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BANKING AND TRADE OF CARBON EMISSION RIGHTS
A CGE Analysis

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Abstract:

This paper analyses trading and banking of carbon emission rights. Within the framework of a modestly simple, integrated assessment model that brakes the world economy in just two regions, North and South, it can be shown: (1) There exists separability between environmental targets and the choice of instruments. Increasing the "when and where" flexibility in greenhouse gas abatement either through banking or trading of carbon emission permits or both positively affects global welfare. It has, however, almost no impact on global climate change. (2) Depending upon the choice of instruments there are significant distributional effects across regions. Both regions can improve welfare simultaneously, if carbon emission rights are traded on open international markets. But if it were feasible to bank or borrow carbon permits, then - independent of whether there is trading of carbon rights or not - the South suffers welfare losses compared to a no banking no trade situation.

Keywords: Carbon rights, climate policy, integrated assessment, banking and trade.

JEL-Classification: Q4, F2

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1. Introduction

Does banking and trading of carbon dioxide emission permits on open international markets affect the atmospheric accumulation of greenhouse gases? Will banking and borrowing of carbon emission rights improve welfare? Does efficiency in greenhouse gas abatement depend upon whether there is intra - or intertemporal trading of carbon rights or both? Are there regional differences, if emission permits are allowed to be banked, traded or even borrowed? Analyzing these issues within the framework of an integrated assessment model of global climate change is the issue of this paper.

Typically the economic literature argues that for a given environmental quality the more flexible a policy intervention can be handled by those who should be regulated the lower are the welfare losses due to the specific policy measure. For an international agreement on greenhouse gas abatement this seemingly implies: A global climate convention that keeps flexibility in "where and when" to abate greenhouse gases as high as possible is expected to be more efficient than any other proposal.

Despite opposition of the developing countries the Kyoto protocol has left space for flexibility in greenhouse gas abatement. Principally it allows for trading of emission permits - at least between industrialized (Annex I) nations. However, the details of such a system of marketable carbon emission rights are still to be negotiated. In particular, it must be decided whether or not there might be banking and borrowing of greenhouse gas permits.

Banking of marketable emission permits is by no means a new institution. The 1990 US Clean Air Act Amendments explicitly allow for trading and banking of sulfur dioxide (SO2) emission permits. The owner of a permit is entitled to emit a certain amount, say one ton, of SO2 in the year for which the permit is labeled. But he can also save it either to sell it or to use it in later years.

The US Department of State has suggested to establish a similar system of tradable and bankable carbon emission permits under the Framework Convention on Global Climate Change (USDOS 1997). The reasoning seems quite obvious. Trading of carbon dioxide emission permits on open international markets increases the "where to abate" flexibility. Banking of carbon rights can provide flexibility in "when to abate" greenhouse gas emissions. This should reduce the costs of greenhouse policy. Banking and trading of carbon emission rights can promote efficiency simply by transferring abatement activities in space and in time.

There is, however, a major difference between sulfur dioxide and carbon dioxide (CO2). Global climate change is a stock damage problem. It is driven by the accumulation of CO2 in the atmosphere and is not directly associated with the flow of emissions. Therefore, the timing of emissions and damages is not coincident as in the case of SO2. For this reason environmentalists conclude that excessive banking or borrowing of permits today could cause quite drastic damages in the future. In other words: What might be beneficial today can be damaging tomorrow.

Furthermore the theoretical literature is rather ambiguous about the welfare effects of an intertemporal permit system. For example, Biglaiser et al. (1995) show that intertemporal permit trade is not optimal. Kling and Rubin (1997) lay out that unrestricted banking and borrowing of flow pollutant rights is not granted to be socially optimal. At the same time they insist that the banning of permit banking and borrowing is also not optimal. More recently, Leiby and Rubin (1998) have argued that banking of carbon emission rights can lead to welfare losses unless these permits are traded at the correct intertemporal exchange rate. The latter is determined by the ratio of current marginal stock damages to discounted future value of marginal stock damages less the decay rate of emissions.

Global trade in carbon emission rights is a feature of many integrated assessment models (for example, see Nordhaus and Yang, 1996, Manne and Richels, 1995, or Bernstein et al., 1999), but banking of carbon permits typically is not included in these models. This paper analyses trading, banking and borrowing of carbon emission rights within a regional differentiated version of the MEDEA framework (see Stephan and Müller-Fürstenberger, 1998). Braking the world just into North and South it will be shown that optimal climate policy is independent of the choice of policy instruments. Increasing the "when and where" flexibility in greenhouse gas abatement through trading and / or banking of carbon emission rights has virtually no impact on the development of atmospheric carbon concentration. It increases, however, global welfare and might lead to significant differences among regions, depending upon the choice of instruments. Both North and South can improve welfare simultaneously, if carbon emission rights are traded on open international markets. If it were feasible to bank or borrow carbon permits, then the South always suffers from welfare losses compared to a no-banking and no-trade situation.

The rest of the paper is organized as follows. Section 2 characterizes the theoretical setting upon which the numerical exercise is based. Section 3 describes the different scenarios that will be carried out. It also provides first economic insight into the results we can expect. Section 4 discusses the major findings of our numerical analysis, and Section 5 covers concluding remarks.

2. Regional MEDEA

As the purpose of our numerical thought experiments is insight, not numbers, the theoretical framework is kept deliberately simple. To relate our results to the literature, numerical parameters from the RICE (see Norhaus and Yang, 1996), MERGE (see Manne and Richels, 1995) and MEDEA (see Stephan and Müller-Fürstenberger, 1998) integrated assessment models are taken over into our stylized-facts framework of the world economy.

There are two regions of the world. For vividness let them be called North (N) and South (S). North consists of the OECD countries including the former Soviet Union. South covers the rest of the world. Each region is represented as though it were an infinite-lived agent, maximizing the discounted logarithm of consumption.

We take a descriptive rather than a prescriptive view and suppose that both North and South discount consumption at the market rate of interest. South enjoys a higher rate of potential GDP growth than North. This immediately allows for the possibility of different rates of return on capital between the two regions (see Manne and Stephan, 1999).

Time is discrete and periods are one decade in length. For each time period, there are just two tradable commodities: a numeraire and carbon emission rights. The numeraire can be produced within each region and may be used for consumption, investment, net exports and to cover energy costs. Carbon-free energy resources such as hydro or solar are viewed as back-stop resources. They are provided at constant, but high marginal costs. Greenhouse resources such as oil, gas and coal are supplied at low but increasing costs.

Among the various greenhouse gases, carbon dioxide (CO2) is considered as the most relevant one. The demands for carbon emissions are generated through regional consumption of greenhouse resources. Global warming is directly attributed to cumulative CO2-emissions and affects production, but not utilities.

2.1 Climate-economy interaction

There are two channels through which the environment and the economy interact. One is the consumption of greenhouse resources which directly determines the flow of CO2-emissions into the global atmosphere. The second link is provided though the concept of the "green output" by which global climate change is translated into its economic impact.

A "two-box" model is used to cumulate carbon emissions over time, and to translate them into global concentrations (for a detailed discussion, see Joos et al., 1999). In any time period t the stock of atmospheric carbon dioxide, Q(t), is a function of the former one, Q(t-1), and the world's past period emissions, s(t-1):

(2.1) $$Q(t) = \Psi Q(t-1) + \Theta s(t-1).$$

Ψ is the factor by which natural abatement reduces the current stock of atmospheric CO2. Θ is the fraction of past global emissions that has accumulated in the atmosphere.

For the sake of simplicity, we neglect the thermal inertia lag between global CO2 concentration and climate change. We also neglect the cooling effects of aerosols and the heating effects of greenhouse gases other than carbon dioxide. What we reflect, however, is that the climate effect may differ across single regions of the world.

The model is calibrated such that with zero abatement concentrations will rise from 353 ppm (the 1990 level) to 550 ppm (twice the pre-industrial level) by about 2070. This leads to damages of 3.5% of gross output in the South and 1.5% of GDP in the North. At other concentration levels, the regional damages are projected as though they were proportional to the square of the increase in concentrations over the 1990 level:

(2.2) $$\Phi^r(t) = 1 - [Q(t) / \Omega^r]^2.$$

Ω^r marks the critical value of the CO2 concentration. At this atmospheric CO2 perturbation, production in region r = N(orth), S(outh) is reduced to zero.

$\Phi^r(t)$ is the so-called environmental loss factor. It indicates economic damages induced by global climate change in region r = N,S. The corresponding economic costs are measured in terms of forgone GDP. I.e., if the atmospheric stock of carbon dioxide is raised to levels Q(t) above pre-industrial atmospheric carbon, then in region r the productivity of factors is reduced such that only $\Phi^r(t)$ percent of the original gross production is at the region's disposal.

2.2 Production, emissions and abatement

Principally, there are two ways to reduce CO2-emissions. One is to replace greenhouse fuels by carbon-free energy inputs. A second option is to uncouple economic growth from fossil fuel consumption by increasing the energy efficiency and by substituting capital for energy.

To capture both possibilities, the regional production possibilities are represented through a nested constant elasticity of substitution (CES) production functions[1]:

(2.3) $$y^r(t) = [\beta_1(l^r(t)^\alpha k^r(t)^{1-\alpha})^\varepsilon + \beta_2(e^r(t))^\varepsilon]^{1/\varepsilon}.$$

[1] For better readability parameters do not carry regional indices.

Capital $k^r(t)$, labor $l^r(t)$ and energy inputs $e^r(t)$ together produce the conventional (i.e., without climate effects) output, $y^r(t)$. β_1 and β_2 are CES-coefficients derived from base year data, and ε is the CES elasticity of substitution between capital/labor and energy.

Substitution between capital and labor is described by a Cobb-Douglas formulation where α is the corresponding parameter. Total energy inputs into regional production,

$$(2.4) \qquad e^r(t) = f^r(t) + n^r(t),$$

are the sum of flows of fossil fuels $f^r(t)$ and of backstop energy resources $n^r(t)$.

2.3 Material balance of produced goods

Climate change negatively affects the productivity of the regional economies (see (2.2)). Only the fraction $\Phi^r(t)$ of conventional gross output $y^r(t)$ is still at their disposal. Within each region r, "green output" $\Phi^r(t)y^r(t)$ can be consumed, invested into conventional capital formation, or used to supply either greenhouse resources or carbon-free energy.

Energy supply costs are measured in units of gross production. Marginal costs b^r of carbon-free energy are constant, but approximately four times as high as costs of greenhouse resources in the initial year. Marginal costs $a^r(t)$ of greenhouse resources increase over time, depending upon extraction in prior periods.

To prevent an excessively rapid market penetration once renewable resources become competitive, it is assumed that after an energy supply system is installed, it is quasi-irreversible and cannot be abandoned immediately. With this formulation there is the possibility that market prices of energy temporarily overshoot the marginal costs of the renewable resources.

Regional output is considered as numeraire that can be traded internationally. Therefore, if $x^r(t)$ denotes net-imports, $c^r(t)$ consumption, and $i^r(t)$ investment in conventional capital, then for each period t

$$(2.5) \qquad x^r(t) + \Phi^r(t)y^r(t) \geq c^r(t) + i^r(t) + a^r(t)f^r(t) + b^r n^r(t)$$

is the material balance of commodities produced and traded in region r. Finally, since net-imports have to balance out in each period t, condition

$$(2.6) \qquad x^N(t) + x^S(t) = 0$$

has to be obeyed globally.

2.4 Intertemporal decisions and greenhouse policy

At each point of time the society has control over two capital stocks, the endowment of physical capital on the one hand and the environmental capital on the other.

The environmental capital stock is determined by the atmospheric CO2 concentration, hence depends upon abatement activities and the way how climate policy is organized internationally. Throughout this paper it is supposed that regions cooperate in the solution of the greenhouse gas problem. Voluntary they bound themselves to greenhouse gas abatement through implementing a system of carbon emission permits. A credible inter-governmental agency sets and implements optimal global CO2-emission targets, w(t), for each period t. Carbon emission rights $m^r(t)$ are then assigned exogenously to each region r through international negotiations. Roughly, this corresponds to the greenhouse gas emission trading proposal of the US Department of State. In our computations, we suppose North's share in carbon rights to decline over a period of fifty years from 45% to 20%. This reflects a transition from grandfathering to per-capita allocation.

At any point of time t, the regional endowment $k^r(t)$ in physical capital depends upon investment activities, $i^r(t-1)$, the former capital stock, $k^r(t-1)$, and the capital depreciation at rate υ^r

(2.7) $$k^r(t) = \upsilon^r k^r(t-1) + i^r(t-1).$$

At first glance, the natural approach to the economics of global climate change would be to employ an overlapping generations model. It was shown, however, that under reasonable assumptions both an infinitely-lived agent framework and an overlapping generations model will identify the same greenhouse policies as being efficient (see Stephan et al., 1997). Therefore, without loss of generality it can be supposed that for striking an optimal balance between consumption, physical investment and greenhouse gas abatement regions follow a Ramsey path.

Let δ be the social discount rate, then consumption, production, investment into physical capital and greenhouse gas abatement are determined in each region r =N,S, as if a policy maker has maximized the discounted sum of the logarithm of consumption, $c^r(t)$

(2.8) $$W^r = \Sigma_t\, \delta^{-t} \ln(c^r(t)).$$

If there is no capital mobility and no investment into greenhouse gas abatement, both regions would develop independently. But if the regions agree to cooperate on greenhouse abatement, prices, supplies and demands are generated through a mult-region multi-period general equilibrium model. Solutions are obtained via Rutherford's sequential joint maximization method - a specialization of the Negishi approach (see Rutherford, 1995).

3. Banking and trade of carbon emission rights

Given the presumption that climate policy is coordinated internationally through implementing a system of carbon emission permits, four "flexibility" scenarios suggest themselves: (1) No-Trade-No-Banking (NT&NB), (2) Trade but No-Banking (T&NB), (3) No-Trade but Banking (NT&B), and finally, (4) Trade and Banking (T&B).

Without trade, banking and borrowing of carbon emission permits (NT&NB), each region r were allowed to consume per period its own endowment, $m^r(t)w(t)$, of carbon dioxide emissions only. This represents the situation of lowest "when and where" flexibility. Thereby optimality in global greenhouse gas abatement is assured, but - as we expect - in an inefficient way, hence at highest economic costs.

International trade of carbon rights grants that the marginal costs of abatement are identical across regions. This is a necessary requirement for pareto-efficiency in climate policy. Consequently, compared to the NT&NB scenario both regions should gain from increasing the "where to abate" flexibility.

If emission permits can freely be transferred between regions as long as the world's restrictions in carbon endowment are obeyed, then in a T&NB scenario condition

(3.1) $$[w(t) - s^N(t) - s^S(t)] \geq 0,$$

has to be fulfilled in each period t.[2] And since each region r can generate additional income by selling carbon emission rights, it must be assured that it stays on it’s intertemporal budget constraint. This means, net-imports have to be financed through counter trade of carbon rights and vice versa.

"When" flexibility in greenhouse gas abatement is given if the regional economies were allowed to allocate freely their endowment of carbon emission rights over time. Therefore, if trading of emission permits is not feasible in addition, a region r has to fulfill

(3.2) $\sum_t[m^r(t)w(t) - s^r(t)] = 0.$

I. e., regional economies may save and borrow carbon emission permits, but they are not allowed to sell or buy them.

At first glance one might expect that banking and borrowing of carbon emission rights might have a similar effect on welfare as trade has. Since carbon abatement activities are now allocated efficiently over time, costs of abatement should be reduced and welfare should be positively affected. However, there could be two countervailing effects on regional welfare.

First, since costs of abatement are borne early but benefits do not accrue until the distant future, at least the North has an incentive to borrow carbon emission rights. This might lead to what environmentalists fear - a change of the time profile of carbon emissions with higher atmospheric carbon concentration in the future, hence higher ecological damages and - as a consequence - additional welfare losses (see Section 2.1).

Second, since the global climate has the properties of a public good, the South is affected by the North's banking and borrowing decision. In other words, if the North is allowed to operate banking and borrowing of carbon rights independently, this might create an intertemporal external effect on the southern economies. For an optimal solution it were necessary, however, to internalize these effects. This is possible only, if the South compensates the delay in greenhouse gas abatement by the North through increasing his abatement activities in the near distant future. Again this can imply welfare losses for the southern economies.

Full flexibility in greenhouse gas abatement both in space and in time is given, if carbon emissions rights may be banked and borrowed, bought and sold on internationally open markets (T&B). Instead of regional and annual restrictions on CO2 emissions, the world now has to observe a single intertemporal constraint:

(3.3) $\sum_t[w(t) - s^N(t) - s^S(t)] = 0.$

Based on conventional wisdom we expect that full inter- and intra-temporal flexibility in greenhouse gas abatement promotes economic efficiency, but can create the same problem as mentioned for the NT&B scenario.

[2] $s^r(t)$, r =N,S, denote the CO2-emissions of region r in period t.

4. Computational Experiments

Parameters for the computational experiments are benchmarked against 1990 data (for details, see Appendix). To reduce end-of-time-horizon effects, results are reported till 2150 but computations are carried out till 2200.

4.1 Carbon emissions and atmospheric accumulation

Banking allows nations to decide individually and independently when to exercise their carbon emission rights. Does such a loss of control over the timing of emissions lead to what environmentalists fear - excessive borrowing or banking of carbon emission permits at early periods such that the time profile of atmospheric carbon will be changed significantly?

As Figure 1 shows the answer to this question is no. Increasing the "when-and-where" flexibility can even force lower atmospheric carbon concentrations, in particular in the middle of the time horizon. An explanation could be that the rate at which emissions accumulate is unimportant as long as emissions are small compared to the atmospheric carbon stock and as long as the total allowable amount of emissions is not exceeded. In any case, it is optimal to stabilize the atmospheric concentration below 550 ppm. This corresponds roughly doubling the pre-industrial level.

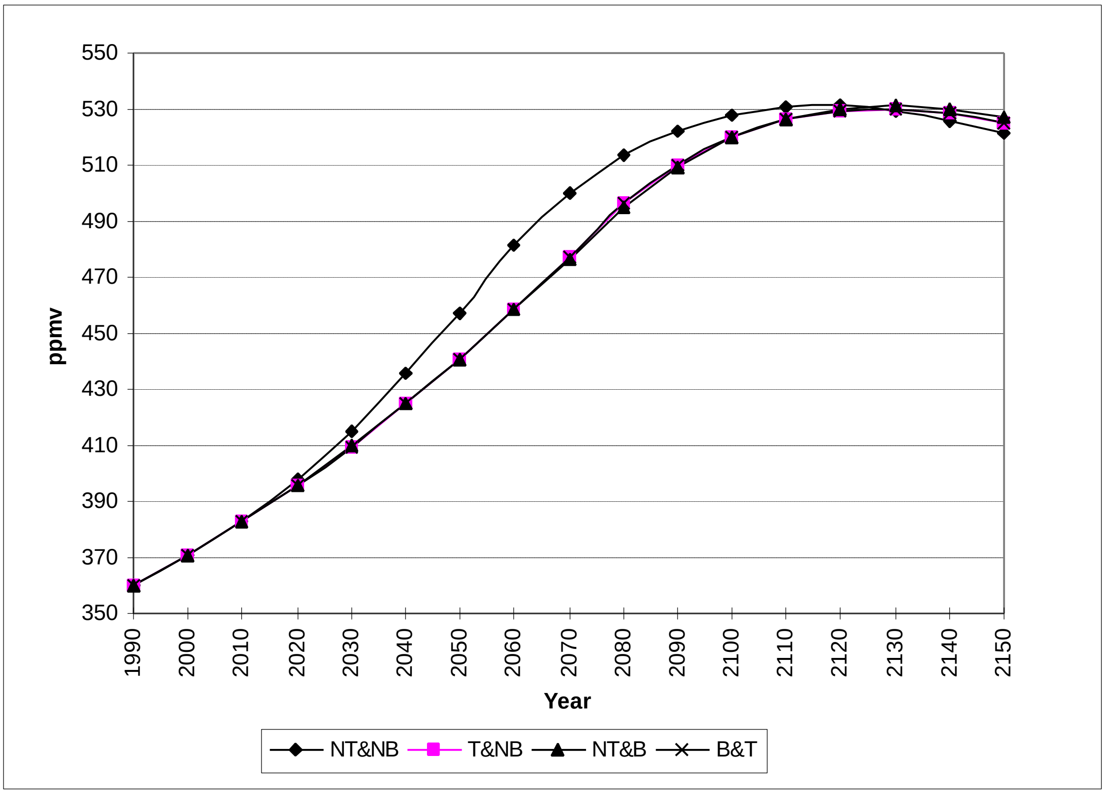

Figure 1: Atmospheric Carbon

Although trading and banking of carbon rights does not significantly affect the atmospheric accumulation of carbon dioxide, the interregional allocation of emissions is notably changed. As Figure 2 illustrates, increasing flexibility stipulates CO2-emissions in the northern hemisphere. If the option exists to buy carbon rights from the South, the North takes this option to reduce abatement activities and costs. If there is "when" flexibility, the North is motivated to borrow from himself carbon rights and to postpone abatement, just as was expected in Section 3. Since banking without trade imposes an adding-up constraint on total regional emissions (see (3.2)), increasing emissions in early periods must be compensated by lowering them by the end of the time horizon, unless there is international trading in carbon permits. This explain the differences between a pure banking and the trade scenarios. Note that adding "when" flexibility to an international trade setting induces no changes in emission pattern.

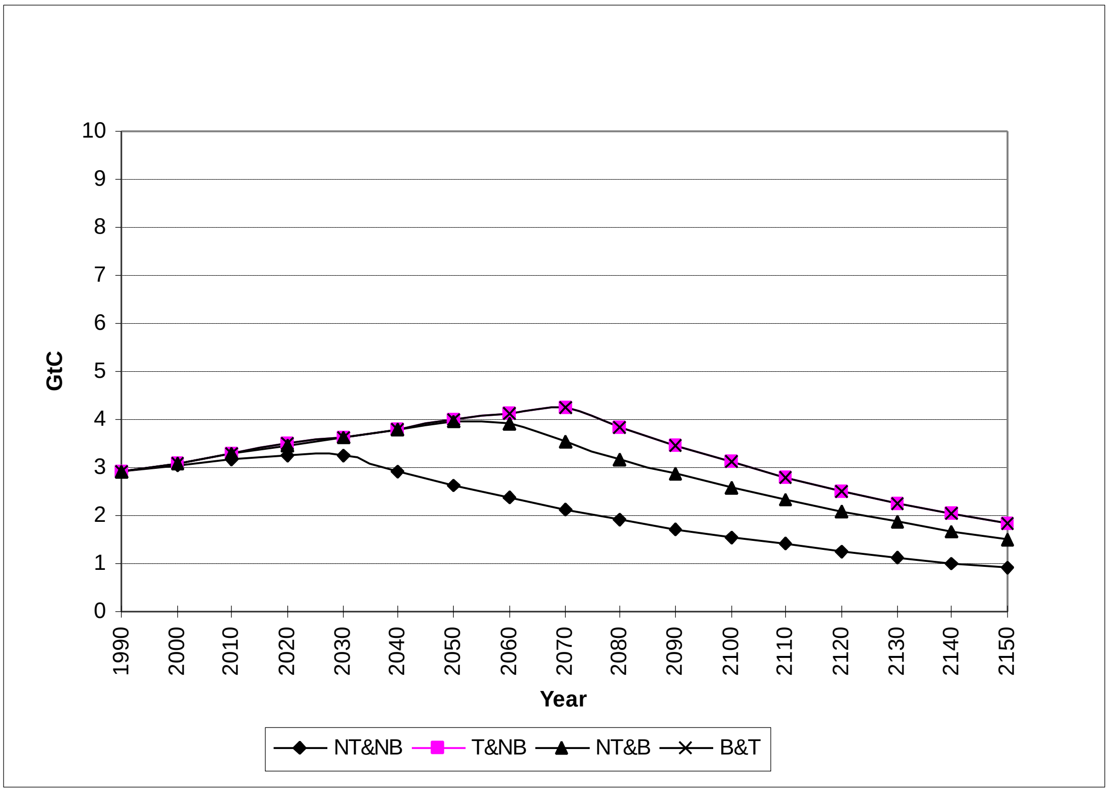

Figure 2: North's Carbon Emissions in GtC

A similar invariance result is observed for the South (see Figure 3). Once international trade in carbon rights is allowed, banking does not induce further changes in emissions. With respect to trading of carbon permits either with or without banking, the South exhibits quite the opposite pattern than North. The South trades a significant share of its emission rights against imports in numeraire from the North. Therefore domestic abatement activities have to be extended. And if banking were allowed, the South will save carbon permits for the first century. Afterwards, emissions coincide with those in a no-trade no-banking (NT&NB) scenario.

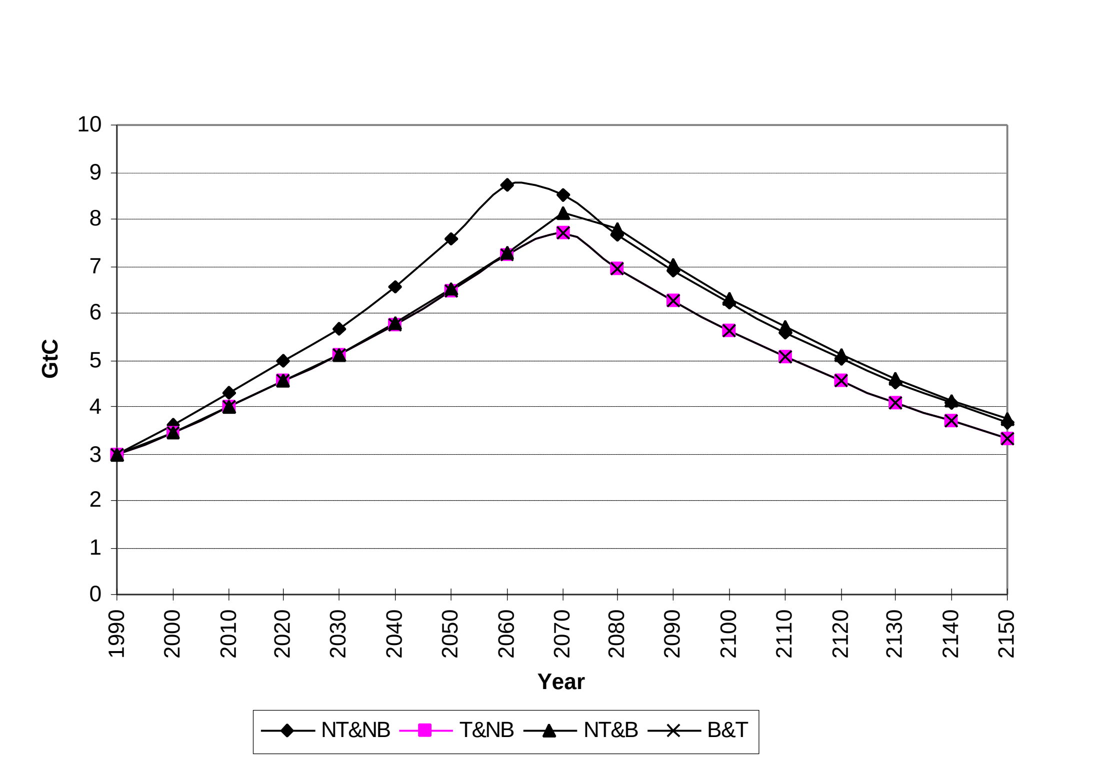

Figure 3: South's Carbon Emissions in GtC

Summing up, our simulations suggest: If carbon emission rights are already traded on a open international market, then allowing for banking does not impose additional costs in terms of climate change. Moreover, in terms of atmospheric carbon concentration, differences between pure trade (T&NB), pure banking (NT&B) as well as banking and trade of carbon rights (T&B) can almost be neglected.

4.2 Economic effects

As we expect, increasing the flexibility in greenhouse gas abatement - either trough trading or banking and borrowing of carbon emission permits or both - has a positive impact on welfare (see Table 1).

	NT&NB	T&NB	NT&B	T&B
Total welfare	5.7698	5.7759	5.7738	5.774
welfare North	3.2017	3.2044	3.2059	3.2065
welfare South	2.5681	2.5715	2.5679	2.5675

Table 1: Global and regional welfare effects

As so far the calculations are not surprising. What surprises, however, is: (1) Differences in aggregated and discounted welfare are almost negligible. (2) Banking is less favorable than trade, even if combined with trade. (3) There are obvious differences between regions depending upon the choice of instruments.

Both regions will gain simultaneously in terms of discounted welfare, if international trade of carbon emission permits is allowed. If banking of carbon permits were feasible, then only the North will be better of compared to a No-Trade-No-Banking (NT&NB) as well as the pure trade (T&NB) scenario. The South looses welfare under such circumstances and - equally important - total welfare is smaller with banking than in a situation where trading of carbon permits is feasible.

The reasoning for this outcome was already given in Section 3. If banking and borrowing of carbon emission permit were allowed, then without international coordination the North can use this opportunity to delay his abatement. However, through reducing costs of carbon abatement, he negatively affects the development of the world climate and imposes an intertemporal external effect on the South. Since the economic costs of climate change are higher in the South than in the North (see Section 2.1) the South has to counteract for an optimal solution by extending his abatement activities in early periods.

Within our representative agent framework, regional welfare is directly related to the logarithm of consumption (see (2.9)). Therefore, per capita consumption might be used as proxy for regional welfare. For evaluating how different stages of flexibility in greenhouse gas abatement affect regional welfare, per capita consumption of the T&B scenario is taken as base-line. For better visibility, T&B per capita consumption is set equal to one and differences in welfare are then expressed as per-cent deviation in consumption from the base-line.

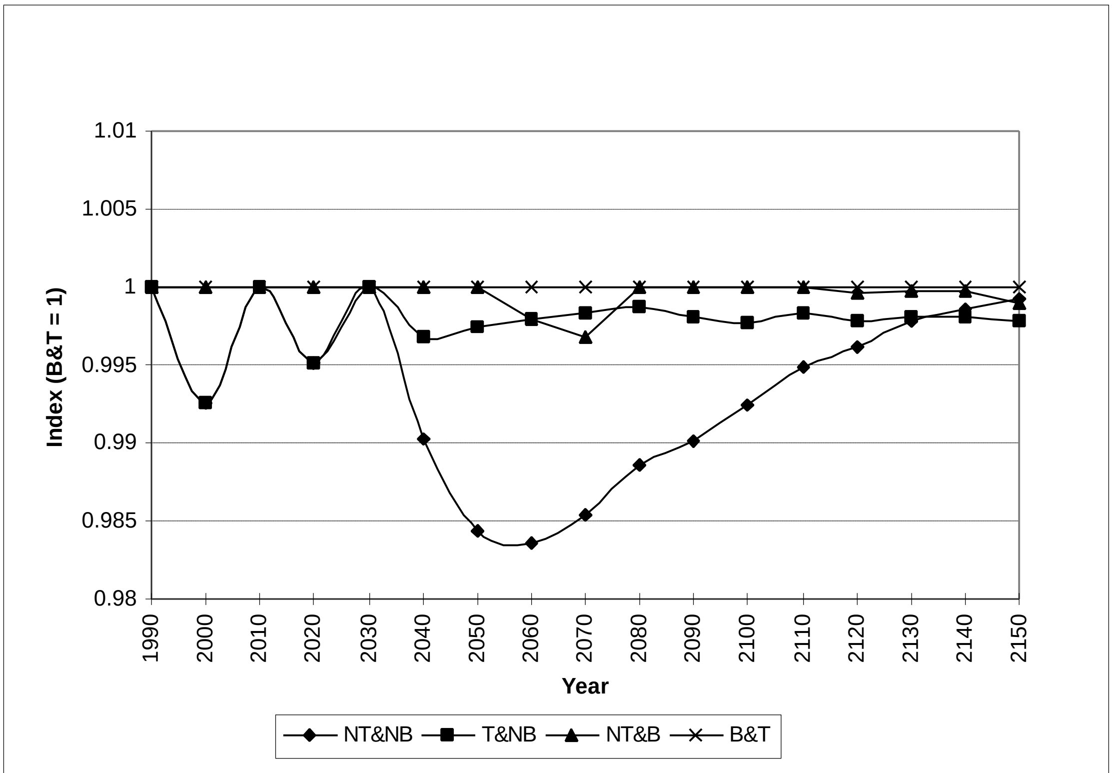

Figure 4: North's consumption relative to banking-and-trade scenario

On the one hand economists' conventional wisdom tells that welfare is positive correlated to "where to abate" flexibility. Trading emission carbon rights on an open international markets implies identical marginal costs of abatement across all regions - a requirement that is necessary for efficiency in greenhouse policy. On the other the theoretical literature (for example, see Leiby and Rubin, 1998) suggest that welfare will decrease with "when to abate" flexibility, unless carbon emission rights are traded at the correct intertemporal exchange rate.

Our results do not completely support the last conjecture, but clearly identify winners and looser from "where and when" flexibility (see Figures 4 and 5). For the next century, No-trade and no-banking (NT&NB) is the worst case for both regions. For latter periods the results look a bit different. In any case flexibility works mainly in favor of the northern region which gains mostly from postponing abatement either by trade or by banking.

If there were only one type of flexibility at choice, the North would prefer "when" over "where" flexibility in greenhouse gas abatement. To him the option to exercise a major part of its own carbon rights just at the beginning of the next century is superior to buying carbon rights from the South.

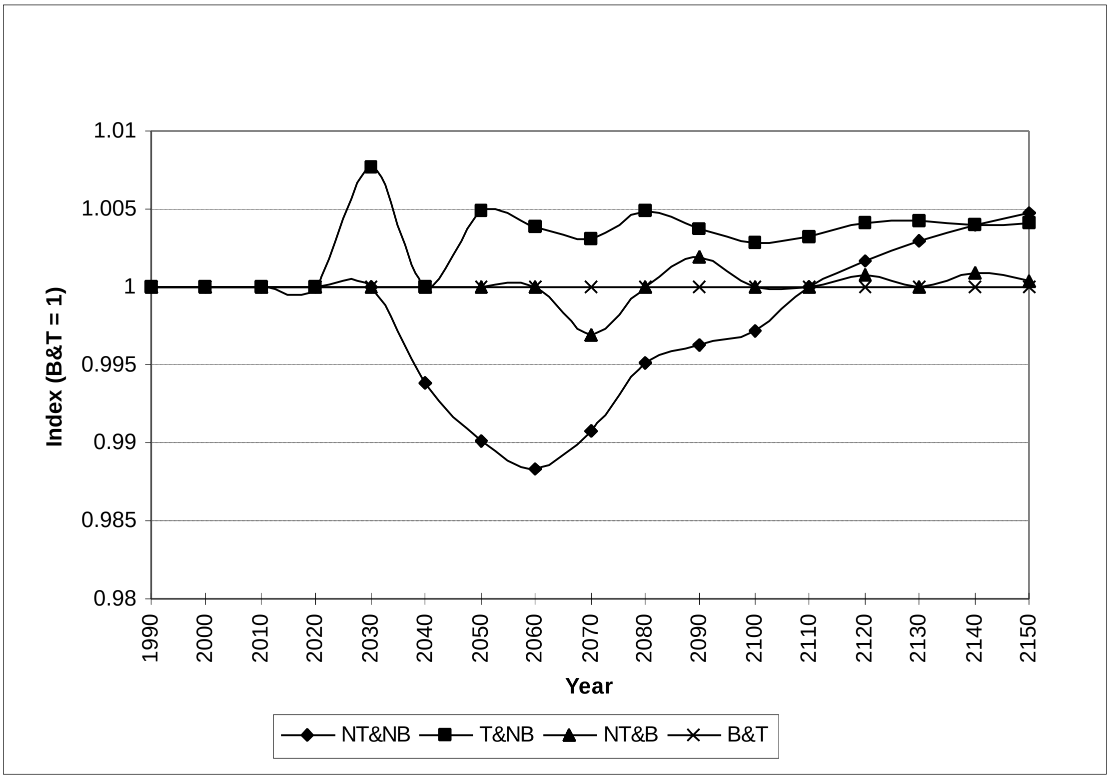

Figure 5: South’s consumption relative to banking-and-trade scenario

From South’s perspective, trade and banking (T&B) is least preferred scenario. If the South has to vote for at least one type of flexibility, he would prefer international trading of carbon rights. This is due to potential gains from selling carbon rights to North. Banking decreases North’s demand for carbon rights since it offers a substitute to trade. This worsens the terms-of-trade, imposing welfare losses on South. Therefore, a trade only (T&NB) scenario is preferred to a trade and banking (T&B) scenario.

5. Conclusions

In summary this analysis reveals two important results. First, contrary to the theoretical literature, increasing flexibility in greenhouse gas abatement has no negative impact on the global climate. The accumulation of the atmospheric carbon stock is almost independent of whether there is trading and banking of carbon rights or not. This implies that there exist separability between ecological targets and the choice of policy instruments.

Second, our paper shows that there exists a conflict between North and South with respect to "when and where" flexibility in greenhouse gas abatement. North is best of in a regime that allows for both banking and trade of carbon emission rights. The worst outcome would happen to the North if there were no banking and no trade in carbon rights at all. For the South just the opposite is observed. South is best of in a pure trade scenario, but banking and trade of carbon emission rights is a bad situation for him even compared with a no flexibility scenario. Trading of carbon emission rights is a compromise. Both regions will gain welfare under such circumstances.

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7. Appendix

Data are taken from Manne and Stephan (1999) and Stephan and Müller-Fürstenberger (1998). Key economic data are listed below.

Table 1
Basic Economic Data

Data	North	South
GDP 1990 (US$ trillions)	16.3	4.5
Capital-GDP ratio	2.5	3.0
Energy consumption (Exajoules)	176	168
Elasticity of substitution energy-value added	0.2	0.35
Carbon emissions (GtC)	2.9	3.0
Economic damage due to double pre-industrial CO2 (%)	1.5	3.5
Utility discount rate	0.03	0.03

Table 2
Potential GDP growth rates

	North	South
1990 - 2120	1.5	3.5
2130	1.5	3.25
2140	1.5	3
2150	1.5	2.75
2160	1.5	2.5
2170	1.5	2.25
2180	1.5	2
2190	1.5	1.75
2200	1.5	1.5