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The benefits and costs of waiting: early action versus delayed response in post-SRES stabilization scenarios

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Abstract This paper analyzes the economic impact of mitigation policies that lead to stabilization of CO_2 concentrations at levels of 550 and 450 ppmv, respectively. We successively use each of the four new IPCC scenarios as a baseline. We analyze the impact of two different mitigation paths to the same long-term stable concentrations, which we call early action versus delayed response. The two issues that determine the advantages and disadvantages of early action are the timing of the entrance of new regions into an agreement and the development of the emission price, once all countries participate. The mitigation path is intertemporally efficient if most of the mitigation takes place after all countries have entered an agreement and if the real emission price increases over time with a growth rate equal to the real interest rate. The impact on global utility depends on the dynamics of the emission price. The emission price, for its part, depends on (1) which of the IPCC scenarios is chosen, (2) on the ultimate concentration rate, and (3) on the timing of the scenarios. The distribution of the income effects over regions depends mainly on the regional assigned amounts agreed upon in the agreement.

Key words Climate change · IPCC SRES scenarios · Macroeconomics · Stabilization · Intertemporal efficiency

Introduction

The UN Framework Convention on Climate Change (UNFCCC) calls for stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with climate systems. Stabilization of emissions of greenhouse gases by the industrialized countries, so-called Annex B countries, as agreed upon in the Kyoto Protocol, is far from sufficient to stabilize concentrations worldwide. This will need the extension of the Kyoto Protocol to include non-Annex B countries.

The time frame over which emissions reductions will be achieved is an important source of uncertainty in assessing the economic costs. One has to balance the costs of early and more gradual action against the costs of later, more rapid, forced action. To illustrate the effects of the timing of abatement, we consider two strategies: early action and delayed response. Early action (EA) starts with full implementation of the Kyoto protocol and immediate action toward global stabilization afterwards. Delayed response (DR) assumes a delay in the implementation of the Kyoto Protocol and an initial delay in meeting global targets.

The economic costs of stabilization depend crucially on the baseline used. IPCC introduced a number of new scenarios which quantify a wide range of future worlds (IPCC 2000). In our analysis, we systematically try to compare the relationship between baseline and mitigation scenarios. It is hard to tell what CO_2 concentration level is "safe". Therefore, in our analysis, we work with two levels of concentration of CO_2. We consider both 550 ppmv and 450 ppmv as targets for stabilization by the end of the 21st century. Altogether, this gives us 16 mitigation variants. Associated with each baseline scenario, we consider an early action and a delayed response variant. We carry out this analysis for both the 550 ppmv and 450 ppmv concentrations.

Stabilization at a certain level is reached by introducing a carbon tax (or carbon price). We assume a global trading regime for emission permits. Costs of mitigation depend crucially on the dynamics of the carbon price. It can be argued that an efficient carbon price evolves over time in line with the real interest rate. This argument draws on Hotelling's analysis of nonrenewable resource depletion (Krautkraemer 1998)

Our analysis is based on simulation with WorldScan. WorldScan is a multiregion, multisector, applied general-equilibrium model which focuses on long-term growth and trade in the world economy (CPB 2000). The model is especially adapted to quantify the effects of policies to mitigate CO_2 emissions.

The organization of the paper is as follows. First, methodological issues are addressed. We briefly describe some key features of WorldScan. Next, we present the IPCC scenarios and explain how these scenarios were implemented in WorldScan, and then we present feasible mitigation strategies. Later sections discuss the simulation results to some extent and conclude with the main findings.

Methodology

Key features of the WorldScan model

To quantify the baseline scenarios and the policy variants, we use the WorldScan model. WorldScan is a multiregion, multisector, applied general-equilibrium model, which focuses on long term growth and trade in the world economy (CPB 1999). WorldScan has been developed to construct scenarios. In this case it is used to supply the general characteristics of the SRES scenarios with corresponding trends of endowments, technology, and international specialization patterns. Distuinguishing characteristics of WorldScan are an Armington trade specification, imperfect capital mobility, consumption patterns depending upon per capita income and converging towards an universal pattern, a low-productive sector in developing countries and a distinction between low- and high-skilled labor.

Dynamics in WorldScan stem mainly from consumption and investments, which are forward looking.

In this paper we distinguish four broad regions: OECD, Eastern Europe and the former Soviet Union (EEFSU), Asia (ASIA), and the Rest-of-the World (ROW). The group of Annex B (A-B) countries is made up of OECD and EEFSU, while ASIA and ROW are in the non-Annex B (NA-B) group. It is important to distinguish between A-B and NA-B, because of the different roles they play in the Kyoto Protocol. The large differences between OECD economies and EEFSU countries legitimizes the further division of A-B. To assess the role of energy-exporting countries, ASIA and ROW are separated. There are 11 producing sectors in WorldScan. Four sectors concern the supply of energy: coal, oil, gas and electricity. This allows for substitution between different energy carriers. The other sectors are agriculture, energy-intensive products, consumption goods, capital goods, services, transport, and raw materials.

Value-added, energy, and materials are inputs to production. Primary inputs to value-added are labor (low-skilled and high-skilled), and capital. In agriculture and in the oil-, gas- and coal-producing sectors, we also distinguish a fixed factor as a primary input to value-added. The fixed factor in fossil energy production can be thought of as a fuel-specific natural resource. Other sectors are characterized by constant returns to scale. These sectors have a horizontal supply curve; the supply elasticity approaches infinity. For all sectors, except the electricity sector, energy input to production is a composite of coal, oil, gas, electricity, biofuels, and renewables.[1] Renewables consist of nuclear, geothermical, solar, and wind energy.[2] We do not consider these to be generated by a separate production sector. Biomass is produced by agriculture. Renewables are produced by the services sector. As a consequence, the prices of biomass and renewables equal the price of agriculture and services, respectively. Since renewables are produced by the utilities sector, a sector with a horizontal supply curve, this input factor serves as a carbon-free backstop in our model.

Technology enters the model in two ways. First, value-added is becoming increasingly productive over time. This technological change is neutral concerning input factors in value-added: labor, capital, and the fixed factor. This value-added productivity is the main driving force behind GDP growth. Next, we assume an energy-specific technological change making the input of energy-producing factors more or less efficient over time. This second form of technological change is, together with changes in relative prices, a force driving behind the change in energy intensities.

The model only accounts for energy-related carbon emissions, i.e. the direct consumption of coal, oil, and gas, and their related emissions.

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[1] For the electricity-producing sector we assume a somewhat different structure. Electricity itself is not an input in the production of electricity, but it serves as an input in the production of materials.

[2] Strictly speaking, the renewables is not the correct label for this category, since nuclear energy is non-renewable.

Calibration

The model is calibrated to the benchmark year 1995, based on the GTAP4E data set (see Hertel et al. 1997; Malcolm and Truong 2000). The energy data in GTAP4E are an improvement over previous data, such as that in GTAP4. This improvement is due to the incorporation of data on energy and volumes prices provided by the International Energy Agency into the GTAP database. Implicit prices result from the confrontation of the value of output and trade per region in GTAP4 with volume data of output and trade. There is a clear difference between domestic prices and internationally traded prices in some regions. We assume that energy subsidies are the cause for these differences. From the GTAP database we also derive non-energy data such as demand, production, and trade patterns of other goods, and labour and capital intensities in the various sectors. For the source of other data we refer to CPB (2000).

After the calibration of the base year, the model is solved in 5-year intervals spanning the horizon from 2000 to 2100. The data and projections for population size and labour supply coincide with the SRES scenarios. Overall and energy-specific technologies are chosen in such a way that GDP and energy use in the SRES scenarios are reproduced.

Four IPCC scenarios

The baseline scenario is of overriding importance for the costs of stabilization of CO_2 concentrations. In this paper we consider four new IPCC scenarios. The IPCC (IPCC 2000) comissioned a new report on emissions scenarios (the Special Report on Emissions Scenarios, or SRES). These SRES scenarios are known by the rather unimaginative names of A1, A2, B1, and B2. The four scenarios can be roughly characterized by two dimensions: globalization versus regionalization, and economy versus the environment (see Fig. 1). The A1 and A2 worlds are dominated by the objective of the people to maximize income, rather than to pursue any environmental goals. In the B1 and B2 worlds local environmental objectives—such as local air pollution and soil degradation—are also important. A1 and B1 are characterized by further globalization, while in A2 and B2 the regions remain more diverse and isolated. Globalization may evoke rapid technological progress, leading, e.g., in the A1 scenario to technologies, with relatively low use of fossil energy.

The stories behind these four scenarios have been implemented by different modeling groups. This has resulted in detailed trajectories for GDP, population, and final energy demand. As mentioned above, we mimic these trends by calibrating scenario-specific technological progress. Furthermore, we have introduced other scenario-specific elements to concur with the different storylines. Globalization in A1 and B1 is modeled by reduction of tariffs, lower international transportation costs, and higher long-term price elasticities of trade flows, all leading to more intensified trade relations during the scenario period. Further integration of international capital markets is modeled as convergence of risk

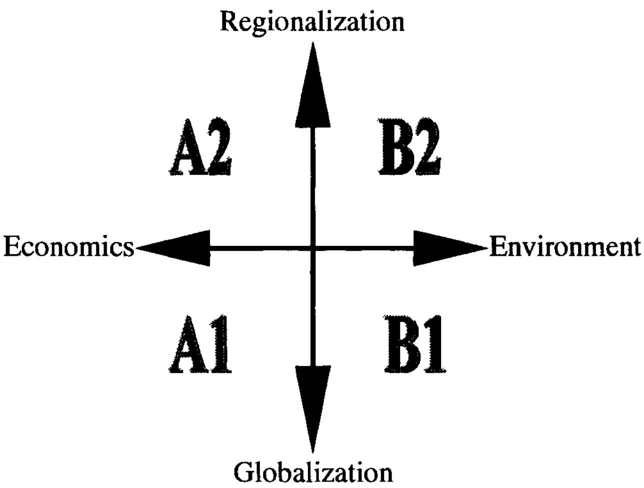

Fig. 1. The four IPCC marker scenarios

Table 1. Driving forces in the SRES scenarios

	A1	A2	B1	B2
Technology				
Value-added productivity	large	large	Small	small
Energy specific technological change	small	small	Large	large
Convergence				
Internationalization	yes	no	Yes	no
Risk aversity	yes	no	Yes	no
Skill composition / Consumption patterns	yes	no	Yes	no
Environment				
Consumption energy-intense goods	more	more	Less	less
Energy subsidies	yes	Yes	No	no

premiums. In these globalization scenarios we also assume more rapid convergence of consumption patterns and skill intensities. We have modeled the environmental awareness in the B1 and B2 worlds by changing consumption patterns towards less energy-intensive products and by abolishment of energy subsidies. Table 1 lists the scenario-specific model characteristics.

Mitigation variants

One has to balance the costs of early and more gradual action against the costs of later, more rapid, forced action. Based on "integrated assessment" models, some authors have argued that the least costly way to achieve concentration stabilization would be to let emissions continue unconstrained for a certain period of time, followed by drastic cuts later (Wigley et al. 1996). However, Ha-Duong et al. (1997) reach the conclusion reach the conclusion that a strategy of early and modest abatements may prove less costly if, as more scientific information becomes available, more rapid reductions will become necessary. In this exercise we apply both an early action (EA) emissions profile and a delayed response (DR) trajectory. These stabilization paths are slight modifications of the so-called WRE and WGI profiles (IPPC 1995). These mitigation paths refer to the fossil energy related emissions, only. In the mitigation profiles the scenario-specific net land use related emissions are taken into account.

There is no agreement on which GHG concentration level is "safe". Much literature focuses on the threshold of 550 ppmv of CO_2. This levels corresponds to roughly twice the concentration level in pre-industrial times. To assess the effect of a more stringent target, we also impose an CO_2 stabilization level of 450 ppmv. We assume concentrations to stabilize around 2150.

Burden sharing, the distribution of future emissions right among nations, is an important policy question. In EA variants we assume that the Kyoto Protocol is implemented in each Annex I region from 2000 till 2010. There is full permit trading within the abatement group. After the Kyoto period the regions that comply with the international agreement take the responsibility of matching the global reduction profile and thus ensure additional domestic reductions in case of carbon leakage to non-participating countries. In 2025 ROW is assumed to join the carbon coalition. ASIA enters in 2035. In this exercise the entrance of new regions is exogenous. However, the year of entrance roughly corresponds with attaining a welfare trigger of US$ 10000 per capita. ASIA is lagging in GDP per capita. Each new entrant is granted a grace period of 10 years. In this period emissions are kept constant at the level of entrance. After this grace period, gradual convergence to equal emissions per capita is assumed. That means that only after several decades the amounts assigned to non-Annex B countries depart significantly from their baseline emissions. In DR variants the implementation of Kyoto is postponed with 10 years and there is a global constraint from 2020 onwards. Again, in 2025 the coalition is extended with ROW, in 2035 with ASIA. Like in early action, there is a grace period of 10 years and a gradual convergence to equal emission per capita afterwards.

The storyline behind a certain baseline scenario, and not just the numbers, does matter, because the storyline provides a context for the abatement policies which can be expected. In this respect an international permit trading system does not seem a plausible mechanism in every "world". Regarding our four baselines, global permit trading seems less likely in A2 and B2 and one might expect B-worlds to favor early action more than A-worlds. One could also think of other flexible mechanisms like the Clean Development Mechanism. However, in this exercise we are more interested in the effect of different baselines and targets. To make the comparison clear, we apply the same policies in every baseline.

In order to analyse the potential impacts of additional climate policies within each narrative, four sets of different global emission profiles are considered.

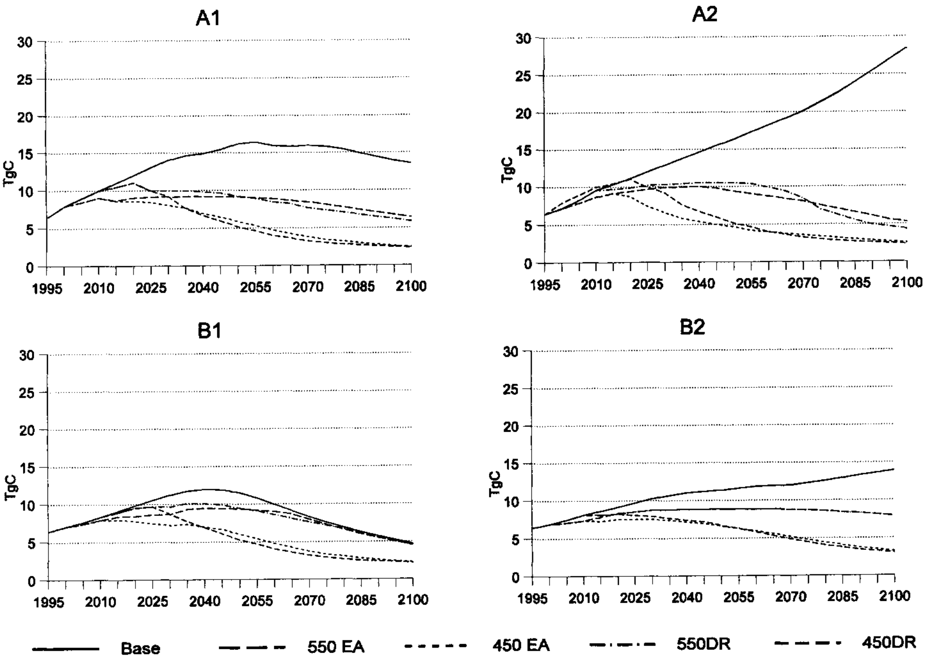

Fig. 2. Global baseline emissions and assigned amounts in A1, A2, B1 and B2

- early action towards a concentration of 550 ppmv (550EA)
- delayed response towards a concentration of 550 ppmv (550DR)
- early action towards a concentration of 550 ppmv (450EA)
- delayed response towards a concentration of 550 ppmv (450DR)

Figure 2 shows the global baseline emissions and the stabilization emissions trajectories in the all four SRES worlds. As an llustration, Fig. 3 shows the assigned amounts per capita in A2-550EA per region.

In principle, we consider 16 stabilization variants (4 baselines × 2 policies × 2 stabilisation targets). Table 2 gives an overview.

However, we were not able to run two scenarios. It seems to be too ambitious to reach 450 ppmv stabilization in the A2 world with delayed response. The reductions needed at the end of the scenario period are simply too large. An opposite problem occurs in the B2 world. There the baseline emissions remain in certain sub-periods under the delayed response emission profile, which would lead to considerable lower stable concentrations. To a lesser extent this occurs in the B1 world. In this case the baseline concentration are so close to the 550 ppmv target, that imposing the early action/delayed response trajectory leads

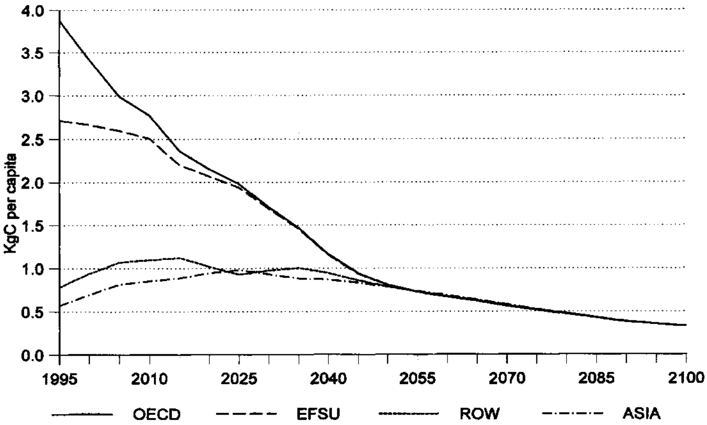

Fig. 3. Assigned amounts per capita by region in A2-550EA

Table 2. Overview stabilization variants

	A1	A2	B1	B2
Early action				
550 ppmv	yes	yes	yes	yes
450 ppmv	yes	yes	yes	yes
Delayed response				
550 ppmv	yes	yes	yes	yes
450 ppmv	yes	no	yes	no

to negative carbon taxes. Therefore we opted for a slightly lower stabilization target.

Results

In this section we present the WorldScan results. First, we discuss early action to reach a concentration level of 550 ppmv in the A2 baseline (A2-EA550). We take this mitigation variant as a benchmark policy. We discuss the consequences for emissions, the permit price, permit purchases and welfare. Second, we compare early action with delayed response. Next, the effects of different baselines on the outcomes are discussed. Finally, we see how a more strict concentration level influences the results.

Early action towards a 550 ppmv stabilisation in A2

Figure 4 shows the actual emissions relative to the assigned amounts the in the EA550 variant for all four regions. The OECD appears to become a net importer of permits throughout the period, so that their actual emissions remain above

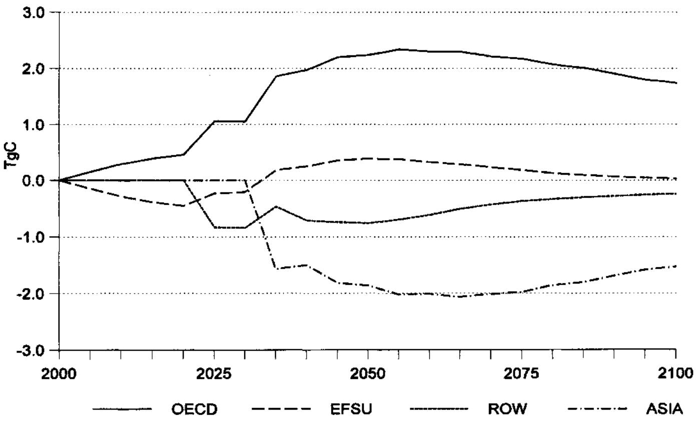

Fig. 4. Actual emissions minus the assigned amounts in A2-550EA

their assigned amounts. During the Kyoto period Central Europe and the Former Soviet Union (EEFSU) export permits to the OECD. Once other regions, with lower marginal abatement costs, enter an international agreement, the EEFSU becomes a significant net importer of permits.

During the Kyoto period the emissions in Asia and Rest of the World (ROW) exceed their baseline emissions, reflecting the carbon leakage as result of the abatement policies in Annex-B countries. As energy in Annex B becomes more expensive due to a carbon tax, energy demand will fall. This leads to a downward pressure on energy prices and an upward pressure on energy demand elsewhere. Moreover, Annex B will shift part of its energy intensive production towards non-Annex B. Both channels lead to an increase in the demand for energy and emissions in non-Annex B. With the entrance of ROW to the abatement club in 2025, reductions in OECD, EEFSU and ROW diminish. Carbon leakage to Asia increases. With the entrance of ASIA, abatement efforts in other regions decrease. Asia undertakes a considerable abatement effort in exchange for permit payments. Once ASIA and ROW have entered an international agreement, their emissions drop sharply, even significantly below their assigned amounts.

Up till 2020 EEFSU is the sole exporter of permits. After 2025 ROW partly takes over this job. After 2035 a new member enters the stage. Asia becomes the largest exporter of permits. Now, EEFSU becomes a net importer of permits. The role of ROW as an exporter of permits diminishes, but does not vanish completely. This exchange of roles creates a possible instability in the carbon coalition. Since EEFSU loses from the entrance of others, this might lead to objections to extending the coalition.

Figure 5 shows the development of the carbon tax over time in case of early action towards a concentration of 550 ppmv in the A2 scenario. The carbon tax steadily increases to 68 \$/tC in 2020. When ROW enters the agreement in 2025, the price declines to 43 \$/tC. The reason is that the low-cost abatement options in

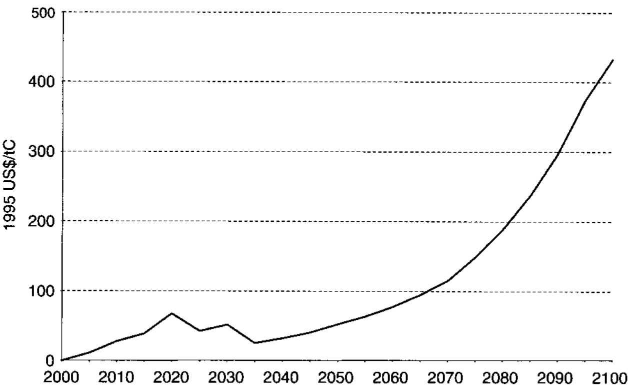

Fig. 5. Carbon tax in A2-550EA

the ROW can now be used and that ROW partly takes the weight of the shoulders of Annex-B. The carbon tax drops further to 25 $/tC when Asia enters the agreement in 2035. Thereafter the price rises again steadily at a rate somewhat above 3% annually to a level of 431 $/tC in 2100. These dynamics of the carbon tax already give an indication of the efficiency of the mitigation path. An efficient time path of emission reduction would lead to a price that increases at a rate equal to the rate of return in the economy. That means that the sharp drops at moment that new regions enter the agreement are clearly inefficient. Any mitigation policy is more efficient if more regions are part of an international agreement. This argument works in favor of delayed response before 2035 when all regions comply with an international agreement. After that the early action mitigation path is more or less efficient in the A2-scenario becomes the rate of return also centers around 34%. Given the fact that the baseline emissions in the A2 scenarios grow abundantly, it is not surprising that one should not wait too long before imposing serious restrictions on global emissions.

Figure 6 shows three indicators of the costs of stabilization for all four regions. It shows GDP and real national income as percentage deviation from the baseline. The third shows utility, or the discounted value of future real consumption, again as percentage deviation from the baseline. The points in time reflect the horizon over which consumption is cumulated. That means the value in 2100 shows the impact on discounted cumulative consumption from 1995 till 2100. The value in 2050 shows the impact on discounted cumulative consumption from 1995 till 2050. The discount factor in these calculations is 3% annually. Besides terms-of-trade effects the most important difference between the impact on real production and the impact on real income are the transfers related to imports and exports of permits.

For the OECD real income loss as a result of the mitigation policies increases to above 2.5% of the baseline in 2100. Since the most significant losses occur later in the scenario period, which get a low weight in the cumulated discounted

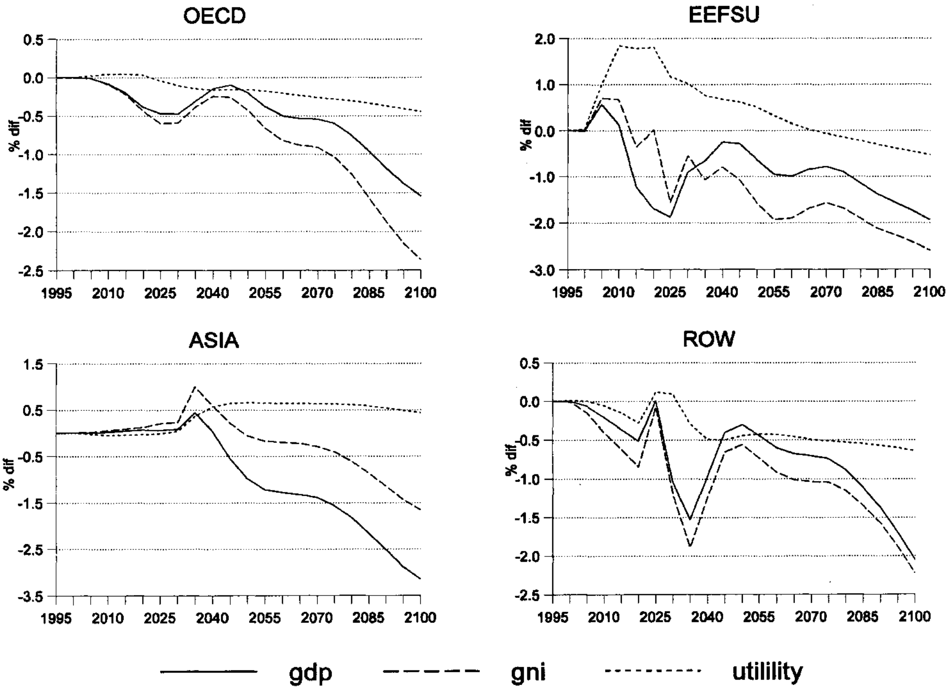

Fig. 6. Cost of stabilization in A2-550EA

consumption, the impact on this discounted consumption is only somewhat above 0.5%. Also the decline in real GDP is smaller than the decline in real income, since the OECD remains a net importer of permits.

The ultimate impact in 2100 on the EEFSU is more or less the same with a decline in real income by 2.7%, of cumulated discounted consumption by 0.5% and of real GDP by 2%. However the time path of the losses is rather different. In the beginning the EEFSU even gains from the mitigation policies. Income rises as a result of revenues from permit exports. The rise in consumption is even larger than the rise in real income, because the savings rate declines in the beginning. This is caused by lower interest rates as a result of the inflow of transfers. This makes cumulated discounted consumption, computed over a shorter time horizon so positive.

For ASIA the period of higher income as a result of revenues from permit exports is even longer. Only very late the impact on real national income becomes negative, although real GDP declines earlier and much sharper. The long period of positive impacts on income and consumption implies that the discounted value of consumption, cumulated over the whole period, is positive.

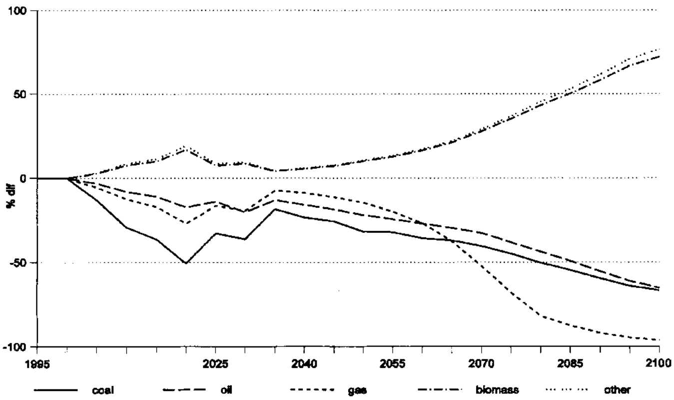

Fig. 7. Energy Demand in the A2-550EA, relative to baseline

Although ROW, like ASIA, remains a net exporter of permits, their income and consumption losses are even larger than those of the OECD and the EEFSU. This is mainly due to the fact that this region contains large energy exporters, which suffer a decline in both the prices and volumes of energy exports.

Figure 7 shows the impact of the stabilization to 550ppmv with early action on energy demand, relative to the baseline. The Figure show the largest decline in demand four coal, because of the high carbon content of coal and because coal is abundantly used in the A2 baseline. The large impact on the demand for oil in the second half of the century is somewhat misleading. In the A2 world the oil reserves are virtually exhausted at the end of the scenario period. In OECD the drop in demand for fossil fuels eases with the entrance of new regions to the abatement club. The demand for both biofuels and renawables is a mirror image of the demand for fossil fuels. All regions show a significant increase in both biofuels and renewables.

Early action versus delayed response

What is the impact of a more postponed mitigation, or, in terms of this paper, delayed response in the A2 world? Figure 8 gives the impact on cumulated discounted utility for both delayed response and early action.

The end points in Fig. 8, at the year 2100, show that the impact on utility, defined as the cumulated discounted consumption over the whole period doesn't differ a lot between EA and DR. Especially for the EEFSU and ASIA the differences are minimal. However, for both regions, early action is beneficial in the beginning of the mitigation policies. This is caused by the fact that they can export a lot of permits in the first decade after they enter the agreement and their assigned amounts are still hardly restrictive. Because in EA there is larger demand for permits in the beginning of the scenario period, the revenues from permit exports are also higher. Later on in the scenario period DR is more

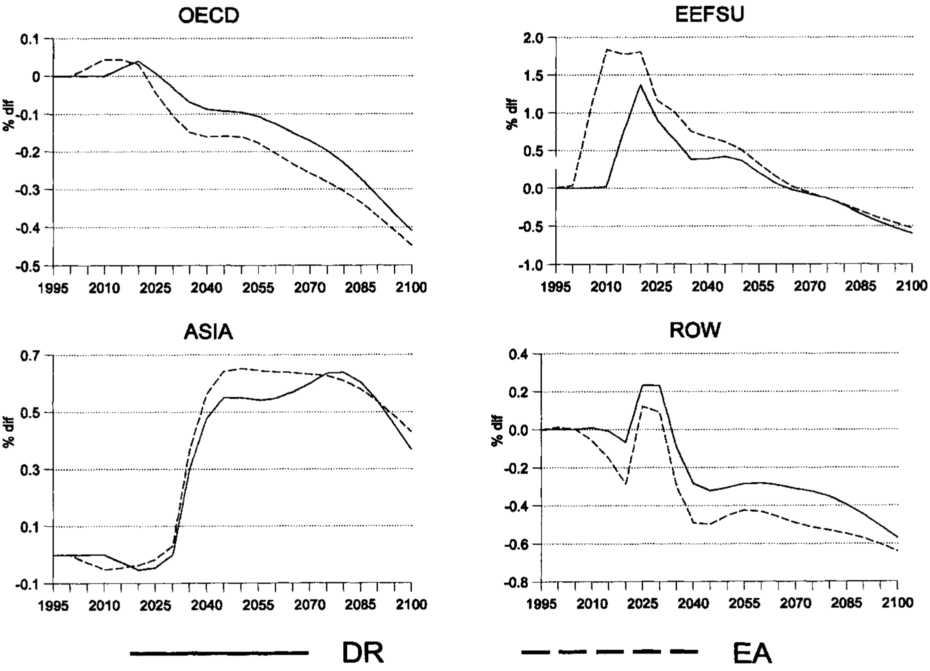

Fig. 8. Welfare effects in EA and DR in A2-550 at 3% discount rate

beneficial, which more or less cancels out with the benefits of EA in the beginning. For the other two regions EA lead to larger losses in utility, mainly because of the inefficiencies in the beginning when not all regions have entered the agreement. DR seems to be more inefficient towards 2100, but that doesn't completely cancels the advantages of DR in the beginning for these two regions. Globally DR is slightly beneficial, mainly due to inefficiency when not all regions comply with a mitigation target.

Different baselines and different targets

We now turn to the outcomes in different "worlds" and under different targets.

Figure 9 shows carbon taxes in the period 1995–2040. Table 3 shows the carbon tax in 2100, Table 4 shows the growth rate of the carbon tax in the period 2040–2100. Between 2000 and 2040 the prices are slightly more smooth in DR, as might be expected. This reflexes the fact that DR is more efficient than EA in this period. However, between 2050 and 2090 the prices increase at a higher rate in DR compared to EA. This rate of increase may be well over the rate of return in the economy, which reflexes that DR is less efficient in the second half of the 21st century.

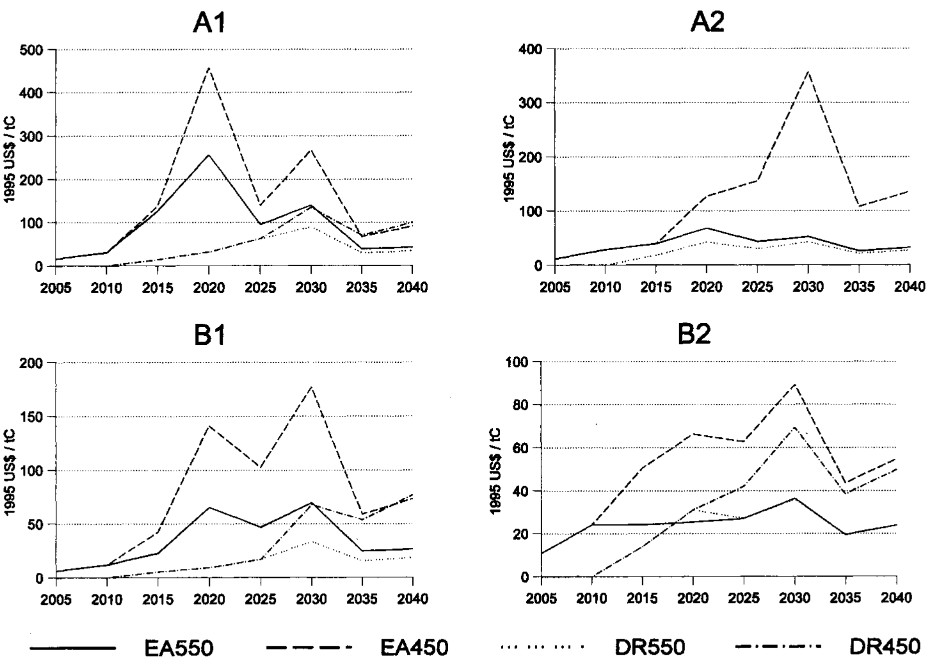

Fig. 9. Carbon price 2005–2040 in all four scenarios

Table 3. Carbon tax in 2100 in 1995 US$/tgC

	A1	A2	B1	B2
Early action				
550 ppmv	90	425	0	60
450 ppmv	475	950	90	225
Delayed response				
550 ppmv	115	550	0	n.a.
450 ppmv	500	n.a.	95	240

Table 4. Average annual growth rate carbon tax 2040–2100

	A1	A2	B1	B2
Early action				
550 ppmv	2.5	4.4	!3.7	1.6
450 ppmv	3.5	3.2	0.2	2.3
Delayed response				
550 ppmv	3.5	5.3	!3.3	n.a.
450 ppmv	3.2	n.a.	!0.1	2.7

Table 5. Welfare effects for all stabilization variants in 2040 and 2100

		A1		A2		B1		B2	
550		2040	2100	2040	2100	2040	2100	2040	2100
OECD	DR	−0.1	−0.1	−0.1	−0.4	−0.1	−0.1		
	EA	−0.1	−0.1	−0.2	−0.4	−0.1	−0.1	−0.1	−0.1
EFSU	DR	0.0	−0.1	0.4	−0.6	0.0	−0.4		
	EA	0.0	−0.1	0.7	−0.5	0.2	−0.4	−0.2	−0.1
ROW	DR	−0.1	−0.2	−0.3	−0.6	−0.2	−0.3		
	EA	−0.2	−0.2	−0.5	−0.6	−0.3	−0.4	−0.5	−0.4
ASIA	DR	0.2	−0.1	0.5	0.4	0.1	0.0		
	EA	0.3	0.0	0.6	0.4	0.1	0.0	0.4	0.0
		A1		A2		B1		B2	
450		2040	2100	2040	2100	2040	2100	2040	2100
OECD	DR	−0.1	−0.2			−0.1	−0.3	−0.1	−0.2
	EA	−0.2	−0.3	−0.7	−1.3	−0.2	−0.3	−0.2	−0.3
EFSU	DR	0.0	−0.5			−0.2	−1.3	0.0	−0.5
	EA	−0.3	−0.5	−2.5	−3.0	−0.2	−1.3	−0.3	−0.5
ROW	DR	−0.1	−0.7			−0.2	−0.9	−0.1	−0.7
	EA	−0.2	−0.7	0.0	−1.6	−0.4	−1.0	−0.2	−0.7
ASIA	DR	0.3	−0.5			0.3	−0.1	0.3	−0.5
	EA	0.4	−0.4	1.9	0.0	0.3	−0.1	0.4	−0.4

The picture in A1 is rater similar to the one for A2 discussed above. Except that in the EA550 case the fluctuations are somewhat larger, but here also the developments of the carbonprice in the DR-cases are smoother than in the EA cases. Since in the beginning of the mitigation period baseline emissions in A1 are significantly higher than in A2, mid-term effects of early action strategy, before all regions entered an agreement, is less efficient. This also holds, but to a lesser extent in the B1 world. In B1 early action eads to carbon taxes that are by far too high in the early years, given the average price over the whole period.

In the A2 world delayed response with stabilization at a level of 450 ppmv is not possible. With early action the carbon price increases to 900 $/tC in 2100. For the other scenarios, delayed response is still an option with the considerable advantage of smoother price developments in the firts half of the 21^{st} century.

Summary and conclusions

This paper analyzes the economic impact of mitigation policies that lead to stabilization of CO_2 concentrations at levels of 550 and 450 ppmv, respectively. We successively use each of the four new IPCC scenarios as a baseline. In all cases we consider two different mitigation paths that lead to the same stable concentration in the long run. In one path, which we have called early action (EA), significant reductions are already realized at an early stage. In the other path, delayed response (DR), early mitigations are relatively modest, while mitigation rates are higher later on. The reductions relate to the use of fossil fuels only, but in the determination of the necessary mitigation rates the net land-use emissions, which differ between the IPCC scenarios, are taken into account. For all simulations we use WorldScan, a multiregion, multisector, dynamic equilibrium model of the world economy.

In the EA simulations it is assumed that the Annex B countries will comply with the Kyoto Protocol. After that, other regions will gradually enter a new agreement. We assume that in the new agreement the participating regions commit themselves to achieving a global target. This means that they will compensate for any carbon leakage to non-participating countries by additional CO_2 reductions. Insofar as the Kyoto Protocol falls short of providing for the necessary global restrictions, because of high baseline emissions in non-participating regions or because of leakage, this deficit is compensated for reducing admissible global emissions after the Kyoto Protocol. Full trading of emission permits is assumed between all participating countries.

This paper focuses on the difference between delayed response and early action. Two issues that are relevant in this comparison are extensively explored here. The first is the entrance of new regions into an agreement. Significant reductions during the period in which not all regions have entered the agreement are inefficient, because not all reduction options can be used. This inefficiency often shows as a decline in the emission price after a new region has entered the agreement. The second issue is the development of the emission price once all countries participate. The mitigation path is intertemporally efficient if the real emission price increases over time with a growth rate equal to the real interest rate. Because the dynamics of the emission price depend on which of the IPCC scenarios is chosen, on the ultimate concentration rate, and on the timing of the scenarios, all these elements determine the impact on global utility. The distribution of the income impacts over regions depends mainly on the regional assigned amounts agreed upon in the agreement.

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