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Intensity Targeting or Emission CAPS: Non-Cooperative Climate Change Policies and Technological Change

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INTENSITY TARGETING OR EMISSION CAPS:
Non-Cooperative Climate Change Policies and Technological Change

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Abstract

This paper analyses costs and benefits of three different post-Kyoto policy options: On the one hand there is PARETO which is the nickname for the pareto-efficient internationalization of the external effects of global climate change through trading carbon emission rights on open global markets. And there is QCAP as well as ICAP on the other. Both are unilateral climate policies. QCAP denotes a scenario where regions aim for reducing domestic carbon emissions by a certain percentage annually. ICAP is a short cut for intensity targeting which is the US' most preferred climate policy option. In a world without uncertainty about future GDP and carbon dioxide emissions it refers to the same abatement policy, however by means of technological progress only.

Key Words: Climate policy, intensity targeting, R&D investments, Integrated Assessment.

JEL-Classification: O33, Q38, Q43

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1 Introduction

Global climate change defines a large-scale public good problem. And since it will be necessary to proceed beyond *no-regret* policies, economists typically argue that there must be some international arrangement for abatement and burden sharing. The Kyoto Protocol reflects some of their wisdom, but – as is well documented - suffers from several deficits (see Nordhaus and Boyer, 1999). For example, Kyoto abatement strategies are not based on economic principles such as balancing costs and benefits of greenhouse gas reduction. Nor does emission trade as allowed in the Kyoto Protocol stipulate efficiency. Moreover, the lion's share of costs have to be covered by the US, Japan and Europe. It is no surprise therefore that some of the most important players have resisted ratifying the Kyoto Protocol.

Of course, taking the complexity of the issue as well as the conflicting national interests into account it is no surprise that the Kyoto Protocol can be considered only as a preliminary step towards a global climate policy. Nonetheless, in our view, three further aspects have to be considered. First, rather than implementing an universal schema for carbon emission control, and rather than establishing emission trade on an open global market with a single price for carbon, Kyoto rules differ across regions and emission trading systems are fragmented: Within jurisdictions like the European Union permit trade is active, but between jurisdictions, where the greatest gains from trade can be expected, markets are thin and encumbered by the friction of different rules.

Second, global climate change is driven by burning fossil fuels, hence the penetration of carbon-free energy into the economy is important for the future climate. For example, Chakravorty et al. (1997) have shown that, if technology improvement in carbon-free energy were to follow historical rates, carbon emissions would peak before the middle of the century, even without climate agreements. Now, independent of whether this is a too optimistic forecast or not, it makes us aware of the importance of technological innovations. Consequently, global climate policy should send creditable signals for adopting low-carbon technologies, but the existing price signals are to weak. For example, today sequestration of the CO_2 effluent from coal plants is profitable only at prices over $100 per ton of CO_2, which is roughly ten times as much as the price seen in the European Emission Trading System.

Third and finally, the Kyoto framework gives no credit for technology improvements - a fact that partly explains the impasse between the US and the EU. While the European Union focuses on capping emissions, the United States officially has announced an alternative approach to the challenge of global climate change[1]: G*reenhouse gas intensity targeting should allow economic growth and environmental protection to go hand in hand. It focuses on reducing the growth of GHG emissions, while sustaining the economic growth needed to finance investment in new, clean technologies. And it holds the promise of a new partnership with the developing world.*

The rational behind this policy seems quite obvious. Since it is technically feasible to uncouple the development of carbon emissions from economic growth through technological change, one could vision an alternative way of providing greenhouse gas insurance - even without the need of international coordination and cooperation in greenhouse gas mitigation. For example, this could be the case if at least one player were able to provide sufficient technological progress from which all can profit. Could this be the beginning of a new way of coping with the global climate problem? Or is it nothing else than a fallback into a regime of economically inefficient climate policies? Is there realistic hope that putting technological change into the driver's seat will solve the problem of global warming? Or is it nothing else than a cheap excuse for non-cooperation? And finally, what are the effects of stipulating research and development in carbon-free energy on the world economy?

For analyzing these questions this paper considers three post-Kyoto options: On the one hand there is PARETO, and there is QCAP and ICAP on the other. PARETO is the nickname for the pareto-efficient internationalization of the external effects of global climate change through internationally tradable emission rights. This might be not a realistic post-Kyoto scenario since it requires cooperation of all nations. And it requires that there is an open international market on which emission rights can be traded without any restriction. Here it serves the purpose of a reference scenario.

Both QCAP and ICAP are unilateral climate policies. In contrast to PARETO where all regions can profit from trading carbon emission rights globally (see Müller-Fürstenberger and Stephan, 2002), QCAP and ICAP do not allow for greenhouse

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1 See *www.whitehouse.gov/news/releases/2002/02/climatechange.html*

gas abatement where costs are lowest. Carbon dioxide emissions have to be reduced in the region of origin. This decreases flexibility and will increase economic costs of climate policy.

In principle, emissions can be limited by an absolute cap on quantities (QCAP), or by some maximum allowable intensity to some measure such as GDP (ICAP). As this indicates, the major advantage of ICAPs over QCAPs is that they provide more flexibility in case of uncertainty about the future development. However, in a world where future emissions and the economic output are known with certainty, both types of regulations have identical effects on abatement (see Ellerman and Wing, 2003). Hence, the question arises: What are the differences between QCAP and ICAP? Under QCAP, regions can use a series of measures to reduce carbon emissions. This includes technological progress, fuel substitution as well as structural change within the regional economy. Typically it is argued that since resources are scare, investing in environmental capital through emission abatement will reduce investment in conventional capital, which in turn might slow down economic development.

Obviously, these effects very much depend on the development of costs of abatement. ICAP aims for reducing carbon emission through investments in advanced energy and sequestration technologies only. This reduces costs of abatement so that the same emission target could be reached without lowering investment in conventional capital. In other words, Intensity Targeting (ICAP) is viewed as a policy for circumventing the investment crowding out effects and the negative impact on economic growth just mentioned. And there should be a further positive side effect. Since the rest of the world might profit from technology spillovers, the overall costs of greenhouse gas abatement could be reduced. However, is it realistic to suppose that a more rapid technological change in the energy sector comes at no cost in terms of less rapid technological change in other sectors, conventional investment and – as a consequence of that – less economic growth?

Answering these questions requires at least two kinds of an innovation. First, technological innovation as well as the spreading of technological knowledge across regions has to be made endogenous. Second, integrated assessment analyses that are based on intertemporal computable equilibrium models typically apply a so-called Negishi-approach for obtaining numerical solutions. This means that the analysis is restricted to cooperative behavior. However, both QCAP and ICAP are unilateral, strategies. Therefore we have to develop solution methods that allows for non-cooperative behavior.

The rest of this paper is organized as follows. Section 2 presents a top-down integrated assessment model of global climate change with endogenous technological change. This model is sufficiently transparent as to allow the implications of alternative viewpoints in post-Kyoto climate change policies to be explored. Numerical parameters are taken from MERGE (see Manne et al., 1995), RICE (see Nordhaus and Boyer, 2000) and MEDEA (see Stephan and Müller-Fürstenberger, 1998). This allows to relate our results to the existing literature. Section 3 presents the main results of our numerical exercise, and Section 4 covers some concluding remarks.

2 Modeling

The following analysis is based on a small-scale intertemporal general equilibrium model that integrates sub-models, which provide a reduced-form description of the economy, emissions, atmospheric carbon concentrations and damage assessment. And it includes a top-down, micro-founded modeling of endogenous technological change both in energy supply and energy demand.

For simplicity, there are just two regions of the world. North (N) consists of the OECD countries plus the former Soviet Union. Roughly, this corresponds to the ANNEX I parties. South (S) covers the rest of the world, and is used as an acronym for the developing part of the world. Each region is represented as if there were an infinite-lived representative agent who maximizes the discounted utility value of consumption subject to an intertemporal budget constraint. Each region produces a homogenous output that can be used for consumption as well as to cover energy costs. And it can be invested both in the formation of physical capital stock and in a stock of energy related technological knowledge. This means in particular that costs of energy supply as well as the productivity of energy depend on technological progress.

There is no allowance for international trade in produced commodities. Nevertheless, there are two channels through which regions interact. One is global climate change, which is directly attributed to cumulative CO_2 emissions and affects gross production of different regions of the world in different ways. The second channel is the diffusion of energy related technological knowledge from one region into the other. This is consistent with general beliefs (see Keller, 2004): Knowledge is a public good, and technological progress is an externality from which all parties can profit.

2.1 Technological change

There is increasing awareness that climate change policy and technological change interact (for example, see Goulder and Schneider, 1999). The reasons are obvious. On the one hand, climate change policy affects relative prices. This stimulates firms to develop less carbon-intensive processes and products. On the other hand, due to the long time span involved, technological change affects abatement costs, hence the choice of an optimal climate change policy.

In general there are two polar views on how to make technological change endogenous within a framework of integrated assessment. One is to follow the lines suggested by bottom up models, i.e., to suppose that technological progress is induced through learning by doing (see Gerlach et al, 2004). A second approach is to allow for investment in knowledge, i.e., to view innovation as a function of expenditure in research and development (see Nordhaus, 2002). Both approaches have their advantages. For example, there is a transparent micro-consistent framework for assuming that technological change is endogenously driven by piling up a stock of technological knowledge through research and development (R&D). However, as is argued sometimes (see Goulder and Mathai, 2000) this might lead to an underestimation of innovative potentials compared to the learning by doing approach. The latter in turn has the drawback of being based on structural as well as behavioral assumptions that are made implicitly only and which are not consistent with microeconomic reasoning.

This paper takes up the idea that at any point of time there is a stock of basic, applied and engineering knowledge. In the short-run this stock, hence technologies are fixed. But over the long-run knowledge is quite malleable and new technologies can be implemented through research and development activities. Note that our approach differs from existing ones in two respects: First, there is costless spillover of technological knowledge from the North to the South. Second, there is endogenous technological progress both in energy supply and energy productivity. That means, technological progress has three different effects: (1) It affects the marginal cost of energy supply, (2) it affects the carbon intensity of energy, and (3), it affects the energy efficiency of regional gross production.

2.1.1 Technological innovation and energy efficiency

To allow both for price-induced and autonomous (non-price) technological change in energy efficiency as well as for macroeconomic feedbacks economies are modeled through nested constant elasticity production functions. These functions determine how in each region r = N,S, aggregate economic output, $y_r(t)$, depends upon the inputs of labor, $L_r(t)$, capital, $K_r(t)$, and energy, $e_r(t)$

(1) $$y_r(t) = \left[\left(K_r(t)^{\alpha_r} L_r(t)^{1-\alpha_r}\right)^{\rho} + \left(a_r(t)e_r(t)\right)^{\rho}\right]^{1/\rho}.$$

Technical parameters α_r and ρ_r are exogenous and constant, while the productivity of energy, $a_r(t)$, is subject to endogenous technological change.

Before describing how investment into technological knowledge affects the energy efficiency of the regional macro production, let us note: (1) Technological progress is purely energy augmented. Typically this is called Harrod neutral. (2) Energy is viewed as energy services derived from both fossil fuels and carbon-free sources. In other words, energy inputs are lumped into a single aggregate. Hence, changing this mixture will affect carbon emissions from energy consumption.

Technological innovation does not fall from heaven, and technical knowledge will deteriorate over time without training and education. Moreover, research and development do not translate one-to-one into technological knowledge. To capture these aspects, let $Z_r^e(t)$ be the stock of technological knowledge that is attributed to energy efficiency in region r at period t and let $c^e(t)$ be the R&D expenditure into that stock of knowledge. Then the stock of energy consuming technologies changes over time according to

(2) $$Z_r^e(t+1) = \delta_r^e Z_r^e(t) + \varphi_r^e (c_r^e(t))^{\kappa}.$$

δ_r^s denotes the factor at which knowledge deteriorates, φ_r^S is a production coefficient indicating the fraction of investment that is transformed into technological knowledge, and κ is an output elasticity parameter.

To translate technological knowledge as represented by $Z_r^e(t)$ into productivity gains, assume that R&D induced innovation is embodied in new capital goods only. That means, the productivity of energy is determined by the fraction μ_r of new capital in the total stock as well as the stock of energy related knowledge. The share of new capital goods in the total capital stock is given by

(3) $$\mu_r(t+1) = \max\left(\frac{K_r(t+1) - \delta^{\kappa} K_r(t)}{K_r(t+1)}, 0\right).$$

Given that, marginal productivity, $a_r(t)$, of energy develops according to

(4) $$a_r(t+1) = (1 - \mu_r(t+1)) a_r(t) + \mu_r(t+1) a_r(t) \gamma Z_r^e(t)$$

where γ is a technical parameter.

2.1.2 Technological innovation and energy supply

Let $Z_r^S(t)$ be the stock of technological knowledge that is in region r attributed to energy supply in period t. Similar to the notation of Section 2.1.1, let $c_r^S(t)$ denote the R&D expenditure into energy supply technologies, let δ_r^s be the factor at which knowledge deteriorates and let φ_r^S be the coefficient that indicates which fraction of investment is transformed into technological knowledge. Then the new stock of technological knowledge $Z_r^S(t+1)$, which is available in period t+1, is

(5) $$Z_r^S(t+1) = \delta_r^s Z_r^s(t) + \varphi_r^S (c_r^S(t))^{\kappa}.$$

As was already mentioned above, energy is an aggregate of different fossil fuels and carbon free sources. Therefore, investing into energy supply technologies has two effects. On the one hand R&D affects the cost of energy supply, and it affects the carbon content of the energy inputs on the other. To take up the first aspect, for each region r the marginal costs of energy supply, $m_r(t)$, are linked to the stock of technical knowledge by

(6) $$m_r(t) = \overline{m}_r(t) + \hat{m}_r(t) e^{-\nu Z_r^S(t)}.$$

$\overline{m}_r(t)$ and $\hat{m}_r(t)$ denote lower and upper bounds, respectively, and ν is a technical parameter. Note, this functional specification mimics two key characteristics of R&D driven technological change. First, as the so-called ‘fished out’ approach (see Jones, 1995) suggests, because of a limited pool of ideas, there is a negative stock effect of already accumulated knowledge on the marginal productivity of R&D activities. That means, the marginal cost of developing new ideas increases as the stock of current knowledge increases. Second, marginal costs decline with increasing knowledge, but there are lower bounds that cannot be undercut.

The second aspect of technological innovation in energy supply, i.e., a change in the carbon content of the energy aggregate, is discussed in the following section.

2.2 Regional emissions and global climate change

Energy consumption directly determines the flow of CO_2 emissions into the atmosphere. That means, regional carbon emissions, $s_r(t)$, are related to regional energy inputs $e_r(t)$ through

(7) $$s_r(t) = \eta_r(t)\, e_r(t)\,,$$

where $\eta_r(t)$ is the regional emission coefficient.

Recall that within our framework, there are three options for reducing regional carbon emissions. One is input substitution, i.e., substitution of energy through capital and/or labor inputs in regional macro production (see equation (1)). A second option is to increase energy efficiency of regional production through R&D (see equations (1) and (4)). Finally, R&D in energy supply technologies does not only reduce marginal costs of energy supply (see equation (6)), but can also have the welcome effect of reducing emissions. For example, in the case of a coal-fired power plant, increasing the efficiency of the energy transformation process results in lower carbon emissions per unit of energy. This is the rationale behind coupling the emission coefficient η_r (t) to the stock of technological knowledge

(8) $$\eta_r(t) = \overline{\eta}_r(t) + \hat{\eta}_r(t) e^{-\varsigma Z_r^S(t)}\,,$$

where lower and upper bounds on the emission coefficient are given by $\overline{\eta}_r$ and $\hat{\eta}_r(t)$, respectively, and ς is a technical parameter.

The flow of carbon emissions contributes to the atmospheric stock of carbon A(t), which evolves according to

(9) $$A(t+1) = \phi_1 A(t) + \phi_2 \sum_{r=N,S} s_r(t)\,.$$

The parameters ϕ_1 and ϕ_2, respectively, describe natural degradation of atmospheric carbon dioxide and immediate uptake of emissions in the ocean. The model is calibrated such that with zero abatement, carbon 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.

For simplicity, we neglect the thermal inertia lag between global concentrations and climate change. We also neglect the cooling effects of aerosols and the heating effects of greenhouse gases other than carbon dioxide. Instead, potential global warming is directly attributed to increased atmospheric CO_2 concentration and will be translated into its economic impact according to a quadratic damage function

(10) $$\theta_r(t) = \left(\frac{\Delta A(t)}{\Omega_r}\right)^2, \text{ where } \Delta A(t) = \max(0, A(t) - A(0)).$$

$\theta_r(t)$ measures the fraction of conventional wealth that is available to region r for disposal as *green GDP.* Or to phrase it differently, 1-$\theta_r(t)$ is the region-specific environmental loss factor. Ω_r marks the critical value of the CO_2 concentration at which regional production is reduced to zero.

Regional *Green GDP* $\theta_r(t)y_r(t)$ can be used to cover energy expenditures, $c_r^E(t)$, it can be consumed c(t), might be invested into physical capital $i_r(t)$, or spent on R&D $c_r^{R\&D}(t) = c_r^s(t) + c_r^e(t)$. Therefore,

(11) $$(1-\theta_r(t))y_r(t) = c(t) + i_r(t) + c_r^E(t) + c_r^{R\&D}(t)$$

is the material balance of produced goods in region r, where costs of energy supply $c_r^E(t)$ are measured in terms of GDP and are determined through

(12) $$c_r^E(t) = m_r(t)\, e_r(t).$$

At any point of time - or to phrase it more precisely - for any given state of technology, the marginal costs $m_r(t)$ are constant, but due to technological change, marginal costs of energy supply will vary over time (see equation (2)).

2.3 Non-cooperative equilibrium

Energy-related R&D activities are carried out in the North only. But they create a public good whose benefits accrue to the South with a time lag of two years. That means

(14) $$Z_S^j(t) = Z_N^j(t-\Delta t),\, j = e,s,$$

where index j refers to the type of technology stock.

At any point of time t, the regional endowment $K_r(t)$ in physical capital depends upon investment activities, $i_r(t-1)$, and the former capital stock, $K_r(t-1)$

(15) $$K_r(t+1) = \delta^K K_r(t) + \omega_r i_r(t),$$

where δ^K is the capital survival rate and ω_r a technical parameter.

Let β be the social discount rate. Then consumption, production, investment in 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 single-period utility (the logarithm) of consumption, $c_r(t)$

(16) $W_r = \Sigma_t \beta^t \ln(c_r(t))$.

Except for PARETO, regions do not cooperate in greenhouse gas abatement. Instead they maximize their welfare independently. Since there is no market-oriented trade, it is unnecessary to use a Negishi based solution procedure as in MERGE, RICE or MEDEA. Therefore, the challenge for computing this non-cooperative equilibrium is to match expected future carbon emissions with the aggregated emissions in both regions.

3 Computational Experiments

What are the economic as well as the climate effects of the three policy scenarios PARETO, ICAP and QCAP? Answers to this question are based on numerical calculations, which are carried out by means of the GAMS/CONOPT3 software.[1] Results are reported for the time span 2000 – 2100. However, to avoid end-of-the horizon effects, calculations are carried out till 2170.

3.1 Benchmark Data

2000 is the base year for our numerical experiments. Model parameters are either derived through benchmarking against base-year data (see Table 3.1) or are taken directly from the literature (see Table 3.2).

[1] For a description of this software, see the GAMS homepage http://www.gams.com/solvers/solvers.htm#CONOPT

MACROECONOMIC VARIABLES	NORTH	SOUTH
Labor income (trillion US$)	16.490	3.710
Capital income (trillion US$)	7.070	1.590
Energy expenditures (trillion US$)	1.240	0.900
Energy related R&D expenditures (billion US$)	14.017	
R&D share energy consumption technology (%)	17	
Carbon dioxide emissions (GtC)	3.200	3.400
Climate damage at 560 ppmv in % of GDP	1.5	3.5
Potential growth (%)	1.500	2.500

Table 3.1: Benchmark data and parameters

PARAMTERS	NORTH	SOUTH
Capital survival rate [δ^K]	0.950	0.950
Investment technology [ω_r]	0.200	0.200
R & D output elasticity [κ]	0.500	
Knowledge depreciation in % [$\delta_r^{s,e}$]	5.000	
Max. marginal energy costs savings [%]	- 30	- 30
Max. carbon intensity reductions of energy [%]	- 75	- 75
Elasticity of substitution [ρ]	-.500	-.500
Utility discount factor [β]	.975	.975
Climate system parameter [ϕ_1]	0.99	
Climate system parameter [ϕ_2]	0.64	

Table 3.2: Model parameters as taken from the literature[2]

How to specify and calibrate production technologies, social welfare functions and the functional proxy of the climate system is almost common practice in Integrated Assessment Models (for example, see Stephan and Müller-Fürstenberger, 2004). Introducing R&D driven technical change, however, requires considerable effort to reconcile modeling demand and data availability.

As discussed in Section 2, there are two steps through which energy-related technical progress enters our model framework. First, R&D expenditures are translated into stock-of-knowledge additions (see equations (2) and (5)). The corresponding parameters are taken from Griliches (1979) as well as Goulder and Mathai (2000). They are displayed in Table 3.2. Second, the technological knowledge is linked to production possibilities. It is central to our calibration approach that all parameters of the corresponding equations (see (1) and (4)) are calibrated such that in the base year investing in new knowledge yields the same market returns as investing in physical capital. There are no positive externalities encountered, i.e., external effects due to climate change impacts and technological spillovers are not accounted for in the calibration process.[3] With respect to cost savings in energy supply, there is a lower limit relative to the current state of technology (see Goulder and Mathai, 2000). And there is a lower bound on the carbon intensity of energy with respect to the benchmark intensity (see Table 3.2).

In our model, technological progress is completely R&D driven. Calibration requires data about energy related R&D expenditures. According to IEA statistics, governments of OECD member countries spent 8.410 billions US $ on energy related R&D in 2000. This accounts for roughly 60 % of total energy related R&D investments.[4] About 17 % of this budget was allocated to energy conservation technologies. In our terminology, this is R&D expenditures on energy consumption.

Unfortunately, data availability does not allow to discern between de-carbonizing technical change and efficiency improvements in energy supply. This problem has

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2 R & D output elasticity is taken from Goulder and Mathai (2000:20). The knowledge depreciation factor value has been suggested by Griliches (1979).

3 Calibration refers to the “real world” economy, which - given the current state of affairs – does not internalize positive externalities of R&D.

4 Dooley (1999) reports for the United States that in 1996 around 44 % of energy related R&D expenditures were spent by the private sector. The private sectors in Japan, Germany and Italy account for 36, 30 and 71 %, respectively. Given the shaky grounds on which these data are based, we take the mean value and fix share of the private sector at 40 % of total energy related R&D.

been sidestepped in the literature by coupling emission reduction to general technical progress (see Buonanno et al., 2001). Here we slightly improve this approach by coupling de-carbonizing progress to improvements in the energy supply technology. We calibrated such that doubling energy supply related R&D efforts in the benchmark period (base year) reduces the emission intensity of GDP by 3 % in the base year.

3.2 Simulation results

Before presenting the outcome of our computational experiments, let us shortly recall the key characteristics of the policy scenarios under consideration. ICAP assumes that the North pursues intensity targeting by R&D investments in energy-related technologies. More precisely, based on technological progress the North aims to reduce the carbon dioxide to GDP ratio by 3 % per year. The South is free of any climate policy restriction, but can profit from the North's technology improvements through costless spillover.

QCAP assumes that the North imposes constraints on carbon dioxide emissions such that the global atmospheric carbon concentration is similar to those under ICAP. In other words, from a climate change perspective ICAP and QCAP do not differ. Finally, PARETO refers to full international cooperation in combating with global climate change. But what if there were no climate policy intervention at all? This is described by a scenario called BASE, where both North and South develop independently without any restriction on carbon dioxide emissions.

Figure 3.1 reports for each scenario how atmospheric carbon will develop over time. Within the report period, none of the scenarios exhibits a turning point, neither in regional emissions nor in accumulated atmospheric carbon. However, the growth rates, and as a consequence of that the climate damages, differ significantly across scenarios. As expected, BASE yields the highest stock of atmospheric carbon. It implies a doubling of the pre-industrial concentration of atmospheric carbon dioxide by 2060. This is only slightly earlier than in PARETO. The lowest carbon concentration is reported for QCAP and ICAP. By definition, these yield equal carbon emission and concentration paths. This indicates that both scenarios impose a tighter constraint than a pareto-efficient climate policy would prescribe.

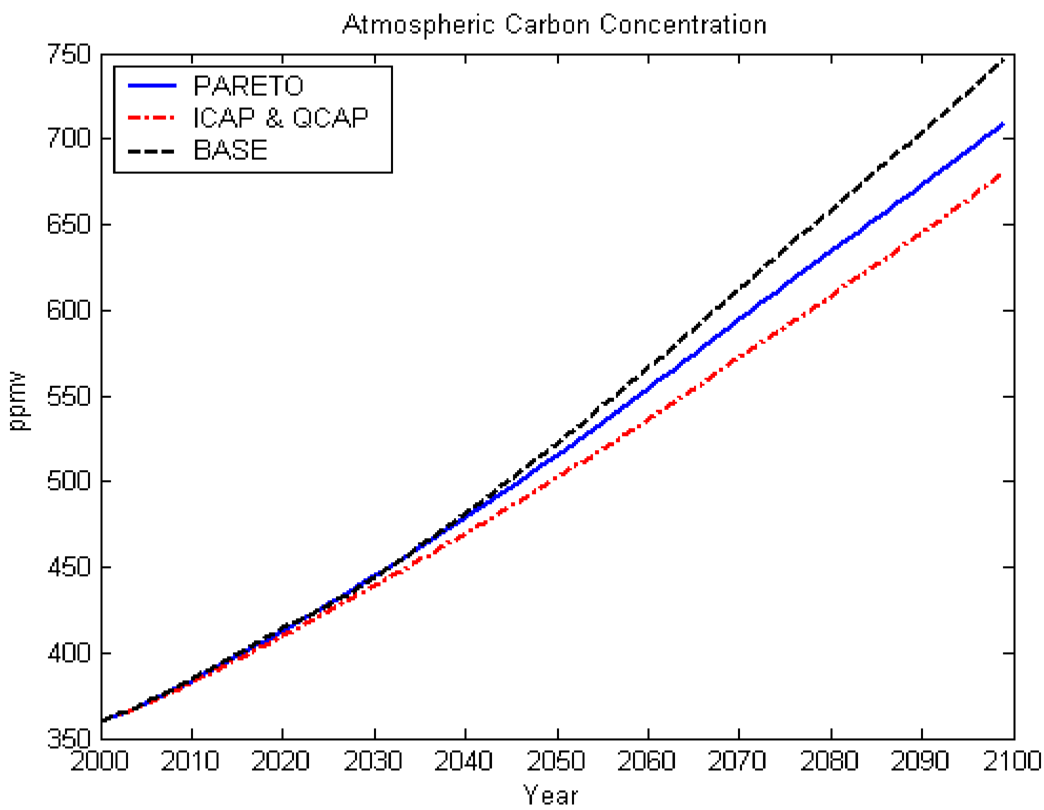

Figure 3.1: Atmospheric carbon concentration.

Now let us turn to the economic impacts. Figure 3.2 shows how GDP will develop in the North. Since the effects are small, Table 3.3 gives the per cent deviations from the BASE for 2030, 2050, 2070, and 2100. As can be expected for the long-run, PARETO is best in terms of green GDP, whereas QCAP performs worst. This could be viewed as an argument to support the skeptical position of many US economists against the Kyoto Protocol. However, two observations are astonishing. First, there is almost no difference between BASE and PARETO till 2075. Since PARETO assumes full international cooperation in climate policy, whereas in BASE there is no climate policy at all, this implies that in terms of regional welfare cooperation does not really pay for the North within the next 75 years. Second, ICAP is superior to QCAP. Obviously this result is driven by positive externalities of northern R&D expenditures, which outweigh efficiency losses of using one instrument only. Note that QCAP also induces higher R&D expenditures than BASE. But under QCAP, the economy can also substitute energy for capital, which helps to minimize instantaneous abatement costs.

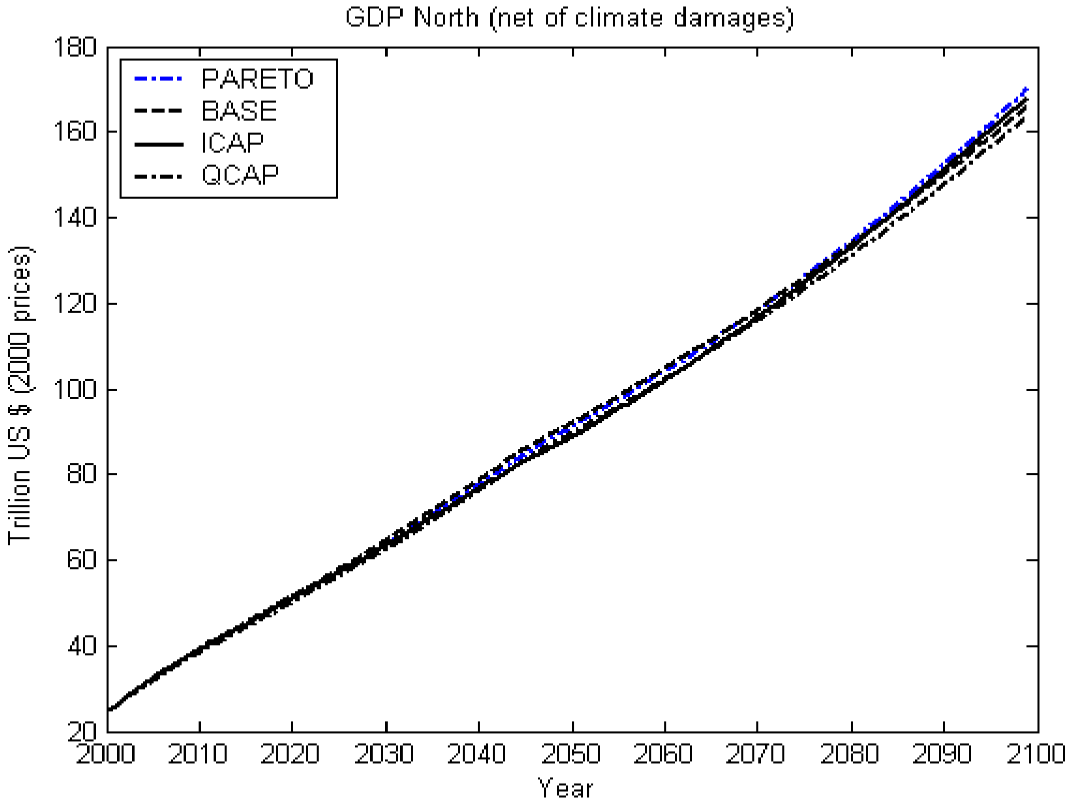

Figure 3.2: Green GDP in North

Figure 3.3 shows how the economy of the South is affected by the different policy options. No climate policy at all (BASE) is the worst case for South. This simply results from the fact that all other scenarios imply lower climate damages and higher technological spillovers.

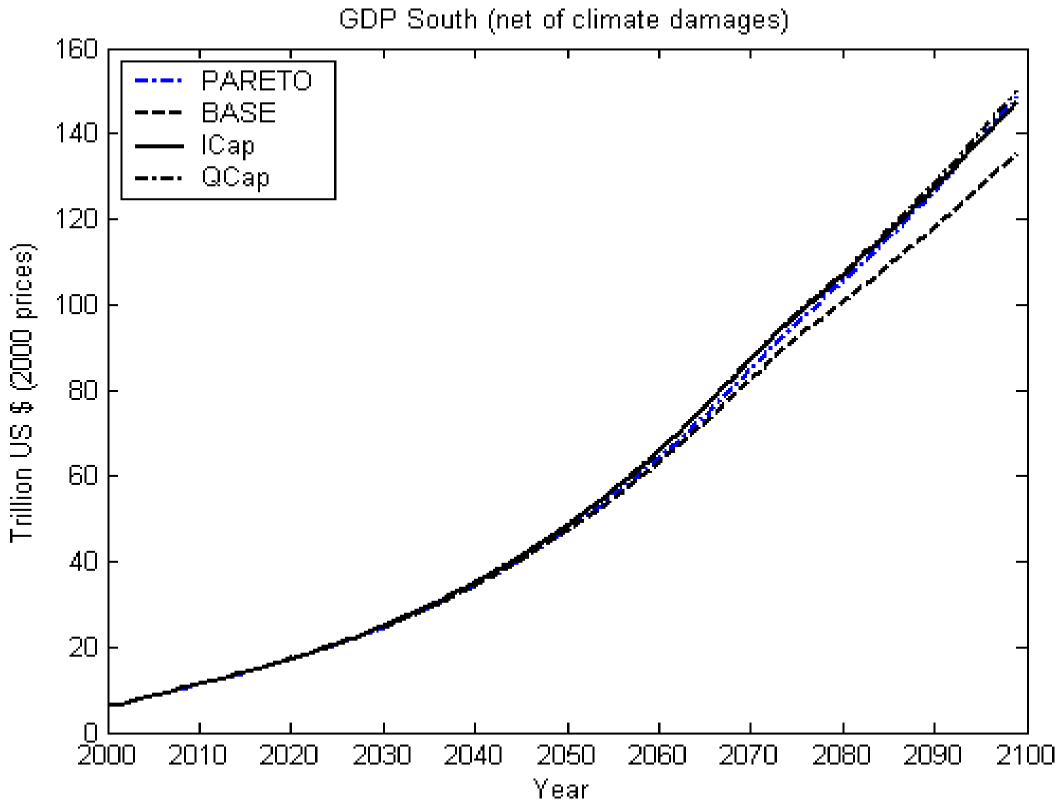

Figure 3.3: Green GDP in South

While this outcome is in line with economic intuition, ICAP and QCAP exhibit counter-intuitive patterns. There is almost no difference between these two non-cooperative policy scenarios. How can this be explained? Now, recall that the technology spill-over from the North to the South gives rise to two first order effects: First, given the same resource endowment the South can realize a higher GDP. Second global emissions, hence climate damages decline, provided that a higher productivity of energy consumption and lower marginal costs of energy supply do not outweigh the de-carbonzation effect of declining carbon intensities of energy input.

Year	Region	PARETO	ICAP	QCAP
2030	N	- 1.3	-1.43	-2.98
	S	-.39	.6	.86
2050	N	-1.0	-3.63	-2.67
	S	.3	2.41	2.69
2070	N	-.28	-1.61	-2.28
	S	2.54	5.3	5.5
2100	N	2.42	1.22	-1.35
	S	2.59	8.8	10.63

Table 3.3: Deviations in green GDP from BASE (measured in %t)

Figure 3.2 and 3.3 suffer from the fact that effects are very small which make it hard to discriminate among the scenarios. Therefore, Table 3.3 again displays these results for four time points, but now measured in per cent deviation from BASE. Thereby the main massage is that both PARETO and ICAP pay back for North in the very long run only. Welfare gains due to climate policy mainly materialize in the South.

4 Conclusions

Using a regionally disaggregated Integrated Assessment Model, we have discussed what generally is called the intensity targeting approach to climate change. This type of climate policy was just recently advocated by the US-administration as an alternative to a Kyoto-style policy. One has to be aware, however, that the main focus of this policy is not to reduce carbon emission per unit of GDP. This is a welcome side effect. Its main focus is the pivotal role of R&D driven technological progress.

Our numerical analysis shows that intensity targeting by R&D investments can be superior to a unilateral quantity constraint on carbon dioxide imposed by the North only. In particular from the South's perspective, both intensity targeting as well as constraining emissions are beneficial policies with only negligible differences. By stimulating technological change, the North can provide an incentive to abate more carbon emissions in the South than without such a policy. As such, the technological externality that the North produces pays back in terms of weaker constraints on its emissions.

It must be mentioned that technology progress is extremely difficult to specify even in a small-scale Integrated Assessment Model. In particular it requires heroic assumptions with respect to functions and parameter choices. In this paper it is assumed that energy related technical progress is initiated by R&D efforts in OECD countries. After a short time lag, new technologies spread worldwide and present some type of public good. This means that we have to consider two types of externalities within our model: A negative externality due to carbon dioxide emissions on the one hand, and a positive externality due to technological spill-over on the other.

Obviously, our results are driven a good deal by the assumption that there is costless diffusion of advanced technologies from the developed to the less developed parts of the world. This is consistent with conventional beliefs, and what just recently has received empirical evidence. However, as Keller (2004) summarizes, there is no indication that diffusion occurs automatically. This is part of the scenario experimental setting and subject to future research.

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