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ABSTRACT

On the Consequences of the US Withdrawal from the Kyoto/Bonn Protocol*

The US decision not to ratify the Kyoto Protocol and the recent outcomes of the Bonn and Marrakech Conferences of the Parties has important implications for both the effectiveness and the efficiency of future climate policies. Among these implications, those related with technical change and with the functioning of the international market for carbon emissions are particularly relevant, because these variables have the largest impact on the overall abatement cost to be born by Annex B countries in the short and in the long run. This Paper analyses the consequences of the US decision to withdraw from the Kyoto/Bonn Protocol both on technological innovation and on the price of emission permits (and, as a consequence, on abatement costs). A first goal is to assess the impact of the US defection on the price of permits and compliance costs when technological innovation and diffusion is taken into account (the model embodies international technological spillovers). A second goal is to understand for what reasons in the presence of endogenous and induced technical change the reduction of the price of permits is lower than in most empirical analyses recently circulated. A third goal is to assess the role of Russia in climate negotiations, its increased bargaining power and its eventual incentives to follow the US defections.

JEL Classification: H00, H10 and H30
Keywords: agreements, climate, incentives, negotiations and policy

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On the Consequences of the U.S. Withdrawal from the Kyoto/Bonn Protocol

1. Introduction

The dynamics of climate change negotiations has recently received new impulses. After the US decided to withdraw from the Kyoto Protocol, the remaining Annex B parties reached a compromise on the climate treaty at the resumed COP6 in Bonn, July 2001. The outcome of the Bonn negotiations has been interpreted as a commitment to the approach embodied by the Kyoto Protocol. Nevertheless, after the first euphoria has passed, it became clear that even after the Bonn agreement, there still remain a lot of open questions. Some of them have been answered at COP7 in Marrakech, but a lot still has to be done (IEA, 2001; Egenhofer and Legge, 2001)

In addition, a crucial element of the Kyoto protocol has become increasingly binding. A precondition for the Protocol to become enforced is that at least 55 Parties to the Convention, representing at the same time at least 55% of 1990 carbon dioxide emissions of Annex I Parties, must have ratified the treaty. After the US withdrawal, almost all the remaining industrialised countries must ratify the protocol in order to reach the needed percentage. Due to their large share of 1990 emissions, Russia and Japan play a major role in this context[1]. As a consequence, their bargaining power in the negotiations has increased (even because of the EU unilateral commitment) and in Marrakech they have been able to exploit this increased bargaining power by further reducing their obligations and/or the related costs. Therefore, the climate strategy adopted by the Annex B_{-1} countries[2], and in particular by Japan and Russia, crucially depend on the US defection. The Annex B_{-1} countries face different incentives with respect to the participation in the agreement than some months ago. And these incentives depend on their bargaining power and on the carbon abatement costs resulting from the US withdrawal from the Kyoto/Bonn agreement.

[1] A further important aspect with respect to Russia (and other Eastern European countries) regards the so-called "hot air": since Russia economic activity has been decreasing during the 1990's, also their carbon emissions were declining. Therefore, the emission limits set by the Kyoto Protocol imply excess emission rights which are commonly called "hot air". Provisions in the protocol allow the sale of these rights to countries which search low-cost abatement options. Furthermore, they can also be "banked" for later periods.

[2] We denote by Annex B_{-1} countries all Annex B countries less the United States.

In the aftermath of the changed US climate policy and the Bonn agreement, a lot of studies emerged which demonstrated the convenience for the EU and Japan to remain within the Kyoto regime.[3]

For example, model calculations by Hagem and Holtsmark (2001) show that both the effect on global emissions and the international permit price markedly decrease if the Kyoto Protocol is implemented without the US. In particular, the global emission reductions would be negligible and the permit price would be reduced to one third of the value obtained in the case of US participation.

In line with these results, Kopp (2001) predicts that the US rejection will drive the permit price very low and thus prevent environmental progress. Eyckmans et al. (2001) confirm the extreme decline in the international permit price and emphasise that the global abatement objective is substantially weakened as a consequence of the US withdrawal and the Bonn agreement. Similar conclusions are obtained also in Vrolijk (2001), Kemfert (2001) and Den Elzen and Manders (2001).

Therefore, all these studies conclude that the permit price would sharply decrease as a consequence of the missing US demand for permits. As a consequence of the additional allowances for sinks, the large supply of permits and their low prices, the Annex B_{-1} countries can achieve emission reductions at much lower costs.

However, most of the above analyses are based on the assumption that markets behave competitively and focus on the impacts of the US defection on the permit market without accounting for possible strategic behaviours. In particular, the above studies assume that Russia and other Eastern European countries (EITs) do not adapt their behaviour to the weaker demand for emission permits, which is caused by the new sinks provisions and the US withdrawal.

Other studies (e.g. Manne and Richels, 2001; Böhringer, 2001) have considered the possibility of a strategic behaviour on the supply side of the permit market. In particular, they recognise that above all Russia will suffer the consequences of the decreased demand for emission permits. Since the US would have been the largest demander of permits, Russia's "hot air" will not be as highly requested as previously expected in 1997, when the Kyoto Protocol was signed. As a consequence, Russia will be the first country that could be tempted either to defect from the agreement, or to renegotiate it and/or to apply a strategic behaviour - e.g. banking in order to save the expected revenues from its excess allowances for later periods – and/or to exploit its monopoly power in the permit market.

Manne and Richels (2001) and Den Elzen and de Moor (2001) analyse some of these possibilities. They demonstrate that, after the US defection, those countries which own emission rights have an essential

[3] See Hagem and Holtsmark (2001), Kopp (2001), Kemfert (2001), Eyckmans et al. (2001), Vrolijk (2001), Den Elzen and Manders (2001).

interest in saving a substantial portion of permits for successive periods. As a consequence of the banking provision, not only the demand for permits decreases after the US withdrawal, but at the same time also supply decreases. Therefore, the permit price does not fall as much as suggested in previous studies and thus mitigation costs for the remaining Annex B countries will be marginally below the value that has been calculated for the implementation of the Kyoto Protocol including the US.

Manne and Richels (2001) and Böhringer (2001) also find that, even if banking is not allowed, seller countries might be able to reduce the negative impacts of the US defection on the permit price. This can be done by organising a sellers' cartel and by fully exploiting the consequent monopolistic power in the permit market. For example, Böhringer (2001) argues that the implications of the US rejection and the new Bonn provisions, by increasing the probability of monopolistic permit supply by Russia, Ukraine and Eastern Europe, are likely to minimise the fall of the permit price and of the abatement costs (Russia could for example exert price-discriminating behaviour due to the prevailing monopoly situation).

However, other effects, in addition to the lower impact on prices of a demand shift in the case of monopolistic markets, could be induced by the US defection. In particular, if the focus is on the supply side of the market, seller countries, and Russia in particular, could react to the US decision not to ratify the Kyoto protocol by: (i) reducing their abatement effort; (ii) reducing their R&D effort on energy-saving technologies and practices; (iii) increasing their investments; (iv) leaving the agreement; and of course by banking some of their allowances. All these decisions reduce the supply of permits and raise their price. Similar decisions could also be taken by the other Annex B_{-1} countries.

As said, the role of banking has already been analysed. Therefore, this paper will focus on the other strategic reactions that could follow the US defection from the Kyoto/Bonn protocol. In particular, this paper, by using a model in which technical change is endogenous and responds to environmental policies, will quantify the changes of R&D, emission-output ratio and investments implied by the US decision to withdraw from the Kyoto Protocol. These changes -- and the related impact on the demand and supply of permits -- will provide additional explanations on why the price of permits and abatement costs are not going to be markedly lowered by the US defection.

Finally, robbed of its expected gains of the "hot air" sales, Russia could be tempted to leave the Kyoto/Bonn agreement. We also explore this scenario in which, as expected, the permit price is going to be dramatically higher because of the absence of the main supplier in the permit market. As a consequence, abatement costs in Annex B_{-1} regions would be much higher. This scenario explains, more than other legal aspects, the increasing bargaining power of Russia in climate negotiations and the consequent outcomes observed in Marrakech.

The structure of the paper is as follows. The next section will provide a detailed overview of the main conclusions achieved in recent studies devoted to analyse the implications of the decisions on climate policy observed in the last year. Then, sections 3 and 4 will present an analysis of these implications based on a dynamic game theoretic framework in which technical change is endogenous. This will enable us to assess the role of technical change, of knowledge spillovers and of the related incentives to behave strategically. Section 5 will explore the consequences of a scenario in which both the US and Russia do not comply with the Kyoto Protocol. The final section outlines the conclusions of our work.

2. Review of the recent literature on the implications of the Bonn Agreement

This section analyses in detail the studies briefly presented in the Introduction in order to provide an overview of the most recent research on the latest events in international climate policy. As said, most studies conclude that the costs of GHGs mitigation policy are lower for those countries remaining within the Kyoto process after the Bonn agreement. The main reason for this conclusion depends on the fall of the permit price if the US are no longer the main buyer in the market. Indeed, without the US, the demand for emission permits would decrease and the price for emission permits would fall, even though the demand for emission permits would increase in the EU and Japan.

A large part of the existing studies of the consequences of the US withdrawal is based on a competitive view of the permit market and on the assumption that cost effective policies will be adopted[4].

Using a static partial equilibrium model and not considering the new sink provisions, Hagem and Holtsman (2001) find for example that "[t]he withdrawal of the United States results in the permit price falling from US$ 15 per ton CO2 equivalent to only US$ 5" (Holtsman and Hagem, 2001, p.4). As a consequence, the implementation of the Kyoto Protocol without the US implies only a negligible global impact on emissions: environmental effectiveness is reduced to almost zero because of the greater use of hot air by the remaining Annex B countries. Emissions trading is therefore mainly based on the transfers of hot air and in this way a lot of abatement is suppressed.

Other studies are based on marginal abatement cost functions which have been derived from simulations with general equilibrium models[5]. These analyses show that the US non-ratification and its implied

[4] See for example Hagem and Holtsman (2001), Eyckmans, van Regemorter and van Steenberghe (2001), Den Elzen and Manders (2001), Den Elzen and de Moor (2001) and Kopp (2001).

[5] For more details see for example Eyckmans, van Regemorter and van Steenberghe (2001), Den Elzen and Manders

decline in permit demand results in a sharp fall of the equilibrium carbon price and a severe fall of compliance costs. In particular, "the price of the permits decreases by more than 50%" (Eyckmans et al, 2001, p. 10). Including the new sink provisions, the permit price falls by more than 70% and the total abatement costs are reduced by more than 90% (see Table 1). Nevertheless, due to the big losses of the permit exporting countries, the total costs for Annex B_{-1} countries do not change a lot. However, world abatement decreases since the global abatement objective is drastically eroded.

A further group of analyses accounts for the implications of international trade[6]. However, also the insights gained by these papers do not particularly change the conclusions drawn above: their results confirm that the lower demand induced by the US rejection causes a sharp decline in permit prices if international emissions trading is allowed for. In particular, "the permit price would drop to $US 8 per ton of carbon" (Kemfert, 2001, p.14) or, taking into account also the new sink credits in the emission reduction requirements "the permit price even hits zero" (Böhringer, 2001, p.18)[7]. Moreover, the remaining Annex B countries can benefit from the larger availability of low cost abatement options. As a consequence, seller countries lose revenues while the remaining Annex B countries face "zero costs for meeting the new Kyoto targets" (Böhringer, 2001, p.18). The burden is thus reduced for all the remaining OECD countries even if they suffer from welfare losses induced by the higher emission reduction requirements. Due to these higher reduction targets and the financial transfers, the permit exporters still experience some welfare gains. Notwithstanding the positive effects found with respect to aggregate costs induced by the US withdrawal, these papers conclude that environmental effectiveness is reduced to zero.

More convincing results are obtained by a recent strand of literature which pays more attention to the role of sellers' strategic behaviour in the permit markets as a consequence of the US withdrawal[8]. These studies go beyond the traditional competitive view of the Kyoto Protocol and predict changes in incentives after the Bonn agreement. In particular, the interplay of the US withdrawal, the over-supply of permits and the additional sink allowances of the Bonn agreement, imply potentially large problems for the Kyoto permit market.

Some of the implications found in the literature include the intensified use of the "banking" provision (Manne and Richels, 2001) and the reduction of incentives to invest in CDM projects which implies reduced benefits for developing countries and a smaller availability of funds foreseen for adaptation

(2001) and Den Elzen and de Moor (2001).

[6] See for example Kemfert (2001) and Böhringer (2001).

[7] In the case where sinks credits are not considered, the permit price nevertheless falls close to zero.

[8] See for example Manne and Richels (2001), Böhringer (2001a and b), Den Elzen and de Moor (2001), Eyckmans et al.(2001) and Vrolijk (2001).

(Vrolijk, 2001). Generally, this literature highlights that the restriction of the permit supply by permit exporters becomes very likely as a consequence of the monopolistic situation.

One of the first studies which investigates the possibility of strategic behaviour induced by the absence of an US ratification has been undertaken by Manne and Richels (2001), who focus on the implications of the "banking" provision of the Kyoto Protocol in the context of the excess supply of Russian hot air. Based on an intertemporal general equilibrium model, the paper emphasises that the decline in overall mitigation costs which is expected as a consequence of the US rejection is smaller than commonly assumed (see Table 1)[9].

The reason for the smaller decrease in costs can be found in the new situation with respect to the incentives for Russia and other EITs. Following the drop-out of the world largest demander for emission permits, the permit market is characterised by a much lower demand and a much higher supply of permits. Consequently, the permit price decreases and thus these countries face a different situation with respect to the sale of hot air: their revenues and profits become smaller.

In order to maintain some of the benefits which were prevailing primer to the US withdrawal, the seller countries are tempted to make use of banking since it is "in the interest of owners of 'hot air' to defer a substantial portion of their excess emission rights for later use." (Manne and Richels, 2001, p. 1). In other words, if banking is allowed, only a small part of the hot air is going to be sold within the first commitment period and therefore the permit price declines only marginally. Even if the possibility of banking is not given, the concentration of hot air in a small number of countries implies that "these countries may be able to organize a sellers' cartel and extract sizable economic rents" (Manne and Richels, 2001, p. 10).

Other studies based on marginal abatement cost functions also conclude that the permit exporters can influence the international permit price in order to halt its decline either by banking, or by imposing a minimum price or by restricting the permit supply via other strategies enabled by their monopolistic power[10]. Model simulations show that the implementation of the Bonn agreement reduce the international price only by 45% instead of 75% if banking of 50% of the excess allowances takes place (Den Elzen and de Moor, 2001). Furthermore, "[e]fficiency losses from monopoly behaviour by FSU in the case of U.S. withdrawal double the total compliance costs compared to a competitive permit market system which achieves the same environmental target." (Böhringer, 2001b, p.3). As a consequence of the monopoly

[9] However, this paper is based on the initial assumption that the US will re-enter the Kyoto Protocol in 2020. In particular, in 2020 the US adopts - until the end of the century - an emission target which coincides with the one given by the Kyoto Protocol.

[10] For more details see for example Böhringer (2001a and b), Den Elzen and de Moor (2001) and Eyckmans et al.(2001).

power, the aggregate abatement costs are thus expected to decline only marginally for the Annex B_1 countries during the first commitment period compared to the situation with the US ratification. In this way, a reduction of the environmental effectiveness to zero as a consequence of the falling permit price is prevented although environmental effectiveness still decreases considerably.

A summary of the main conclusions achieved in the studies that we have analysed can be as follows (see Table 1 for a quantitative synthesis):

- all studies conclude that the US withdrawal and the sink provisions of the Bonn agreement highly reduce the environmental effectiveness of the Kyoto/Bonn agreement;
- all studies coincide in finding a decline in the demand for emission permits;
- however, even if the lower demand implies both a decrease of the permit price and a decline in the compliance costs, the possibility of strategic market behaviours modifies the size of the expected changes in prices and costs. In particular, these changes are much smaller than initially suggested when banking and monopolistic behaviour in the permit market are taken into account.

However, other effects and feedbacks have not yet been taken into account. The next section will explore the role of technical change and investments within a game-theoretic framework in which these variables can be used strategically.

Table 1. Implications of the U.S. withdrawal on permit price and compliance costs (1990-2100)

	International permit price			Total compliance costs		
	Kyoto Protocol	**KP plus sinks**	**KP plus other provisions**	**Kyoto Protocol**	**KP plus sinks**	**KP plus other provisions**
Hagem and Holtsmark (2001)	- 66.7%	-	Ceilings: + 6.7%	-	-	-
Kemfert (2001)	- 84.6%	-	-	-	-	-
Eyckmans et al. (2001)	- 54.3%	- 54.1% (with CPR)	CPR + ceilings: - 37.3%	+/- 0	- 27.6% (with CPR)	CPR + ceilings: + 31%
Den Elzen and Manders (2001)	- 63.2%	- 73%	-	- 87.5%	- 92.5%	-
Böhringer (2001a)	- 100%	- 100%	-	- 100%	- 100%	60% banking - 50%
Manne and Richels (2001)[11]	-	-	Sinks + banking: - 12.7%	-	-	-
Den Elzen and de Moor (2001)	- 55.6%	- 75%	50% banking: - 44.4%	- 81.6%	- 89.5%	50% banking: - 72.1%
Böhringer (2001b)	- 13.5%	-	-	- 55%	-	-
Buchner et al. (2001) *(this study)*	- 34.9%	-	-	- 66.76%	-	-

3. On the consequences of the US defection from Kyoto when technical change is endogenous

The results described in the previous section are obtained using models in which technical change is assumed to be exogenous. Does the endogenisation of technical change modify the above conclusions?

We would like to answer this question by using a modified version of Nordhaus' RICE model, in which technical change performs a twofold role: on the one hand, by increasing returns to scale, it yields endogenous growth; on the other hand, by affecting the emission-output ratio, it accounts for the adoption of cleaner and energy-saving technologies.[12] This model, called ETC-RICE, has already been used in Buonanno, Carraro and Galeotti (2001) and is briefly described in the Appendix.

In this model, six countries/regions (US, EU, Japan, FSU, China+India and ROW) optimally set the intertemporal values of four strategic variables: investments, R&D, abatement effort and demand for permits. Given the interdependency of countries' decisions, the equilibrium value of these variables is the solution of a dynamic open-loop Nash game between the six countries/regions.

Two important assumptions qualify our results. First, all countries/regions which adhere to the Kyoto/Bonn agreement are assumed to meet the Kyoto constraints from 2010 onward.[13] We therefore adopt the so-called "Kyoto forever" hypothesis (Manne and Richels, 1999). Our reference to the Kyoto/Bonn agreement is partly imprecise since, for the sake of brevity, we will sometimes call "Kyoto protocol" or "Kyoto/Bonn agreement" a "Kyoto forever" scenario. Second, all countries are assumed to adopt cost effective environmental policies. In particular, cost-effective market mechanisms (e.g. emission trading) are chosen over "command-and-control" measures in order to guarantee an efficient implementation of environmental targets.

In the sequel, we will compare the case where emissions trading is working perfectly amongst all original Annex I parties (including US) with the situation in which trading is allowed only amongst the remaining Kyoto countries (i.e., Annex I minus US) and then with the case in which emission trading takes place in the Annex I countries without both the US and Russia.

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[11] As mentioned above, this paper assumes that the US will start complying with its Kyoto emissions constraint in 2020.

[12] This idea is supported by the existing empirical research on the environmental Kuznets curves, which seems to support the conclusion that economic growth is associated with a decreasing emission-output ratio (see Galeotti and Lanza, 2001 for some recent results).

[13] The use of the "Kyoto forever" hypothesis is a strong assumption. However, the CO2 concentration levels implicit in this assumption (if RICE is a good description of the world) coincide with those in the A1B scenario (IPCC, 2000) which can be considered the "median" scenario among those currently proposed.

In the first case, we make the counterfactual assumption that all Annex I countries (including the US) ratify the Kyoto Protocol and that full emission trading is taking place across Annex I countries. In the second case, we assume that the US rejects the Kyoto Protocol and consequently does not adopt any kind of emissions target and timetable, but optimally implements the welfare maximising abatement level through domestic measures. In this second case, international trade in emission rights is taking place across the remaining Annex I countries. The third case depicts the situation in which both the US and the Former Soviet Union do not participate in the emission trading scheme, which is adopted by the remaining Annex I countries.

Please note that our analysis focuses only on CO2. There are other man-made greenhouse gases and the Kyoto Protocol takes some of them into account. Moreover, both the Bonn agreement and the subsequent Marrakech deal emphasise the role of sinks in meeting the Kyoto targets. As shown by several recent analyses (e.g. Manne and Richels, 2001; Jensen et al., 2000), the inclusion of the other greenhouse gases and of sinks would further reduce mitigation costs .

Let us return to our basic question. Does the endogenisation of technical change modify the conclusions on the consequences of the US withdrawal from the Kyoto/Bonn agreement described in Section 2? Let us start by analysing the effects of the US defection on the price of permits and on total abatement costs. These are shown in Figures 1 and 2. Table 2 shows the estimated percentage change of abatement costs in the next 50 years.

Figure 1. Price of emission permits before and after the US defection

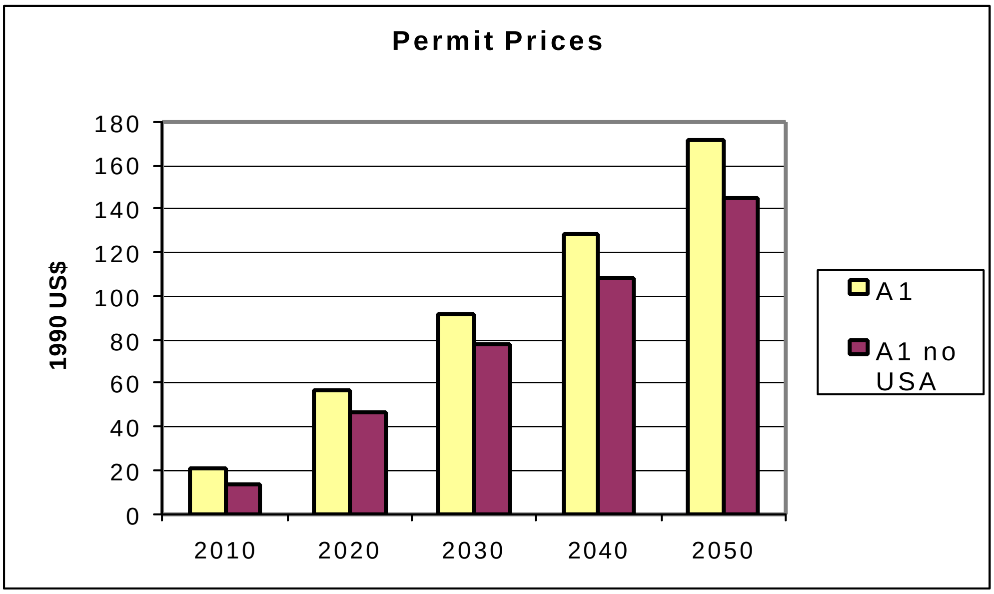


Figure 2. Abatement costs in the first commitment period before and after the US defection

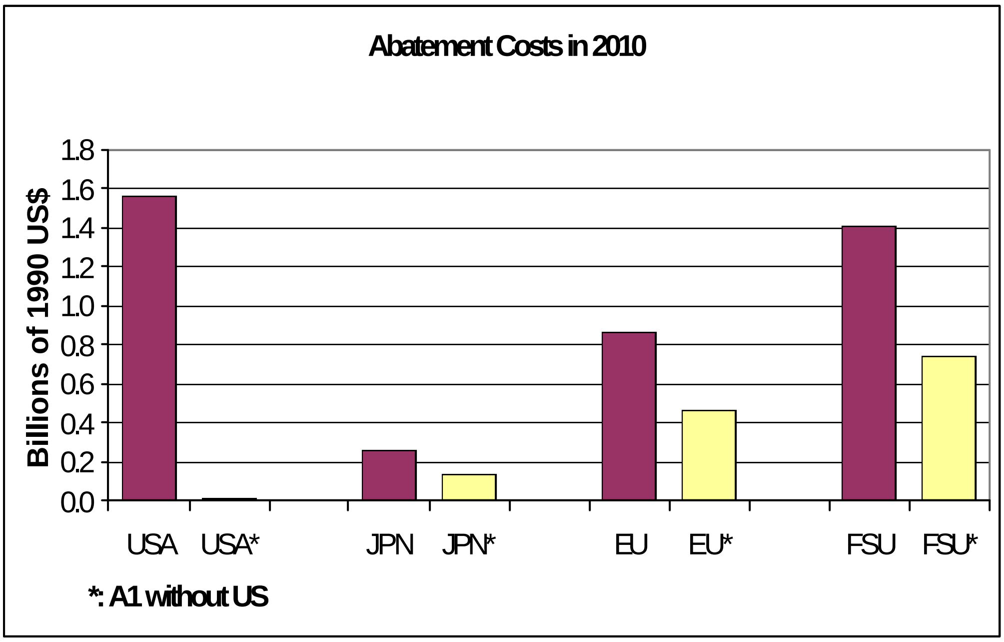


Table 2. Percentage Changes of Abatement Costs (A1 without US vs. A1)

	USA	JPN	EU	FSU
2010	-98.9%	-47.5%	-45.8%	-47.2%
2020	-99.7%	-25.2%	-24.6%	-21.4%
2030	-99.8%	-22.0%	-21.6%	-15.0%
2040	-99.9%	-22.5%	-22.2%	-13.7%
2050	-99.9%	-22.3%	-22.0%	-13.7%

The above results show that a reduction of the permit price and of compliance costs actually occurs, but it is much smaller than in all studies presented above in which no strategic behaviour is taken into account (see Table 1 again).

How can this smaller change be explained? What is the role played by endogenous technical change? A first conjecture could be that a lower permit price constitutes a smaller incentive to undertake environment-friendly and energy-saving R&D in all Annex B countries. This would increase domestic emissions and therefore would make it more difficult to meet the Kyoto targets in all Annex B_{-1} countries. As a consequence, domestic abatement and the demand for permits would increase in the EU and Japan. For the same reasons, this effect would decrease the supply of permits from Russia. The effect on Russia could be particularly relevant. As shown in a previous paper (see Buonanno, Carraro and Galeotti, 2001), a high permit price induces Russia to over-invest in R&D in order to sell more permits in the market and increase total revenue and welfare.[14] When the price of permits falls because of the US defection and the consequent decrease of permit demand, the strategic incentive to over-invest in R&D vanishes and the supply of permits becomes lower.

The above strategic role of R&D led us to conjecture that the fall of permit prices induced by the US defection may have important feedback effects in the presence of induced technical change. These feedback effects -- i.e. lower incentives to invest in energy saving R&D -- would raise the demand and reduce the supply of permits with respect to the case in which technical change is exogenous. Hence, the fall of the price would be smaller. This conjecture is confirmed by the results shown in Figure 3. Indeed, the total amount of R&D undertaken in Annex B countries is lower after the US withdrawal from the Kyoto protocol. Note that the strongest reduction occurs in the US and in Russia. In the US, because they do not need to comply with the Kyoto obligations any longer. In Russia, because there is a smaller incentive to strategically over-invest in R&D. Therefore, a lower investment in R&D, by increasing demand and reducing supply of permits, constitutes a first explanation of the smaller change of permit prices and abatement costs simulated with the ETC-RICE model.

[14] Therefore, R&D is a strategic variable which plays a role both in the good market – because it increases productivity -- and in the permit market -- because it increases the revenue form selling permits (or reduces the costs of buying permits).

Figure 3. Changes of R&D investments after the US defection.

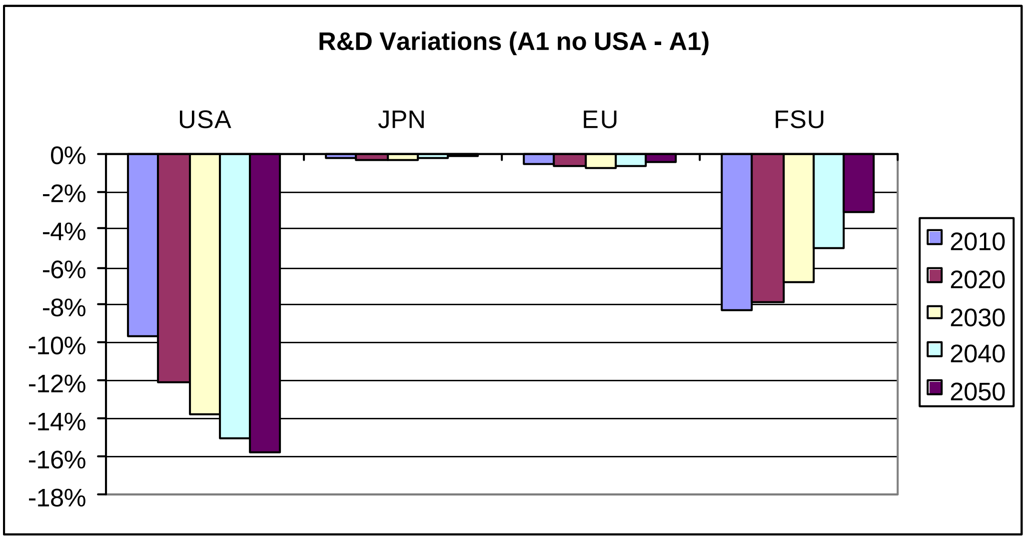
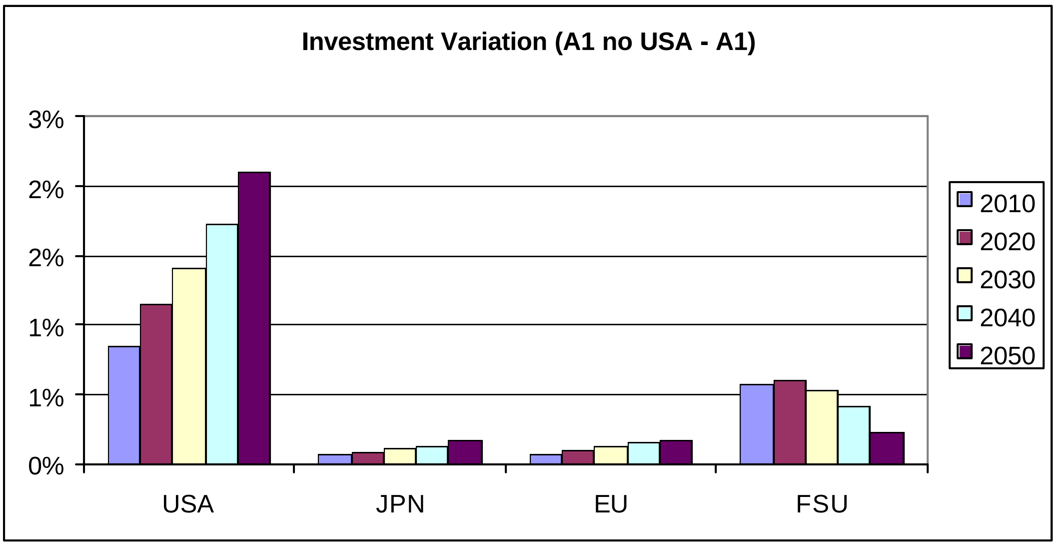


Figure 4. Changes of total investments after the US defection.



This, however, is not the only effect that induces a reduction of permit prices and abatement costs smaller than expected and above all smaller than the one found in other studies. Indeed, a second effect goes through the behaviour of investments. The lower total emission abatement induced by the US defection reduces output below its optimal level (in RICE, the climatic model is such that damages from GHGs emissions are valued in units of output). This output reduction is further enhanced by the presence of endogenous and induced technical change. A lower R&D effort implies both more damages from emissions and a lower growth rate of output.

Therefore, in our game-theoretic optimising framework, after the US defection, the remaining Annex B countries must increase investments to increase output (see Figure 4). These increased investments lead to greater emissions in these countries (see Table 3). As a consequence, the countries which have decided to comply with the Kyoto/Bonn targets face a target harder to achieve, increasing their demand for permits. At the same time, Russia needs more permits to meet its own target and therefore reduces its supply in the international permit markets. As a consequence, the price fall is lower than expected and abatement costs are larger than expected.

Table 3. Change of GHG emissions after the US defection

GHGs Emissions		
A1	**A1 without US**	**Variation**
9.3152	9.5686	2.721%
11.3289	11.7496	3.714%
13.8964	14.4653	4.094%
16.8977	17.5996	4.154%
20.1468	20.9705	4.088%

4. On the role of knowledge spillovers

Do the above conclusions hold even when international technological spillovers are accounted for? A second version of the ETC-RICE model identifies the impact that domestic investments in R&D have on the world stock of knowledge and then on the growth rate and on the emission-output ratio of foreign countries (see the Appendix). Using this version of the model, what are the expected consequences of the US withdrawal from the Kyoto/Bonn agreement?

The presence of spillovers should enhance the effects described in the previous section. Indeed, a reduction of the R&D effort induced by the lower permit price affects all countries and not only the countries which take the decision to reduce R&D. In particular, the relatively large reduction of energy-saving R&D investments which takes place in the US after their defection spills over the other countries, thus further increasing their emission-abatement ratio and therefore their emissions. This makes it more difficult for the Annex B_{-1} countries to meet their Kyoto targets. Therefore, this increases their demand for permits or reduces their supply.

Annex B_{-1} countries could react to the lower spillovers by increasing their own R&D efforts. However, this may not be sufficient to offset the negative effect induced by the lower international technological spillovers. If this is the case, the net demand for permits further increases with respect to the case in which international knowledge spillovers are not considered. As a consequence, the equilibrium price of permits should be higher in the presence of technological spillovers than in the case in which they are not accounted for.

This conclusions is indeed supported by our results. Figure 5 shows that the decrease of the permit price which follows the US defection is even smaller than the one shown in Figure 1. Moreover, Figure 6 shows a smaller reduction for total abatement costs in the first commitment period. The same conclusion can be derived by looking at Table 4, where abatement costs from 2010 to 2050 are shown.

Table 4. Percentage Change of Abatement Costs (A1 without US vs A1 with spillovers)

	USA	JPN	EU	FSU
2010	-99.6%	-11.6%	-11.5%	-11.8%
2020	-99.8%	-6.8%	-6.6%	-6.5%
2030	-99.9%	-5.3%	-4.9%	-4.8%
2040	-99.9%	-3.5%	-3.2%	-3.1%
2050	-99.9%	-1.9%	-1.5%	-1.3%

Figure 5. Price of emission permits before and after the US defection (with spillovers)

Figure 6. **Abatement costs in the first commitment period before and after the US defection (with spillovers)**

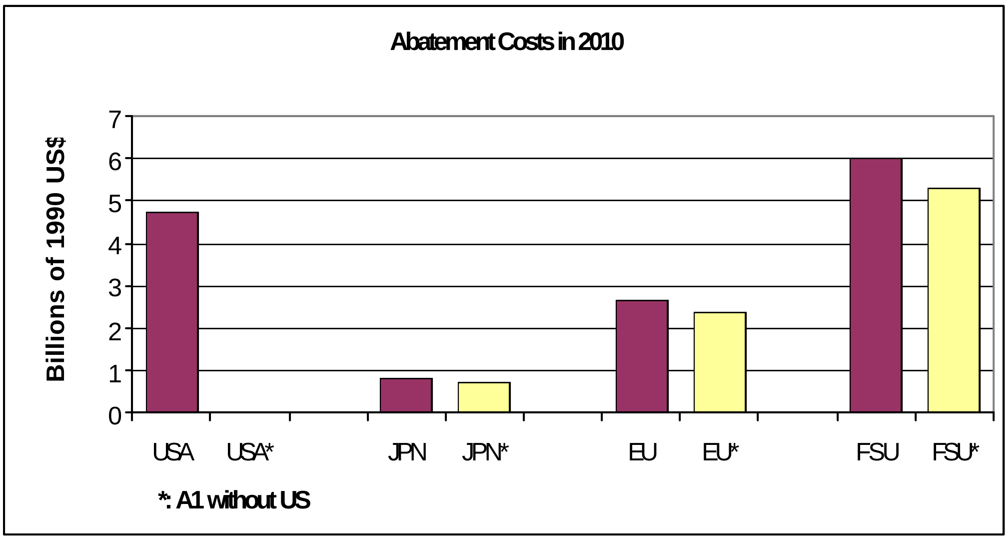
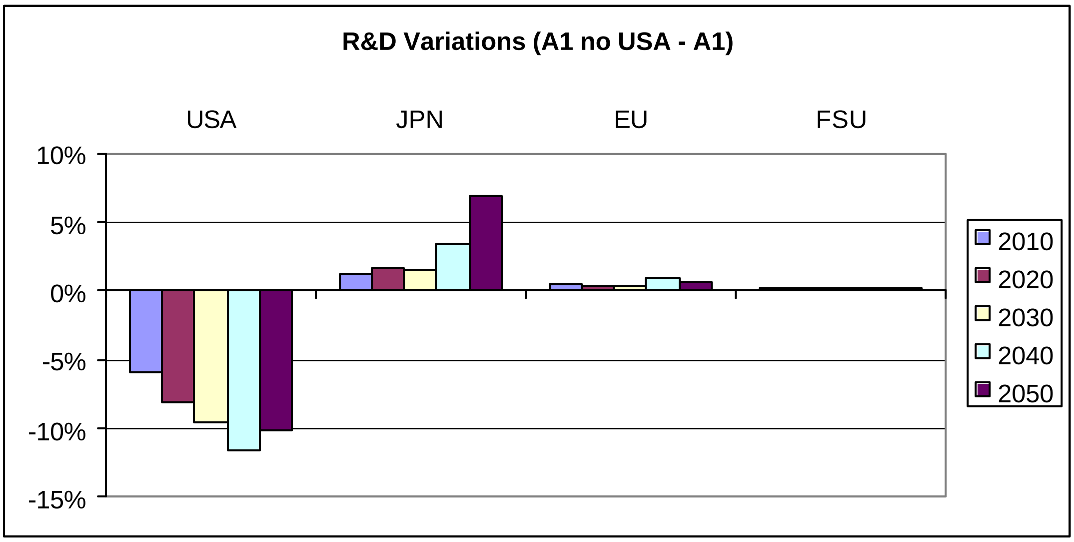


Figure 7. Changes of R&D investments as a consequence of the US defection (with spillovers)



It should be noted that Annex B_1 countries actually react by slightly increasing their R&D effort (see Figure 7). However, world knowledge decreases, thus inducing a negative spillover effect in all countries, namely a higher emission-output ratio and the need to use the permit market to meet the obligations defined by the Kyoto/Bonn Protocol. Demand for permits increases and supply decreases, thus increasing the price of permits and compliance costs.

5. Can the US defection threaten the stability of the Kyoto protocol?

As shown above, the main consequences of the US withdrawal from the Kyoto/Bonn agreement are: (i) a reduction of total energy/saving technological innovation and diffusion; (ii) an increase of total emissions; (iii) a reduction of the equilibrium price in the permit market smaller then expected; (iv) and, finally, a small reduction of the compliance costs.[15]

There is a further consequence that should be taken into account. The loss of revenue for Russia induced by a lower permit price and above all by the reduced exchanged quantity of emission permits may lower total welfare in Russia. This is actually the case with our model. Therefore, Russia may have an incentive either to leave the Kyoto/Bonn agreement, or to renegotiate it in order to reduce Russia obligations and/or the costs to comply with these obligations.

It is therefore important to analyse what would be the consequences of Russia defection from the Kyoto/Bonn agreement. A first consequence is obvious: there would no longer be the pre-conditions for the Kyoto Protocol to enter into force. Indeed, the remaining Annex B_{-1} countries would not achieve the 55% minimum participation constraint. Other consequences are also obvious: the main supplier in the permit market would no longer supply permits, thus inducing a sharp increase in the permit price and, as a consequence, in compliance costs in Japan and the EU (see Tables 5 and 6). Of course, total emissions would also increase sharply (see Table 7).

Table 5. The international permits price under different climate regimes

	International permit price at 2010 1990 US$ per ton of carbon (spillover effects not considered)	**International permit price at 2010 1990 US$ per ton of carbon** (spillover effects considered)
Annex 1	23.1694	43.8127
Annex 1 without US	15.0695 (-34.96%)	40.3374 (-7.93%)
Annex 1 without US and FSU	67.5965 (+348.56%)	96.0607 (+138.14%)

[15] Of course, these conclusions are enhanced when banking and imperfect competition in the permit market are taken into account.

These results have one clear implication on climate negotiations: they sharply increase Russia's bargaining power. Would then Russia leave the climate agreement? The answer is obviously no, unless Japan, and the EU in particular, refuse to pay Russia the "price" for their pivotal role in the path leading to the actual implementation of the Kyoto/Bonn Protocol. This "price" can take different forms. Either an increased role of sinks which makes it easier for Russia to meet its own obligations in the medium term; or a set of measures to prevent the price of permits from falling excessively; or technological transfers and FDI which improve the emission-output ratio in Russia and stimulates growth; or an increased role in international politics, etc.[16]

Table 6. Percentage Change of Abatement Costs (A1 without US and FSU vs. A1 without US)

	USA	JPN	EU	FSU
2010	-0.5%	271.6%	264.3%	-99.9%
2020	-0.8%	227.9%	224.6%	-99.8%
2030	-1.0%	219.1%	216.9%	-99.9%
2040	-1.4%	208.1%	206.3%	-99.7%
2050	-1.9%	187.9%	188.7%	-99.9%

The recent outcome of the Marrakech negotiations and other political events seem to confirm the above conjectures. Almost all of the above "prices" have been paid to Russia in order to provide the correct incentives for Russia to belong to the Kyoto/Bonn coalition. As a consequence, the threat implicit in the costs for the EU and Japan of Russia's withdrawal from the Kyoto Protocol has exerted its effects and has given Russia relevant benefits, which go far beyond the ones that could be estimated on the basis of Russia monopoly power in the permit market.

[16] Recent studies suggest bilateral deals of Russia with the EU and/or Japan in the form of early Joint Implementation in order to maximise Russia's welfare and thus ensure its participation in international climate policy even after the US defection. For further details see e.g., Egenhofer, Hager and Legge (2001) and Egenhofer and Legge (2001).)

Table 7. Total Emissions under Different Climate Regimes

A1	A1 no USA	Variation	A1 no USA&FSU	Variation
9.8121	10.0971	2.904%	10.3677	2.680%
12.0572	12.5043	3.709%	13.0405	4.288%
14.8926	15.4821	3.959%	16.2582	5.013%
18.1560	18.8726	3.947%	19.8284	5.064%
21.5819	22.4225	3.895%	23.4786	4.710%

6. Conclusions

This paper has analysed the effects on technological innovation and diffusion and, consequently, on the costs of complying with the Kyoto targets, of the US decision not to ratify the Kyoto protocol. Our main findings can be briefly summarised as follows.

In the presence of endogenous and induced technical change, the US decision, by reducing the demand for permits and their price, lowers the incentives to undertake energy-saving R&D. As a consequence, emissions increase and feed back on the demand and supply of permits. Indeed, in order to meet their targets, countries which stick to the Kyoto commitments must increase their demand for permits or reduce their supply. As a consequence, the fall of the price of emission permits after the US withdrawal from the Kyoto Protocol is much smaller than the one identified in previous studies.

In addition, the US defection, by reducing R&D investment and increasing emissions, also increases damages from climate changes. This leads to increased investments and therefore increased energy demand and GHGs emissions. As consequence, this second order effect further enhances the previous one by further increasing the demand for emission permits and reducing their supply.

The presence of spillovers provides an additional contribution to the feedback effects just described. Indeed, the US defection induces a strong reduction of domestic energy-saving R&D investments. This reduction spills over the other countries by reducing the world stock of knowledge, thus increasing the emission-output ratio. Therefore, emissions increase in all countries. In order to meet their Kyoto targets, the remaining Annex B countries must increase their demand for emission permits or reduce their supply. As a consequence, the price of permits increases. This feedback effect also partially offsets the initial fall of the permit price induced by the US defection. Therefore, the final equilibrium price is higher than the one usually estimated in previous studies.

Note that, albeit smaller, a fall of the permit price is predicted also by our simulation results. As a consequence, the benefits for Russia from participating in the Kyoto agreement becomes smaller. In addition, the costs for the EU and Japan of a possible Russian defection becomes very large. Without Russia, abatement costs in the EU and Japan would indeed be much higher. These two effects give Russia a larger bargaining power that can be exploited in two ways: (i) either by obtaining further economic incentives to participate in the Kyoto agreement; (ii) or by reducing the costs of participating in the Kyoto agreement through less stringent targets or increased flexibility (e.g. increased sinks allowances).

This latter prediction of the model seems to be confirmed by the recent outcome of the Marrakech Conference of the Parties. Notice however that this might not be the end of the story. If the US realises that, either for domestic or for international political reasons, a large amount of GHGs emission abatement must be undertaken and that these emission reductions are too costly if undertaken through domestic measures only, then they may decide to re-enter into the game, either within the Kyoto framework or outside it. In this latter case, they could offer Russia better conditions than the ones offered by the EU and Japan, thus opening the way for an emission market in which the US and Russia are the main actors. Or, alternatively, the US could negotiate an agreement with China, in order to trade emission permits at a low price, thus reducing abatement costs.

The fascinating dynamics of climate negotiations, and therefore the analysis of these and other policy scenarios, will be the objective of a subsequent paper.

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Appendix. The ETC-RICE Model

The ETC-RICE model is an extension of Nordhaus and Yang's (1996) regional RICE model of integrated assessment, 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 which has been extended to incorporate the interactions between economic activities and climate. One such model has been developed for each macro region into which the world is divided (USA, Japan, Europe, China, Former Soviet Union, and 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, the size of which is dependent upon the amount of abatement (rate of emission reduction) as well as the change in global temperature. The model is completed by three equations 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) respectively.

In our extension of the model, technical change is no longer exogenous. Instead, the issue of endogenous technical change is tackled by following the ideas contained in both Nordhaus (1999) and Goulder and Mathai (2000) and accordingly modifying Nordhaus and Yang's (1996) RICE model. Doing so requires the input of a number of additional parameters, some of which have been estimated using information provided by Coe and Helpman (1995), while the remaining parameters were calibrated as to reproduce the Business-As-Usual (BAU) scenario generated by the RICE model with exogenous technical change.

In particular, the following factors are included: first, endogenous technical change affecting factor productivity is introduced. This is done by adding the stock of knowledge in each production function and by relating the stock of knowledge to R&D investments. Second, induced technical change is introduced, by allowing the stock of knowledge to affect also the emission-output ratio. Finally, international technological spillovers are also modelled.

Within each version of the model, countries play 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). This is a situation in which, in each region, the planner maximises social welfare subject to the individual resource and capital constraints and the climate module, given the emission and investment strategies (in the base case) and the R&D expenditure strategy (in the ETC case) of all other players.

The Standard Model without Induced Technical Change

As aforementioned, it is assumed for the purpose of this model 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), it is assumed that the stock of knowledge is a factor of production, which therefore enhances the rate of productivity (see also the discussion in Weyant, 1997; Weyant and Olavson, 1999). In this formulation, R&D efforts prompt non-environmental technical progress, but with different modes and elasticities. More precisely, the RICE production function output is modified as follows:

$$Q(n,t) = A(n,t) K_R(n,t)^{b_n} [L(n,t)^g K_F(n,t)^{1-g}] \tag{1}$$

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 (1), the stock of knowledge has a region-specific output elasticity equal to b_n $(n=1,\ldots 6)$. It should be noted that, as long as this coefficient is positive, the output production process is characterised by increasing returns to scale, in line with current theories of endogenous growth. This implicitly assumes the existence of cross-sectoral technological spillovers within each country (Romer, 1990). In addition, it should be noted 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). The stock accumulates in the usual fashion:

$$K_R(n,t+1) = R\&D(n,t) + (1-d_R) K_R(n,t) \tag{2}$$

where $R\&D$ is the expenditure in Research and Development and d_R is the rate of knowledge depreciation. Finally, it is recognised that some resources are absorbed by R&D spending. That is:

$$Y(n,t) = C(n,t) + I(n,t) + R\&D(n,t) \tag{3}$$

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.

At this stage the model maintains the same emissions function as Nordhaus' RICE model which will be modified in the next section:

$$E(n,t) = s(n,t)[1 - m(n,t)]Q(n,t) \tag{4}$$

where s can be loosely defined as the emissions-output ratio, E stands for emissions and m for the rate of abatement effort. The policy variables included in the model are rates of fixed investment and of emission abatement. For the other variables, the model specifies a time path of exogenously given values. Interestingly, this is also the case for technology level A and of the emissions-output ratio s. Thus, the model presented so far assumes no induced technical change, i.e. an exogenous environmental technical change, and a formulation of productivity that evolves both exogenously and endogenously. In the model, investment fosters economic growth (thereby driving up emissions) while abatement is the only policy variable used for reducing emissions.

Induced Technical Change

In the second step of our model formulation, endogenous environmental technical change is accounted for. It is assumed that the stock of knowledge – which in the previous formulation was only a factor of production - also serves the purpose of reducing, *ceteris paribus*, the level of carbon emissions. Thus, in the second formulation, R&D efforts prompt both environmental and non-environmental technical progress, although with different modes and elasticities.[17] More precisely, the RICE emission-output relationship is modified as follows:

$$E(n,t) = [s_n + c_n \exp(-a_n K_R(n,t))][1 - m(n,t)]Q(n,t) \tag{4'}$$

In (4'), knowledge reduces the emissions-output ratio with an elasticity of a_n, which is also region-specific; the parameter c_n is a scaling coefficient, whereas s_n is the value to which the emission-output

[17] 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.

ratio tends asymptotically as the stock of knowledge increases without limit. In this formulation, R&D contributes to output productivity on the one hand, and affects the emission-output ratio - and therefore the overall level of pollution emissions - on the other one.

Knowledge Spillovers

Previous formulations do not include potential spillovers effects produced by knowledge, and therefore ignore the fact that both technologies and organisational structures diffuse internationally. Modern economies are linked by vast and continually expanding flows of trade, investment, people and ideas. The technologies and choices of one region are and will inevitably be affected by developments in other regions.

Following Weyant and Olavson (1999), who suggest that the definition of spillovers in the induced technical change context be kept plain and simple - in light of a currently incomplete understanding of the problem - disembodied, or knowledge, spillovers are modelled (see Romer, 1990). They refer to the R&D carried out and paid for by one party that produces benefits to other parties which then have better or more inputs than before or can somehow benefit from R&D carried out elsewhere. Therefore, in order to capture international spillovers of knowledge, the stock of world knowledge is introduced in the third version of the ETC-RICE model, both in the production function and in the emission-output ratio equation. Equations (1) and (4') are then revised as follows:

$$Q(n,t) = A(n,t) K_R(n,t)^{b_n} WK_R(n,t)^{e_n} [L(n,t)^g K_F(n,t)^{1-g}] \quad (1')$$

and:

$$E(n,t) = [\sigma_n + \chi_n exp(-\alpha_n K_R(n,t) - \theta_n WK_R(n,t))][1-\mu(n,t)]Q(n,t) \quad (4'')$$

where the stock of world knowledge:

$$WK_R(j,t) = \sum_{j \neq i} K_R(i,t) \quad (5)$$

is defined in such a way as not to include a country's own stock.

Emission Trading

As mentioned above, throughout the analysis we assume the adoption of efficient policies. As a consequence, the model includes also the possibility of flexibility mechanisms. In particular we compare the case in which emission trading takes place amongst all original Annex I countries (including the US) with first the one in which trading is allowed amongst Annex 1 countries without the US, and then the one in which emission trading takes place amongst all Annex I countries without the US and Russia.

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

$$Y(n,t) = C(n,t) + I(n,t) + R\&D(n,t) + p(t)NIP(n,t) \qquad (3')$$

which replaces equation (3) and:

$$E(n,t) = Kyoto(n) + NIP(n,t) \qquad (6)$$

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 (3'), resources produced by the economy must be devoted, in addition to consumption, investment, and research and development, to net purchases of emission permits. Equation (6) 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 *numeraire* output price. Moreover, there is an additional policy variable to be considered in this case, which is net demand for permits *NIP*.

Under the possibility of emission trading, the sequence whereby a Nash equilibrium is reached can be described 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 as a function of the market disequilibrium and each region's decision process starts again.