

NOTA DI LAVORO

58.2009

How Harmful are Adaptation Restrictions

By **Kelly C. de Bruin**, Environmental
Economics and Natural Resources
Group, Wageningen University, The
Netherlands

Rob B. Dellink, Environmental
Economics and Natural Resources
Group, Wageningen University, The
Netherlands and Institute for
Environmental Studies, VU University
Amsterdam, The Netherlands

SUSTAINABLE DEVELOPMENT Series

Editor: Carlo Carraro

How Harmful are Adaptation Restrictions

By Kelly C. de Bruin, Environmental Economics and Natural Resources Group, Wageningen University, The Netherlands

Rob B. Dellink, Environmental Economics and Natural Resources Group, Wageningen University, The Netherlands and Institute for Environmental Studies, VU University Amsterdam, The Netherlands

Summary

The dominant assumption in economic models of climate policy remains that adaptation will be implemented in an optimal manner. There are, however, several reasons why optimal levels of adaptation may not be attainable. This paper investigates the effects of suboptimal levels of adaptation, i.e. adaptation restrictions, on the composition and level of climate change costs and on welfare. Several adaptation restrictions are identified and then simulated in a revised DICE model, extended with adaptation (AD-DICE). We find that especially substantial over-investment in adaptation can be very harmful due to sharply increasing marginal adaptation costs. Furthermore the potential of mitigation to offset suboptimal adaptation is investigated. When adaptation is not possible at extreme levels of climate change, it is cost-effective to use more stringent mitigation policies in order to keep climate change limited, thereby making adaptation possible. Furthermore not adjusting the optimal level of mitigation to these adaptation restrictions may double the costs of adaptation restrictions, and thus in general it is very harmful to ignore existing restrictions on adaptation when devising (efficient) climate policies.

Keywords: Integrated Assessment Modelling, Adaptation, Climate Change

JEL Classification: Q25, Q28

Address for correspondence:

Kelly C. de Bruin
Environmental Economics and Natural Resources Group
Wageningen University
Hollandseweg 1
6706KN Wageningen
The Netherlands
Phone: +31 317482362
Fax: +31 317484933
E-mail: kelly.debruin@wur.nl

How harmful are adaptation restrictions?

Kelly C. de Bruin^{1,2}, Rob B. Dellink^{2,3} .

¹ Corresponding author, Environmental Economics and Natural Resources Group, Wageningen University, Hollandseweg 1, 6706KN, Wageningen, The Netherlands. Telephone: + 31 317 48 23 62, Fax: + 31 317 48 49 33, email: kelly.debruin@wur.nl .

² Environmental Economics and Natural Resources Group, Wageningen University, The Netherlands

³ Institute for Environmental Studies, VU University Amsterdam, The Netherlands

Abstract

The dominant assumption in economic models of climate policy remains that adaptation will be implemented in an optimal manner. There are, however, several reasons why optimal levels of adaptation may not be attainable. This paper investigates the effects of suboptimal levels of adaptation, i.e. adaptation restrictions, on the composition and level of climate change costs and on welfare. Several adaptation restrictions are identified and then simulated in a revised DICE model, extended with adaptation (AD-DICE). We find that especially substantial over-investment in adaptation can be very harmful due to sharply increasing marginal adaptation costs. Furthermore the potential of mitigation to offset suboptimal adaptation is investigated. When adaptation is not possible at extreme levels of climate change, it is cost-effective to use more stringent mitigation policies in order to keep climate change limited, thereby making adaptation possible. Furthermore not adjusting the optimal level of mitigation to these adaptation restrictions may double the costs of adaptation restrictions, and thus in general it is very harmful to ignore existing restrictions on adaptation when devising (efficient) climate policies.

1 Introduction

Emissions of greenhouse gasses are changing our global climate, leading to damages worldwide. Adaptation can be a very powerful means of reducing the damages caused by climate change. Adaptation refers to adjustments in ecological, social or economic systems to moderate potential damages or to benefit from opportunities associated with climate change (Klein *et al.* 2001). Examples of adaptation are the building of dykes, the changing of crop types, and vaccinations against diseases such as malaria. It has been estimated that in some cases potential damages can be reduced by up to 80% (Mendelsohn 2000). The dominant assumption in economic models of climate policy remains that adaptation will be implemented in an optimal manner and in fact, most models only implicitly make this assumption by including adaptation into the estimate of damages (De Bruin *et al.*, 2009a). There is reason to believe, however, that adaptation will not be undertaken automatically or optimally. Several reasons why optimal adaptation levels may not be attainable have been identified in the literature, such as lack of information, or inertia in the decision making process. We refer to barriers or constraints resulting in suboptimal levels of adaptation as *adaptation restrictions*. These restrictions are the subject of investigation in this paper. There is a great gap in the literature regarding the effects of restrictions on adaptation. Where thousands of mitigation scenarios are considered with varying degrees of mitigation or concentration targets, consistent economic analysis of suboptimal adaptation is virtually absent. This is partly due to the fact that adaptation options are hard to quantify and compare with each other. Where mitigation has a clear common performance indicator, adaptation does not (Lecocq and Shalizi, 2007). There remains a large amount of uncertainty regarding climate change damages and how much of these are avoided through adaptation. In contrast to reality, our model (and essentially all deterministic models) assumes that there is a policy lever that can set some macroeconomic “level of adaptation”. In this paper, we investigate what the effects may be if this policy lever is not performing optimally, i.e. if the information on damages and adaptation costs is incorrect. We thus look at the consequences of

misspecifying adaptation. This can give policymakers insights into the uncertainties regarding adaptation policies.

In this paper we investigate what the effects of certain restrictions on adaptation are for the composition and level of climate change costs. We use an Integrated Assessment Model (IAM), namely AD-DICE to simulate different adaptation restrictions that could occur. AD-DICE is a recently developed (de Bruin et al., 2009a, and de Bruin et al., 2009b) extended version of the well-known DICE model (Nordhaus and Boyer 2001) that includes adaptation as a decision variable.

This paper attempts to answer several important questions. Firstly, what are the effects of different adaptation restrictions on the level and composition of climate change costs? Secondly, how do adaptation restriction affect the optimal mitigation policies, i.e. how do optimal mitigation paths change due to the various restrictions? Thirdly, and linked to the previous question, how can flexible mitigation policies compensate for reduced adaptation and how costly is a “naive” mitigation policy that disregards existing restrictions on adaptation?

This paper is structured as follows. The second section briefly describes the AD-DICE model we use in our analysis. The third section will introduce different restrictions identified in the literature and describe how these are simulated in the model. The fourth section discusses the results and the final section concludes.

2 The AD-DICE Model

For this analysis we use the AD-DICE model as introduced in de Bruin et al. (2009a). This model is based on the Dynamic Integrated model for Climate and the Economy (DICE) originally developed by Nordhaus (1994, 2007). DICE2007 was used to create AD-DICE2007, as described in detail in de Bruin et al. (2009b). AD-DICE is a global model and includes economic growth functions as well as geophysical functions. In the model, utility, based on discounted consumption, is maximised. In each time period, consumption and

savings/investment are endogenously chosen subject to available income, after the subtraction of the costs of climate change (residual damages, mitigation costs and adaptation costs). Climate change damages are represented by a damage function that depends on the temperature increase compared to 1900 levels. Mitigation decreases emissions per unit of output; the marginal costs of mitigation are decreasing over time and increasing with the magnitude of mitigation undertaken.

AD-DICE2007 adds adaptation as a control variable to DICE2007 as described in detail in de Bruin et al. (2009a) and briefly explained here. We define gross damages as the initial damages by climate change if no changes were to be made in ecological, social and economic systems. If these systems were to adapt to limit climate change damages, the damages would be lower. These “left-over” damages are referred to here as residual damages. Reducing gross damages, however, comes at a cost, i.e. the investment of resources in adaptation. These costs are referred to as adaptation costs. Thus, the net damages in DICE are the total of the residual damages and the adaptation costs. Furthermore the net damages in the DICE model are assumed to be the *optimal mix* of adaptation costs and residual damages. Thus the net damage function given in DICE is unravelled into residual damages and adaptation costs in AD-DICE, yielding the level of adaptation as a new policy variable.

Adaptation is given on a scale from 0 to 1, where 0 represents no adaptation: none of the gross climate change damages are decreased through adaptation. A value of 1 would mean that all gross climate change damages are avoided through adaptation. Thus, adaptation (denoted by P) is expressed as the fraction by which gross damages are reduced.

We assume that marginal adaptation costs increase at an increasing rate with the level of adaptation, as cheaper and more effective adaptation options will be applied first. The calibrated adaptation cost curve is represented in Figure 1.

The level of adaptation is chosen every time period (10 years). The adaptation in one time period does not affect damages in the next period, thus each decade the same problem is faced,

and the same trade-off holds. This implies that both the costs and benefits of adaptation are “instantaneous”, i.e. they fall in the same time period. The approach is consistent with the assumption that the majority of adaptation efforts will be *reactive*, rather than *anticipatory*. We leave an analysis with adaptation as a stock variable (which reflects anticipatory investments in adaptation capital, such as the building of sea walls) for future research. When optimal levels of adaptation are attainable, the results will stay unchanged as compared to DICE. The key innovation of the AD-DICE model is that it makes an analysis of suboptimal levels of adaptation possible. Thus, with this model we can control the level of adaptation to simulate restrictions or even completely exclude adaptation as an option for the sake of studying the effects of adaptation.

Insert Figure 1 here

3 Adaptation restrictions

This section examines different restrictions, limits and barriers to adaptation. There are many reasons why the optimal level of adaptation may not be attainable, many of which are linked to the magnitude of climate change (see for example, Klein et al., 2007, Chapter 17). This section discusses some of the key restrictions to adaptation, and “adaptation scenarios” are then constructed to simulate these restrictions in our Integrated Assessment Model framework. As adaptation can be restricted in several ways we have divided adaptation restrictions into four general categories. Each category will be discussed and some examples given per category. The scenarios associated with each category are given in Box 2. Note that the numerical results will depend on the exact specification of the restrictions, and therefore we simulate a range of possible specifications per scenario in Section 4.

3.1 Restriction on the level of adaptation costs

First of all, the amount of dollars that are spent on adaptation may be above or below what is optimal. For example lack of funding can form a significant barrier to adaptation. In this case the amount one can spend to avoid gross damages is limited. Many forms of adaptation need initial investments, and in many cases funds for these investments cannot be raised. This is often the case when large sums of money need to be invested in building adaptation options beforehand, i.e. before climate change occurs. One reason for a barrier to invest ex ante in adaptation is the option costs of investments: it is often very hard or impossible to reverse the decision to invest when new information becomes available. Policymakers therefore tend to be cautious in allocating funds when the level of future damages is uncertain. For example a government may not be able to raise the funds required to build a sea wall or invest in climate proofing infrastructure. Also investments in early warning systems or research and development may involve sums of money that are not available to policy makers. It may also be the case that even if policymakers have funds, adaptation options will have to compete with other options for the funds. For example, policymakers may also need to invest in mitigation, development, health care and so on.

This form of adaptation limitation is modelled by limiting the amounts of funds available for adaptation (i.e. adaptation costs) to a level below the optimal (scenario A1). Furthermore it may be the case that there is an over-investment in adaptation, where e.g. a government chooses to set its adaptation budget which turns out not to be optimal (due to among others a lack of proper information) or when international funds to support adaptation can be secured relatively easily. This may be due to for instance an understatement of the costs of the adaptation measure, for example maintenance costs of adaptation options such as sea walls may be underestimated. Overinvestment in adaptation may also be due to an overstatement of the benefits, for example one may overestimate the benefits of an early warning system by assuming that when in place people will respond to the warnings given. Budgets may also be based on other objectives or constraints than cost-benefit analysis. The total budget available

to finance adaptation may thus be greater than the optimal amount that should be allocated to adaptation. This is simulated in scenarios A2, where adaptation costs are set at levels above optimal.

3.2 Restrictions on the level of adaptation

We distinguish between the level of adaptation and the funds spent on adaptation to distinguish between the effects of uncertainty regarding the effectiveness of adaptation and uncertainty regarding the costs. The restriction given in section 3.1 provides insight into the effects of misspecifying the adaptation costs, whereas here we look at the effects of misspecifying the avoided damages and thus choosing an incorrect level of adaptation. Note, however, that restrictions on the level of adaptation expenditure and the level of adaptation are closely linked through the interactions in the adaptation cost curves. Nonetheless because of dynamic effects these are not exactly the same.

In this section, the actual level of adaptation (P) may be set at a suboptimal level, i.e. the fraction of gross damages that is prevented by adaptation is higher or lower than optimal. There are many reasons why this may be the case. One such reason is a lack of knowledge. There remains a lot of uncertainty regarding the exact level and impacts of climate change, making it hard to employ the correct amount of adaptation. Furthermore, the adaptation measures to be taken may not be known to the people concerned (Fankhauser et al, 1999). Moreover even if the (scientific) knowledge is available, there may be cognitive problems with the assimilation and understanding of this knowledge and the exact implications hereof. Also risk perception can limit adaptation, as individuals may not feel a sense of urgency (risk suppression), especially when simultaneously threatened by other risks. Other reasons for adaptation limitation in this sense are external factors such as pollution, conflict and disease which make ecosystems and people more vulnerable and less able to adapt. In the same sense risks may be amplified, i.e. exaggerated leading to over-investments in adaptation. Technological limits may also play a role, for example many developing regions may not have access to the technology needed to adapt; this is strongly linked to lack of funds

discussed above. Another barrier is of a political or policy nature: it may be the case that adaptation investment is not undertaken as the costs involved are high. Governments may postpone such projects as the benefits will not be reaped within the governing period. This involves bigger, long term projects such as sea walls, setting up insurance schemes *etc.* Furthermore, policymakers may find it morally unjust to accept certain forms of climate change adaptation or certain amounts of gross damages. This is also reflected in social and cultural barriers which may exist when e.g. considering migration as a needed form of adaptation. As often seen in disasters, people are not willing to leave their houses no matter the consequences, they have such ties to their homes that resettlement is not a socially viable option. Moreover certain crops have religious or cultural meaning, which limits the willingness to change crops.

Furthermore due to loss aversion, i.e. people strongly prefer avoiding losses to acquiring gain, people may be inclined to over-protect their assets, i.e. over-adapt. Moreover even though it is usually assumed that there are no externalities involved in adaptation decisions, this may not be the case, particularly on a smaller scale. When e.g. building sea walls against sea level rise or forests against soil erosions, the benefits accrue to numerous people. If cooperation cannot take place between these individuals than adaptation may be set at a level below what is optimal. Finally, myopia, i.e. short sightedness, may cause individuals not to consider the effects of climate change, thus restricting proactive adaptation.

The key aspect that links all these restrictions in terms of our model, is that the amount of gross damages avoided is either too high or too low as compared to the optimal level, i.e. the adaptation level is either too high or too low. Thus, these limitations are mimicked, albeit in a crude fashion, in scenarios A3, where the amount of adaptation is limited to a level below optimal and in A4, where adaptation is set at a level above optimal.

3.3 Restrictions on the timing of adaptation

A third issue that may constrain adaptation is inertia (cf. Burton, 2005): adaptation levels may not be able to change (quickly) over time. This may have many different reasons. Firstly, there may be the problem of delayed reaction. It might take considerable time to implement adaptation measures (Mendelsohn, 2000, and Berkhout et al., 2006). For example large scale adaptation projects such as sea wall construction need time to be set up and completed. As mentioned before cultural and social aspect may also cause barriers to adaptation and these involve slow adjustment phases. Societies need time to culturally accept that climate change is a problem and that certain adaptation measures are needed. Inertia in the political systems and prolonged negotiations on international coordination of climate policies will further delay the implementation of adaptation. Also a tendency to wait for improved information may postpone investments in adaptation. Scenario A5 reflects such inertia by assuming that adaptation will not be available up to a certain point time. Furthermore, it may be the case that adaptation knowledge needs to be acquired to adapt as the climate changes. Thus changing the level of adaptation may be restricted due to the rate at which one can build up adaptation knowledge. Adaptation in its proactive sense also brings with it the idea that a stock of adaptation is built up over time. This stock cannot, however, accumulate or deplete very quickly over time. A similar type of inertia refers to physical and ecological limits. For instance, ecosystems need time to adjust (Klein et al, 2007 Chapter 1). In scenario A6 we simulate this by restricting the change in adaptation levels over time, implying a gradual adjustment and preventing radical adjustment of adaptation policies.

3.4 Extreme climate change

Dramatic levels of climate change may also make it impossible to adapt (Nicholls and Tol, 2006, Tol et al 2006). At lower levels of climate change we are able to gradually change our society, economic structure *etc.* in such a way as to limit the damages caused by the changing

climate. If the climate changes to a too high degree, this will no longer be possible. A whole new society and economic structure will be needed, and for instance large ecosystems will be irreversibly disrupted and consequently these extreme damages cannot be adapted to within a reasonable time scale and will therefore have to be accepted. We simulate this by assuming that after a certain degree of temperature rise we can no longer adapt to climate change. Note that adaptation will be possible until the restriction threshold is reached. This is simulated in scenario A7.

Adaptation Scenarios

Limits on adaptation costs

A1 There is an upper limit on adaptation costs

A2 There is a lower limit on adaptation costs

Limits on adaptation

A3 There is an upper limit on adaptation

A4 There is a lower limit on adaptation

Rigidity of adaptation

A5 Adaptation cannot be implemented up to a certain time period

A6 Adaptation levels can only vary to a certain degree from one period to the next

Extreme climate change

A7 No adaptation is possible at higher levels of climate change

Box 1: Adaptation restrictions scenarios

4 Results

In this section we will present the results of our analysis. First the benchmark simulation where we assume optimal adaptation will briefly be presented; this provides the reference point for the evaluation of the various scenarios with adaptation restrictions. We then look at the effects of each restriction on the composition and level of climate change costs, assuming a responsive mitigation policy, i.e. optimal mitigation levels can be adjusted to accommodate the adaptation restrictions. We then show how the optimal mitigation path is affected by the

different restrictions. Finally we investigate the impact of naïve versus responsive mitigation policies for each scenario.

4.1 The Benchmark: optimal adaptation

We first present the case where there are no restrictions to adaptation. We call this the *optimal* case. All other scenarios include restrictions and thus are cases of constrained optimisation. Figure 2 shows the optimal path of adaptation over time without restrictions. As can be seen the level of adaptation increases steadily, due to increasing damage levels, and levels out at the end of the 22nd century when mitigation policies become more effective as a control option. Roughly speaking, in the first century it is optimal to avoid a quarter of all possible (gross) damages ($P \approx 0.25$) and afterwards optimal adaptation levels increase to one-third of gross damages ($P \approx 0.34$).

Insert Figure 2 here

The Net Present Value (NPV) of total climate change costs (the sum of adaptation costs, mitigation costs and residual damages), given as a fraction of output (GDP), are shown in Figure 3 for the optimal adaptation case and for the case where no adaptation is possible at all. The NPV of total climate change costs equals 9.5% of GDP when optimal adaptation is possible, and increases to 11% of GDP in the case of no adaptation. This shows the potential of adaptation to decrease climate change damages. By far the largest constituent part of climate costs are the residual damages, even in the case of optimal adaptation. This illustrates the trade-off that takes place at the margin: for every adaptation measure one has to weigh the additional benefits in terms of reduced damages with the additional costs of the measure. Thus, it is never optimal to completely eradicate all damages, and optimal climate policies are moderate in the use of both control options.

Figure 3 also illustrates the compensating effect mitigation can have. The case with no adaptation has much higher mitigation costs. Thus due to the lack of adaptation, damages

cannot be reduced after climate change occurs but, will need to be reduced through limiting climate change, i.e. through mitigation. In other words as adaptation decreases, the marginal value of mitigation increases, increasing the level of mitigation and decreasing the damages.

Insert Figure 3 here

4.2 *The components of climate change costs with restrictions*

Restrictions on the level of adaptation costs

In Figure 4 restrictions on the level of adaptation costs are examined. In the right-hand panel of the figure the *minimum* level of adaptation costs is restricted (scenario A2). At the left of the graph the lower limit is 0 and there is thus no binding restriction on adaptation; this mimics the optimal adaptation benchmark and thus results in a NPV of total climate change costs of 9.5% of GDP. Along the x-axis the lower limit is gradually increased and we see that the forced increase in adaptation leads to a slow decrease in residual damages as adaptation costs increase. Also mitigation costs decrease as mitigation becomes less beneficial when adaptation increases, i.e. the higher adaptation efforts partially replace mitigation efforts. The increase in adaptation costs, however, outweighs the decrease in residual damages and mitigation costs and overall climate change costs increase (as expected in a cost-minimisation framework: the switch towards more adaptation is forced and by definition involves a welfare cost).

The left panel of the figure shows the case where adaptation costs have an upper limit (scenario A1). Again, the left end of the graph reflects the unrestricted optimum. Here the right end of the x-axis shows the case where adaptation costs are completely limited, i.e. there is an upper limit of 0, resulting in total costs of 11% of GDP. As the limit is increased, i.e. the restriction loosened (moving from right to left in the graph), adaptation costs decrease while residual damages decrease at a stronger rate, increasing total climate change costs. One can see a sharp increase in climate change costs as the upper limit approaches 0, showing how powerful even small amounts spent on adaptation can be.

Insert Figure 4 here

Restrictions on the level of adaptation

Figure 5 looks at restrictions on the *level* of adaptation as opposed to the *costs* of adaptation in the previous subsection. As adaptation costs are an exponential function of the adaptation level the effects here are similar to Figure 4, but magnified. The right-hand panel shows the lower limit (scenario A4), which is first not binding (at the left end of the x-axis). After a lower limit of about 0.13 (the lowest level of adaptation in the optimal), however, the restriction becomes binding. Tightening this bound further implies that adaptation costs increase and mitigation costs and residual damages decrease but to a lesser degree. When the lower level restriction reaches 0.25 (a level above the optimum for the first decades; cf. Figure 2), adaptation costs increase exponentially resulting in large increases of total climate change costs. The total costs of climate change associated with this restriction can reach enormous amounts, increasing climate change costs by an order of magnitude. As can clearly be seen from comparing the left and right panels of the figure, setting an upper limit on adaptation (scenario A3) has far smaller effects than setting a lower limit. This analysis thus suggests that over-investing in adaptation can be more harmful than under-investing. This is due to the fact that adaptation costs grow steeply over the amount of adaptation applied. As seen in Figure 2 the optimal level of adaptation increases over time and the long-run optimal level of adaptation is one-third of gross damages ($p=0.33$). Over-adapting is better than not adapting at all if it is limited to this long-term optimal level of one-third of gross damages ($p=0.33$). Over-adapting in earlier periods, where the level of adaptation is lower, is less harmful than in later periods. Thus over estimating the amount of adaptation requirements within reason is still better than not adapting at all, especially in the short-run. Caution should be taken, however when undertaking any adaptation option available without carefully scrutinizing the associated costs and benefits, as this can cause large losses. Uncertainties concerning the exact amount of adaptation are not reason enough to postpone adaptation according to this analysis.

The left panel of the figure show the upper limit on adaptation. We observe that increasing the upper limit reduces residual damages significantly while adaptation costs remain limited. This again shows how powerful low levels of adaptation can be. Again notice that the costs of under-investing are lower than those of over-investing, compare the left and right panel.

Insert Figure 5 here

Restrictions on the timing and flexibility of adaptation

The left-hand panel of Figure 6 shows the case where adaptation is not possible up to a certain point in time (scenario A5). We see that after about 200 years of no adaptation, climate change costs have reached the same level as when no adaptation is possible. This result is induced by the positive discount rate, making future damages (and thus future adaptation efforts) less important in net present value terms. Furthermore, restricting adaptation for the first couple of decades affects the composition and level of climate change costs to a small degree, i.e. the graph is relatively “flat”. Two mechanisms are at work here. Firstly as time passes the degree to which the costs are discounted increases. Thus restrictions in earlier periods will *ceteris paribus* imply larger costs. Secondly, the global temperature also increases over time, increasing gross climate change damages and thus also increasing the effectiveness of adaptation. Thus in early periods when damages are low, adaptation will have lower benefits. The latter mechanism dominates in the first couple of decades.

The right-hand panel of Figure 6 shows the components of climate change costs when there is limited flexibility in adaptation over time (scenario A6). Adaptation cannot change more than a certain percentage from one time period to another, i.e. the growth rate of adaptation is restricted. As can be seen at the extreme right of the panel, losing intertemporal flexibility completely (when adaptation cannot change at all over time) increases total climate change costs somewhat, but mostly induces a different composition of these costs. When there is limited intertemporal flexibility it is optimal to choose a relatively low average rate of

adaptation (equalling 20% of gross damages throughout the model horizon). This is because when there is less flexibility you will need to over- and/or under-invest in adaptation in some periods. As we have seen before over-investing is more harmful than under-investing, therefore a lower level is chosen.

Insert Figure 6 here

Restrictions for extreme climate change

Figure 7 shows the effects of not being able to adapt at extreme levels of climate change (scenario A7). When the restrictions on adaptation come into place at lower levels of climate change (moving right in the figure, and becoming binding at 3.6 degrees), substantial increases in the level of mitigation are used to limit climate change. Responsive mitigation policies can keep climate change beneath the adaptation restriction threshold, thus keeping adaptation possible. When, however, adaptation is not possible after 2 degrees (or less) climate change, the additional costs of mitigation to keep climate change beneath 2 degrees outweigh the additional benefits of having adaptation as an option. Then, adaptation will only be possible for the first decades, until the climate threshold is reached (n.b. this change in time profile of adaptation cannot be directly inferred from the net present values in the figure). Surprisingly, the total climate change costs *decrease* when the restriction becomes binding but is not too severe. This counterintuitive result follows from the fact that we are presenting NPV of climate change costs while utility is optimised in the model. Changes in the time profile of adaptation, mitigation and damages may lead to lower NPV of climate costs, but come at a welfare cost. Utility losses from increased climate costs are larger for lower income levels, i.e. in the first decades. Since the higher mitigation costs are borne nearer in the future, and thus impact near-term low income levels, these costs decrease utility more than the lower residual damages and adaptation costs, even though the net present value of the climate costs are reduced. Thus there is a range of restrictions for which both utility and total climate costs are lower. At even more strict thresholds, the increase in mitigation costs becomes so large that total climate costs increase again.

Insert Figure 7 here

4.3 Comparing restrictions

We now compare the effects of restrictions directly with each other in terms of welfare to get an idea which restrictions are the most harmful. As welfare losses are a more accurate indicator of the harmfulness of the restrictions, in figure 8 the utility index levels (where utility is normalised to 100 for the benchmark case with optimal adaptation), are plotted for the different restrictions. We look at 3 levels of restrictions for each type of restriction: a relatively weak, a middle and a strong restriction. These various restrictions are described in Table 1.

Table 1: Description of various restriction levels for each scenario

Scenario	Weak restriction	Middle restriction	Strong restriction
A1	Adaptation costs upper limit is 100% of average optimal level	Adaptation costs upper limit is 75% of average optimal level	Adaptation costs upper limit is 50% of average optimal level
A2	Adaptation costs lower limit is 100% of average optimal level	Adaptation costs lower limit is 125% of average optimal level	Adaptation costs lower limit is 150% of average optimal level
A3	Adaptation upper limit is 100% of average optimal level	Adaptation upper limit is 75% of average optimal level	Adaptation upper limit is 50% of average optimal level
A4	Adaptation lower limit is 100% of average optimal level	Adaptation lower limit is 125% of average optimal level	Adaptation lower limit is 150% of average optimal level
A5	Adaptation is not possible in first 50 years	Adaptation is not possible in first 100 years	Adaptation is not possible in first 150 years
A6	Adaptation cannot vary by more than 10 percent from one period to the next	Adaptation cannot vary by more than 5 percent from one period to the next	Adaptation cannot vary at all one period to the next

A7	Adaptation is not possible after 3.3 degrees of climate change	Adaptation is not possible after 2.8 degrees of climate change	Adaptation is not possible after 2.3 degrees of climate change
----	--	--	--

Looking at Figure 8, we can clearly see that restrictions on the lower level of adaptation are most harmful. Thus over-investing in adaptation causes climate change costs to increase substantially. Also a lower limit on adaptation costs have higher effects than the other restrictions. Besides this, restricting adaptation in the short run also has relatively high welfare costs. This reflects both the positive discount rate and the fact that mitigation is less effective in the short run due to the time lag in the climate system and thus cannot compensate for the lower levels of adaptation. After this extreme climate change creates the highest welfare loss in this analysis.

Insert Figure 8 here

We next compare the weak restrictions for the various scenarios. An upper limit on the amount spent on adaptation (A1) does not affect welfare much in the weak case as many adaptation options have very low costs. The same holds for scenario A3 (upper limit on adaptation level) as most adaptation benefits are reaped at lower levels of adaptation. In scenario A6 (adaptation cannot vary over time) reducing the flexibility of adaptation to 10% per period is not very harmful as in the optimum not much more flexibility is needed (cf. Figure 2). In scenario A7 we see that making adaptation not possible after a 3.3 degree temperature change is hardly restrictive, as this temperature change is below the optimal temperature change only in a limited amount of time periods. Scenarios A2 and A4 mirror scenarios A1 and A3, respectively. The impact of these lower limits is, however, much more pronounced than the corresponding upper limit restrictions. Thus, the welfare costs associated with overinvesting in adaptation are much larger than those associated with under-investing. Scenario A5 is an intermediate case; a weak restriction of this kind will incur some welfare losses, but these are limited.

Obviously, for all scenarios a stricter restriction leads to higher welfare costs. There are however marked differences between the various scenarios. An upper limit on adaptation costs (A1) has small effects in all cases, the difference between the middle and strong restriction is higher than between the middle and weak, reflecting the decreasing benefits of adaptation costs. A lower limit on adaptation costs (A3) shows the same effect, again reflecting the decreasing benefits of adaptation costs. Similarly in scenario A3 (upper limit on adaptation level) the difference between the middle level restriction and the strong level restriction is large due to the exponential adaptation cost curve. The increasing disutility of restrictions is most obvious in scenario A4 (lower limit on adaptation costs), where the difference between the middle and strong restriction is more than twice that of the middle and weak. Whereas in the scenario A5 (adaptation is limited up to a certain time) the difference between the middle and weak levels of the restriction is large due to the discount rate effect explained above. In scenario A6 (limited flexibility over time) we see that there is a small difference between the middle and weak restriction reflecting the fact that adaptation does not vary much more than 5 % from period to period in the optimal case. In scenario A7 (extreme climate change), the large difference between middle and strong reflects the increasing costs of limiting climate change with mitigation investments. Though these levels of restrictions are somewhat arbitrary we can draw some general conclusions concerning welfare. Firstly, lower limits on adaptation can create great losses. Secondly, relatively small restrictions need not be very harmful. Finally restrictions may not be linear in how harmful they are. Beyond certain points restrictions can become extremely harmful very quickly, while for others small restrictions are harmful.

4.4 The effects on mitigation

The analysis in Sections 4.1 and 4.2 indicated that by changing the level of mitigation in response to limited adaptation, the increase in climate change costs can be limited. For instance, increased investments in mitigation are warranted when adaptation levels are too low, as the residual damages are larger and thus the productivity of mitigation increases. Here,

we further explore how mitigation responds to adaptation restrictions. We investigate how the optimal level of mitigation changes with different restriction.

Insert Figure 9 here

Figure 9 plots the optimal levels of mitigation in 2065 for different lower and upper limits on adaptation. In line with the observations made in Section 4.2, optimal mitigation levels are higher when adaptation is restricted below optimal and is lower when adaptation is restricted above optimal. We furthermore see that the effect of restricting adaptation on optimal mitigation seems more or less linear for the relevant range of restrictions. Finally, observe that the two lines do not touch each other, indicating that there is a (small) range where both lower and upper limit restrictions on adaptation are binding.

We furthermore look at the path of mitigation over time with various adaptation restriction scenarios. Figure 10 shows the mitigation path when there is an upper limit on adaptation. One can see that as time passes the level of extra mitigation due to the adaptation restriction increases slightly.

Insert Figure 10 here

Figure 11 shows mitigation paths when adaptation has a lower limit. The effects mirror those of the upper limit, except for the weak restriction. A ‘weak’ lower limit on adaptation will only affect mitigation in the short run, but after the 21st century the effect fades, as optimal adaptation levels increase over time and the restriction is no longer binding.

Insert Figure 11 here

Figure 12 shows the optimal mitigation paths when adaptation is not possible in the short run. As can be seen in the figure, mitigation is particularly higher in the earlier periods when the

restriction applies, but there is an adjustment period after the restriction is relieved where mitigation levels are still higher than in the unrestricted case. This adjustment period lasts for roughly 5 decades and reflects the large inertia in the climate system, and a preference (as expressed in the utility function) to avoid sudden shocks and opt for gradual adjustment. As the time period up to which adaptation is not possible increases, so does the period of extra mitigation.

Insert Figure 12 here

The adaptation scenarios that affect the path of mitigation the most are those with extreme climate change. Because adaptation cannot be used after a certain amount of climate change, mitigation is used to keep temperature below that threshold level. This involves huge amounts of mitigation in early periods. In figure 13 we can see that mitigation reaches almost maximum levels several decades earlier than in the case of optimal adaptation. For higher threshold levels the mitigation peak moves further away in time.

Insert Figure 13 here

4.5 Naive versus responsive mitigation

In our analysis up to now, we have assumed that there is full information about the restrictions of adaptation. This entails that the decision maker can adjust his level of other choice variables (consumption, investment and mitigation) to the lower level of adaptation, making the restriction less harmful. It may be the case, however, that the decision maker is not aware of these restrictions and assumes that adaptation is optimal, as commonly done when using IAMs to design policies. In this case there is no possibility to respond to the restrictions of adaptation and the levels of the other choice variables will not be adjusted to compensate for the limited adaptation. In this section we investigate what the effects are of not knowing that adaptation is limited. We focus on the choice variable mitigation as it is

most likely to be formulated *ex ante* (e.g. in an international agreement) and thus naïve with respect to adaptation. Furthermore both mitigation and adaptation are used to combat climate change and can substitute each other. Thus their optimal levels are strongly linked to each other. We re-run all our previous scenarios, but now keeping the level of mitigation fixed at the level that would be optimal if adaptation was optimal.

When mitigation cannot be used to limit the effects of restricted adaptation, this leads in all scenarios to higher climate change costs than when mitigation is responsive. In Figure 14, the total climate change costs are given for the various scenarios (with middle level restriction) for the cases of naïve mitigation and responsive mitigation. The effects of responsive mitigation are largest in the scenario A6 (inflexible adaptation), and to a lesser extent also in scenarios A7 (extreme climate change) and A2 (lower limit on adaptation costs). Given the relatively small welfare costs observed for scenario A6 and A7 when mitigation is assumed responsive, this shows that the interactions between adaptation and mitigation can be quite powerful. The more far-reaching conclusion is that an international agreement that essentially fixes both mitigation and adaptation levels for a prolonged period of time may be quite inefficient. Rather, leaving sufficient flexibility to vary either adaptation or mitigation levels may reduce climate costs substantially. In some cases, we see that using mitigation to respond to adaptation restrictions is hardly beneficial. This is the case in scenarios A1, A4 and A5. In A1 the upper level of adaptation costs is limited, and as discussed above this restriction does not affect welfare much. Because this restriction is not very harmful, mitigation does not have a large role to play in responding to the suboptimal adaptation. In scenario A4, where there is a lower limit on adaptation, responsive mitigation does not decrease the climate change costs. There are over-investments in adaptation and the appropriate response is thus to decrease the level of mitigation. The adaptation costs are constant over time, mitigation costs are decreased in all time periods, whereas the corresponding larger increase in residual damages is only in later periods. Thus applying responsive mitigation shifts climate change costs to later periods, which in this case essentially increases utility but does not decrease climate change costs. In

the case of adaptation limits up to a certain period (A5) mitigation again has very little effect in responding to the restriction as the restriction primarily affects the short run whereas mitigation efforts will take many decades to take effect. Thus the higher residual damages due to suboptimal adaptation in the short run, cannot be limited by mitigation.

Insert Figure 14 here

Figure 15 compares the climate costs components with and without information on adaptation restrictions for a range of values for the upper limit on adaptation (scenario A3). Total climate change costs may be half a percent-point of GDP higher when mitigation is not responsive to the adaptation restriction. We can furthermore see, as expected, that with full information mitigation costs are larger. From this analysis we can conclude that good mitigation policies can decrease the harmful effects of adaptation restrictions when there is knowledge of these restrictions.

Insert Figure 15 here

5 Final remarks

In this paper we look at the effects of adaptation restrictions. By adjusting our economic and social structures and activities to better fit the new climate we can substantially reduce potential damages of climate change. Virtually all economic models for climate change policy implicitly assume that optimal adaptation is possible and will be implemented. This means that all possible adaptation measures can be employed to the level at which their marginal benefits equals their marginal costs. There are many reasons to believe, however, that such “optimal” adaptation is not possible. Through lack of knowledge there may be over- or under-

investment, funds for adaptation may be limited and adaptation may not be possible at extreme climate change. These are just a few examples of why adaptation may be restricted.

This paper firstly investigated how different adaptation restrictions affect the level of total climate change costs (the sum of adaptation costs, mitigation costs and residual damages). In this analysis, restrictions on the level of adaptation itself are most harmful. Particularly substantial over-adapting may increase the climate change costs to a high degree. When adaptation is not possible at higher levels of climate change or in the short-run, damages can also be increased significantly. Furthermore, rigidity i.e. not having intertemporal flexibility in setting your adaptation levels increases costs of climate change.

Secondly, this paper finds that having knowledge about the restrictions of adaptation and adjusting mitigation policies accordingly can be a powerful way to keep climate change costs low. When the restrictions are not taken into account when designing mitigation policies, adaptation restrictions become up to twice as harmful in terms of increased climate change costs. Integrated Assessment Models that are used to design mitigation policies nearly always assume optimal adaptation. Such an approach can be quite harmful when restrictions on adaptation are prominent, as empirical research suggests (cf. Fankhauser, 2000). This is especially the case when adaptation is restricted at higher levels of climate change and when adaptation is rigid over time.

Thirdly, this paper finds that the mitigation paths are very different with the various restrictions. Compensating for adaptation restrictions by altering mitigation paths will therefore only be beneficial if the policymaker understands the restriction he is facing. This warrants more research in the exact adaptation capabilities.

Fourthly, from an adaptation policy perspective this paper gives insight into the effects of misspecifying adaptation costs and benefits. Uncertainties regarding adaptation are large, and there are no clear policy levers to influence the macroeconomic level of adaptation, or even to measure an overall level of adaptation efforts and the corresponding avoided damages. Policymakers are somewhat in the dark when attempting to set adaptation policies. This paper shows the effects of these uncertainties. We see that in general reasonably sized deviations

from the optimum have small effects, indicating that adaptation policies that are not optimal will most likely still be beneficial.

Fifthly, from the perspective of mitigation policy making, policy makers now form mitigation policies based on an unwarranted assumption of optimal adaptation, and adjusting this assumption will lead to more effective mitigation policies.

There are several caveats and limitations to this study. Firstly this analysis is based on the AD-DICE model and has the same limitations as that model, and as the DICE model on which it is constructed. DICE and AD-DICE do not include certain important issues such as uncertainty and irreversibility. Moreover, the model assumes perfectly functioning markets and one aggregate impact function, rather than making a distinction between different sectors. In some sectors, adaptation is relatively easy. In other sectors, it is more difficult. More detailed modelling of adaptation would also allow for a distinction between different restrictions and their exact effects. Furthermore, a single region model is used. Like sectors, different countries may have a qualitatively different response to climate change, and adaptation and adaptation restrictions may be very different. Nonetheless, de Bruin et al. (2009b) show that a global, single-sector model functions well as a first approximation of the effects that are likely to arise in a multiregional context.

It is also assumed that the adaptation in one time period does not affect damages in the next period, thus each decade the same problem is faced, and the same trade-off holds. This implies that both the costs and benefits of adaptation are “instantaneous”, i.e. they fall in the same time period. Adaptation will however in many cases also have time-lags in costs and benefits. Examples of such measures are building seawalls and early warning systems. While such time-lags may have influence on the interactions between adaptation and mitigation, we feel it is less relevant for an investigation into the (macro-)economic effects of adaptation restrictions *per se* and leave this issue for future research.

Finally the restrictions we study are imposed exogenously and we do not model the causes of the restrictions directly, but limit ourselves to specifying scenarios for their likely impact on adaptation. To understand the full effects of certain restrictions the underlying causes for

suboptimal adaptation would need to be modelled explicitly. Clearly, such an elaborate analysis would imply a major enlargement in terms of model specification and especially data requirements (for instance, it is not clear at all how a lack of information can be included consistently in the analysis). The current paper therefore provides a useful bridge between the overly simplistic models of optimal adaptation and more detailed but less general models of adaptation.

References

- Berkhout, F., J. Hertin and D.M. Gann, 2006: Learning to adapt: organisational adaptation to climate change impacts. *Climatic Change*, 78, 135-156.
- Burton, I. and Lim, B.: 2005, 'Achieving adequate adaptation in agriculture', *Clim. Change* **70**, 191–200.
- De Bruin K, R. Dellink, and R. Tol (2009a), AD-DICE: an implementation of adaptation in the DICE model. *Climatic Change*, forthcoming.
<http://www.springerlink.com/content/b27481357t876238/fulltext.pdf>.
- De Bruin, K., R. Dellink and S. Agrawala (2009b), Modeling of Adaptation Costs and Benefits. OECD Environment Directorate Working Paper, forthcoming.
- Fankhauser, S., J. Smith and R. Tol (1999), Weathering climate change: some simple rules to guide adaptation decisions, *Ecological Economics* (30) (1999), pp. 67–68.
- Klein et al. (2001) Adaptation to Climate Change in the Context of Sustainable Development and Equity, in *Climate Change 2001, impacts adaptation and vulnerability*.
- Klein, R. et al. (2007) Adaptation to Climate Change in the Context of Sustainable Development and Equity, IPCC (2007b), *op.*, Fourth Assessment Report: <http://www.ipcc.ch/activity/ar.htm#ar4>.
- Lecocq, F. and Z. Shalizi (2007). Balancing Expenditures on Mitigation of and Adaptation to Climate Change: An Exploration of Issues Relevant to Developing Countries. World Bank Policy Research Working Paper No. 4299 Available at SSRN: <http://ssrn.com/abstract=1004841>
- Mendelsohn, R. (2000) Efficient adaptation to climate change. *Climatic Change* 45: 583-600.

- Nicholls, R.J. and R.S.J. Tol, 2006: Impacts and responses to sea-level rise: A global analysis of the SRES scenarios over the 21st Century. *Philos. T. Roy. Soc. A*, 364, 1073-1095.
- Tol, R.S.J, M. Bohn, T.E. Downing, M. Guillerminet, E. Hizi, R. Kasprow, K. Lonsdale, C. Mays, R.J. Nicholls, A.A. Olsthoorn, G. Pfeiffer, M. Poumadere, F.L.
- Nordhaus, W.D. (1994). *Managing the Global Commons: The Economics of the Greenhouse Effect*. MIT Press, Cambridge, MA.
- Nordhaus, W.D., Boyer, J (2000) *Warming the World: Economic Models of Global Warming*. MIT Press, Cambridge, MA.
- Nordhaus, W.D., (2007). *A Question of Balance: Economic Modeling of Global Warming*. Yale University Press. http://nordhaus.econ.yale.edu/Balance_2nd_proofs.pdf

NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI

Fondazione Eni Enrico Mattei Working Paper Series

Our Note di Lavoro are available on the Internet at the following addresses:

<http://www.feem.it/Feem/Pub/Publications/WPapers/default.htm>

<http://www.ssrn.com/link/feem.html>

<http://www.repec.org>

<http://agecon.lib.umn.edu>

<http://www.bepress.com/feem/>

NOTE DI LAVORO PUBLISHED IN 2009

SD	1.2009	Michael Hoel: Bush Meets Hotelling: Effects of Improved Renewable Energy Technology on Greenhouse Gas Emissions
SD	2.2009	Abay Mulatu, Reyer Gerlagh, Dan Rigby and Ada Wossink: Environmental Regulation and Industry Location
SD	3.2009	Anna Alberini, Stefania Tonin and Margherita Turvani: Rates of Time Preferences for Saving Lives in the Hazardous Waste Site Context
SD	4.2009	Elena Ojea, Paulo A.L.D. Nunes and Maria Loureiro: Mapping of Forest Biodiversity Values: A Plural Perspective
SD	5.2009	Xavier Pautrel : Macroeconomic Implications of Demography for the Environment: A Life-Cycle Perspective
IM	6.2009	Andrew Ellul, Marco Pagano and Fausto Panunzi: Inheritance Law and Investment in Family Firms
IM	7.2009	Luigi Zingales: The Future of Securities Regulation
SD	8.2009	Carlo Carraro, Emanuele Massetti and Lea Nicita: How Does Climate Policy Affect Technical Change? An Analysis of the Direction and Pace of Technical Progress in a Climate-Economy Model
SD	9.2009	William K. Jaeger: The Welfare Effects of Environmental Taxation
SD	10.2009	Aude Pommeret and Fabien Prieur: Double Irreversibility and Environmental Policy Design
SD	11.2009	Massimiliano Mazzanti and Anna Montini: Regional and Sector Environmental Efficiency Empirical Evidence from Structural Shift-share Analysis of NAMEA data
SD	12.2009	A. Chiabai, C. M. Travisi, H. Ding, A. Markandya and P.A.L.D Nunes: Economic Valuation of Forest Ecosystem Services: Methodology and Monetary Estimates
SD	13.2009	Andrea Bigano, Mariaester Cassinelli, Fabio Sfera, Lisa Guarrera, Sohbeth Karbuz, Manfred Hafner, Anil Markandya and Ståle Navrud: The External Cost of European Crude Oil Imports
SD	14.2009	Valentina Bosetti, Carlo Carraro, Romain Duval, Alessandra Sgobbi and Massimo Tavoni: The Role of R&D and Technology Diffusion in Climate Change Mitigation: New Perspectives Using the Witch Model
IM	15.2009	Andrea Beltratti, Marianna Caccavaio and Bernardo Bortolotti: Stock Prices in a Speculative Market: The Chinese Split-Share Reform
GC	16.2009	Angelo Antoci, Fabio Sabatini and Mauro Sodini: The Fragility of Social Capital
SD	17.2009	Alexander Golub, Sabine Fuss, Jana Szolgayova and Michael Obersteiner: Effects of Low-cost Offsets on Energy Investment – New Perspectives on REDD –
SD	18.2009	Enrica De Cian: Factor-Augmenting Technical Change: An Empirical Assessment
SD	19.2009	Irene Valsecchi: Non-Uniqueness of Equilibria in One-Shot Games of Strategic Communication
SD	20.2009	Dimitra Vouvakis and Anastasios Xepapadeas: Total Factor Productivity Growth when Factors of Production Generate Environmental Externalities
SD	21.2009	Giulia Macagno, Maria Loureiro, Paulo A.L.D. Nunes and Richard Tol: Assessing the Impact of Biodiversity on Tourism Flows: A model for Tourist Behaviour and its Policy Implications
IM	22.2009	Bernardo Bortolotti, Veljko Fotak, William Megginson and William Miracky: Sovereign Wealth Fund Investment Patterns and Performance
IM	23.2009	Cesare Dosi and Michele Moretto: Auctioning Monopoly Franchises: Award Criteria and Service Launch Requirements
SD	24.2009	Andrea Bastianin: Modelling Asymmetric Dependence Using Copula Functions: An application to Value-at-Risk in the Energy Sector
IM	25.2009	Shai Bernstein, Josh Lerner and Antoinette Schoar: The Investment Strategies of Sovereign Wealth Funds
SD	26.2009	Marc Germain, Henry Tulkens and Alphonse Magnus: Dynamic Core-Theoretic Cooperation in a Two-Dimensional International Environmental Model
IM	27.2009	Frank Partnoy: Overdependence on Credit Ratings Was a Primary Cause of the Crisis
SD	28.2009	Frank H. Page Jr and Myrna H. Wooders (Ixxv): Endogenous Network Dynamics
SD	29.2009	Caterina Calsamiglia, Guillaume Haeringer and Flip Klijn (Ixxv): Constrained School Choice: An Experimental Study
SD	30.2009	Gilles Grandjean, Ana Mauleon and Vincent Vannetelbosch (Ixxv): Connections Among Farsighted Agents
SD	31.2009	Antonio Nicoló and Carmelo Rodríguez Álvarez (Ixxv): Feasibility Constraints and Protective Behavior in Efficient Kidney Exchange
SD	32.2009	Rahmi İlkiliç (Ixxv): Cournot Competition on a Network of Markets and Firms
SD	33.2009	Luca Dall'Asta, Paolo Pin and Abolfazl Ramezani (Ixxv): Optimal Equilibria of the Best Shot Game
SD	34.2009	Edoardo Gallo (Ixxv): Small World Networks with Segregation Patterns and Brokers
SD	35.2009	Benjamin Golub and Matthew O. Jackson (Ixxv): How Homophily Affects Learning and Diffusion in Networks

SD	36.2009	Markus Kinaterder (lxxxv): Team Formation in a Network
SD	37.2009	Constanza Fosco and Friederike Mengel (lxxxv): Cooperation through Imitation and Exclusion in Networks
SD	38.2009	Berno Buechel and Tim Hellmann (lxxxv): Under-connected and Over-connected Networks
SD	39.2009	Alexey Kushnir (lxxxv): Matching Markets with Signals
SD	40.2009	Alessandro Tavoni (lxxxv): Incorporating Fairness Motives into the Impulse Balance Equilibrium and Quantal Response Equilibrium Concepts: An Application to 2x2 Games
SD	41.2009	Steven J. Brams and D. Marc Kilgour (lxxxv): Kingmakers and Leaders in Coalition Formation
SD	42.2009	Dotan Persitz (lxxxv): Power in the Heterogeneous Connections Model: The Emergence of Core-Periphery Networks
SD	43.2009	Fabio Eboli, Ramiro Parrado, Roberto Roson: Climate Change Feedback on Economic Growth: Explorations with a Dynamic General Equilibrium Mode
GC	44.2009	Fabio Sabatini: Does Social Capital Create Trust? Evidence from a Community of Entrepreneurs
SD	45.2009	ZhongXiang Zhang: Is it Fair to Treat China as a Christmas Tree to Hang Everybody's Complaints? Putting its Own Energy Saving into Perspective
SD	46.2009	Eftichios S. Sartzetakis, Anastasios Xepapadeas and Emmanuel Petrakis: The Role of Information Provision as a Policy Instrument to Supplement Environmental Taxes: Empowering Consumers to Choose Optimally
SD	47.2009	Jean-François Caulier, Ana Mauleon and Vincent Vannetelbosch: Contractually Stable Networks
GC	48.2009	Massimiliano Mazzanti, Susanna Mancinelli, Giovanni Ponti and Nora Piva: Education, Reputation or Network? Evidence from Italy on Migrant Workers Employability
SD	49.2009	William Brock and Anastasios Xepapadeas: General Pattern Formation in Recursive Dynamical Systems Models in Economics
SD	50.2009	Giovanni Marin and Massimiliano Mazzanti: Emissions Trends and Labour Productivity Dynamics Sector Analyses of De-coupling/Recoupling on a 1990-2005 Namea
SD	51.2009	Yoshio Kamijo and Ryo Kawasaki (lxxxv): Dynamics, Stability, and Foresight in the Shapley-Scarf Housing Market
IM	52.2009	Laura Poddi and Sergio Vergalli: Does Corporate Social Responsibility Affect the Performance of Firms?
SD	53.2009	Valentina Bosetti, Carlo Carraro and Massimo Tavoni: Climate Change Mitigation Strategies in Fast-Growing Countries: The Benefits of Early Action
GC	54.2009	Alireza Naghavi and Gianmarco I.P. Ottaviano: Firm Heterogeneity, Contract Enforcement, and the Industry Dynamics of Offshoring
IM	55.2009	Giacomo Calzolari and Carlo Scarpa: On Regulation and Competition: Pros and Cons of a Diversified Monopolist
SD	56.2009	Valentina Bosetti, Ruben Lubowski and Alexander Golub and Anil Markandya: Linking Reduced Deforestation and a Global Carbon Market: Impacts on Costs, Financial Flows, and Technological Innovation
IM	57.2009	Emmanuel Farhi and Jean Tirole: Collective Moral Hazard, Maturity Mismatch and Systemic Bailouts
SD	58.2009	Kelly C. de Bruin and Rob B. Dellink: How Harmful are Adaptation Restrictions

(lxxxv) This paper has been presented at the 14th Coalition Theory Network Workshop held in Maastricht, The Netherlands, on 23-24 January 2009 and organised by the Maastricht University CTN group (Department of Economics, http://www.feem-web.it/ctn/12d_maa.php).