller in the Annex 1 trade scenario, but this benefit tends to disappear in the long run. Hence, in the last two decades of our optimisation period, the Kyoto scenario seems to provide the largest difference between GNP and its BAU value. The second best and third best long run options are those in which a 15% ceiling is introduced (with global and Annex 1 trade respectively).

The overall conclusion emerging from the results just described is that the efficiency argument in favour of ceilings receives little support from our simulation experiments. Even if the presence of ceilings stimulates technical change, the overall effect on abatement costs and economic growth appears to be detrimental. The explanation is related to the relative importance of cost effects and innovation effects. In our growth model, the cost reduction achieved through free-trading seems to stimulate growth more than the increase of R&D and of technological innovation achieved through restricted trading (ceilings).

Finally, the last set of questions we asked concerns the effects of ceilings on equity. One of the arguments in favour of these restrictions is that they would yield a more equitable outcome by

Figure 1: Equity index: differences



preventing developed countries from exploiting developing countries' natural resources. According to this argument, with ceilings the implementation of Kyoto would be more equitable, because developed countries increase their abatement through domestic policies and do not buy developing countries' "environmental resources" at low prices. Our results do not support this equity argument either. Again, we must distinguish between the short run and the long run.

As shown in Figure 1, the long run most equitable policy scenario is one in which trade is allowed among Annex 1 countries without ceilings. Second is the case with a 33% ceiling (almost never binding), and then comes the case with global trade without ceilings. We can therefore conclude that our results do not support the equity argument because in the long run the highest level of equity is achieved when no ceilings are introduced (or, equivalently, ceilings are not binding). This is true also in the short run, where the most equitable policy option is the one in which all countries trade without ceilings. We conclude that, as far as equity is concerned, our model do not support to assertions emphasising the potential benefits of quantitative restrictions to emissions trading.

4. Conclusions

In this paper we have used a simple climate model with endogenous environmental technical change, obtained by integrating Nordhaus and Yang (1996)'s RICE model with the specification proposed in Goulder and Mathai (1998), to analyse the efficiency and equity dimensions of different policy options for climate change control. In particular, we had two goals: (i) assessing pros and cons of the introduction of ceilings for emission trading; (ii) quantifying the distributional effects of different climate policy options.

Our analysis provides little support to quantitative restrictions on emission trading. Even if the introduction of ceilings increases the R&D efforts of buyer countries and fosters technological innovation, the overall effect on abatement costs and economic growth is negative. The reason is that the benefits from technological innovation are lower, even in the long run, than the costs of adopting a more costly approach to climate change control. In other words, firms benefit more from a low impact of climate policies on their costs than from the stimulus to innovation that these policies induce.

Even equity is not positively affected by ceilings. We find that flexibility mechanisms in the presence of endogenous technical change increase equity and that the highest equity levels are achieved without ceilings, both in the short and in the long run. The main reason is that developing countries receive important transfers from developed countries through the trading of permits, and this tends to reduces income inequalities (see also Nordhaus and Boyer, 1999). Moreover, the introduction of R&D and technical change gives developing countries the possibility to use R&D strategically also to increase their sale of permits.

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