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Catastrophic Risk, Precautionary Abatement, and Adaptation Transfers

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Summary

This paper contributes to the normative literature on mitigation and adaptation by framing the question of their optimal policy balance in the context of catastrophic climate risk. The analysis uses the WITCH integrated assessment model with a module that models the endogenous risk of experiencing an economic catastrophe if temperature increases above a certain threshold. We find that the risk of a catastrophic outcome would encourage countries to reduce emissions even in the absence of a coordinated global agreement on climate change and to realign the policy balance from adaptation toward more mitigation. Our analysis also shows that adaptation transfers from and strategic unilateral commitments to adaptation in developed countries appear to provide weak incentives for reducing emissions in developing countries. Thus our first conclusion is that precautionary considerations, rather than the ability to reduce smooth damage increases, justify mitigation as a fundamental policy option. Accordingly, adaptation is needed to cope with the non-catastrophic damages that countries would fail to address with mitigation. Our second conclusion is that supporting adaptation in developing countries should be considered primarily as a means for ensuring equity or improving development, and very marginally as a mitigation incentive.

The research leading to these results has received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme (FP7/2007-2013) under the REA grant agreement n° 298436 (DYNAMIC), from the Italian Ministry of Education, University and Research and the Italian Ministry of Environment, Land and Sea under the GEMINA project, and from the European Investment Bank under the tender "Adaptation to Climate Change in the EU and its Neighbours".

Keywords: Climate Change, Mitigation, Adaptation, Climate Risk, Integrated Assessment
JEL Classification: C61, D58, Q5

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1. Introduction

As emissions and temperature increase, there have been mounting concerns about the potentially adverse impacts triggered by the trespassing of thresholds and tipping points, which risk causing irreversible changes in the various components of the climate system. Adapting to possible catastrophic events can be very costly, while they can be prevented more effectively by directly addressing the source of the problem, GHG emissions (Pearce et al., 1996; Posner, 2004; Guillerminet and Tol, 2008; Lenton et al,. 2008).

The scientific literature has explored how uncertainty and tipping points can motivate abatement even in the absence of coordinated climate policy architectures. Keller et al. (2004) show that climate thresholds can render significant abatement a utility-maximizing choice. More recently Lemoine and Trager, (2012) and Cai et al. (2013) suggest that mitigation becomes desirable if it reduces the probability of triggering tipping points, and that catastrophic climate risk can induce precautionary abatement (Gjerde et al., 1999; Roughgarden and Schneider, 1999; Yohe et al., 2004). This literature has explored the potential for precautionary abatement on a global scale and without considering the interactions with adaptation policies to climate change, an issue of growing interest also in the policy arena. Parties to the Convention on Climate Change have acknowledged the importance of adaptation ever since, and the Warsaw Outcomes have perceived the need to deal with the losses and damages that are already being caused by climate change. Only a few theoretical contributions have analyzed how adaptation and mitigation can control the risk of climate change (Kane and Shogren, 2000; Ingham et al., 2005, 2007). These studies determine the theoretical conditions under which adaptation and mitigation are complements or substitutes and assess their optimal combination. Results are generally mixed and depend on a broad range of assumptions, including the marginal productivity of either strategy as well as the interaction triggered by direct and indirect effects. The theoretical frameworks proposed in those studies justify both complementarity and substitutability between the two strategies, indicating that possible solutions can be found in many different combinations. What can actually be the optimal mix (cost-efficient and/or cost-effective) between mitigation and adaptation has been investigated by means of empirical approaches based on Integrated Assessment Models (IAMs) (Agrawala et al., 2010; de Bruin et al., 2009; Bahn et al., 2010; Bosello et al., 2011). In a non-cooperative setting, mitigation remains negligible because of its public good nature. Conversely, since adaptation entails almost fully appropriable benefits, it is basically the only climate change strategy being pursued. In a cooperative setting, Bosello et al. (2010) show that adaptation crowds out mitigation, but that analysis does not consider uncertainty and irreversibility.

This paper contributes to the literature on the interlinkages between adaptation, mitigation, and precautionary abatement by developing a modelling framework that integrates mitigation, adaptation, and catastrophic climate change risk into a macroeconomic, hybrid IAM. We assume that countries do not sign a global agreement on emission reduction, but they perceive the risk that future global warming could cause heavy economic losses which adaptation would be unable to prevent. We define this outcome as a catastrophe, though it remains a reversible event, as it does not cause structural changes in the system (Wright and Erickson, 2003). We use the WITCH Integrated Assessment Model (Bosetti et al., 2006; Bosetti et al., 2009), augmented with endogenous adaptation investments (AD-WITCH, thereafter for brevity), as developed in Bosello et al. (2013), and Agrawala et al. (2010, 2011), and explore how the risk of a catastrophe influences the optimal mix between adaptation and mitigation policies, and to what extent the possibility of adapting to climate change weakens the motivation for precautionary abatement. We calibrate the probability of the catastrophic outcome by using the estimates from expert elicitation studies of the likelihood of large-impact, low-probability events (Lenton et al., 2008; Kriegler et al., 2009).

Using this framework, we analyse how the risk of a catastrophe shapes the combination between adaptation and mitigation in countries with different damages and emission reduction costs when there is no international coordination on mitigation policy. The second part of the paper explores the potential of adaptation transfers and unilateral adaptation commitments by OECD countries for inducing greater abatement in non-OECD countries. This research question is inspired by three theoretical studies showing that adaptation can in fact influence the incentive to participate in climate change agreements. Barrett (2010) demonstrates that if more adaptation implies less mitigation, adaptation can increase participation in a mitigation agreement in a non-cooperative theoretical game set-up. The increase occurs because adaptation, by reducing the need to mitigate, pushes the environmental effectiveness of the agreement closer to the non-cooperative effort. Adaptation enhances participation by voiding the agreement of its mitigation content. In a non-cooperative setting, Buob and Stephan (2011) show that, in principle, developed countries could provide adaptation funding to developing countries to foster their abatement efforts as well as global mitigation, if and only if mitigation and adaptation are complements. They also show however, that under strict complementarity it would be economically rational for developed countries to fund adaptation in developing regions only if in exchange the developed regions lowered abatement. But realistically, developing countries will not be willing to accept such an agreement. Auerswald et al. (2011) show that in a leader-follower game, early adaptation commitment from a group of countries can be used as a credible signal of low willingness to mitigate. This would induce other countries to increase their abatement effort. Total abatement effort can then increase or decrease according to the shape of the respective reaction functions. Marrouch and Chauduri (2011) offer an interesting perspective which links Barrett (2010) and Auerswald et al. (2011). They show that, at given conditions, the presence of adaptation can bolster participation in an abatement coalition. Moreover, if the coalition acts as a Stackelberg leader, total emissions can decrease. The intuition is the following. If a country can also adapt to climate damages, it may respond to higher emissions from another country with higher adaptation and lower abatement. On the one hand, this lowers the incentive to free ride on a mitigation agreement and consequently could increase participation. On the other hand, as emission reaction curves are no longer orthogonal, the abatement coalition may increase its abatement effort to lower the emissions in non-participatory countries. This paper evaluates the empirical relevance of the aforementioned theoretical results by investigating i) whether financial transfers for supporting adaptation investments in less developed countries can be used as leverage to increase their abatement effort and ii) whether a unilateral commitment to adaptation can induce other countries to emit less.

The remainder of the paper is organized as follows. Section 2 describes WITCH and how catastrophic risk is modelled. Section 3 presents and discusses the results, and Section 4 concludes.

2. An Integrated Modelling Framework

2.1 Adaptation and non-catastrophic damages in the WITCH model

The AD-WITCH is a Ramsey-Cass-Koopmans growth model with a breakdown of the energy sector into different uses and technologies. The economic system is fully integrated with a simple climate module that translates carbon emissions produced from the use of fossil fuels to radiative forcing and temperature increase. Regional reduced-form damage functions link the global temperature increase above pre-industrial levels to changes in regional gross domestic product (GDP). The model equilibrium is the solution of a non-cooperative game among twelve macroeconomic regions. Agents behave strategically with respect to major economic decision variables including adaptation and energy investments. A forward-looking social planner in each macroeconomic region maximizes his inter-temporal welfare by optimally choosing investments in a generic final good, energy technologies, energy R&D, and adaptation, subject to the budget constraint. The resulting Nash equilibrium is a constrained optimum, which however does not internalize the environmental and technology externalities globally, but only within the boundary of each given region.[1]

At the core of the adaptation module introduced in the WITCH model there are three control variables that broadly represent different forms of adaptation strategies. For the sake of simplicity, the numerous adaptive responses that are actually available in the real world have been aggregated into three categories: building specific adaptive capacity, anticipatory adaptation, and reactive adaptation. Specific adaptive capacity accounts for the investments dedicated to facilitate adaptation activities, such as improvement of meteorological services, early warning systems, the development of climate modelling and impact assessments. Anticipatory adaptation describes measures requiring that a stock of defensive capital be operational before damage materializes, such as the construction of dikes. Reactive adaptation are actions implemented when or right after climatic impacts effectively occur, for the purpose of dealing with any residual damages that anticipatory adaptation or mitigation has been unable to obviate. Examples of these strategies include change in the use of air conditioning or hospitalization and use of health services (see Agrawala et al. 2010, 2011 for more details). We assume that a set of constant elasticity of substitution (CES) production functions aggregates the three different adaptation strategies into an adaptation service nest that reduces the damages caused by global warming as described in Agrawala et al. (2010, 2011).

While the previous versions of the AD-WITCH model have calibrated the regional damage functions on Nordhaus and Boyer (2000), this study uses more recent estimates of climate change impacts. Estimates of the market impacts are from the ClimateCost project (Bosello et al. 2012), which has quantified the physical and economic impacts of climate change on the rise in sea-levels, energy demand, agricultural productivity, tourism flows, net primary productivity of forests, floods, and reduced work capacity due to thermal discomfort resulting from a high-warming scenario. The economic impacts used as input for the regional damages used in this study have been quantified using the recursive-dynamic computable general equilibrium (CGE) model ICES (Eboli et al. 2010). As a consequence, the market impacts represented in the present version of the AD-WITCH model are net of autonomous (or market-driven) adaptation. Non-market impacts include the potential impacts of climate change on ecosystems and health, and they have been monetized by using a willingness-to-pay approach as described in the Appendix.

[1] For further insights on the treatment of technical change in the WITCH model see Bosetti et al. (2006), Bosetti et al. (2009), De Cian et al. (2012). The WITCH model is continually updated, and the latest versions of the models have been used in a number of publications listed on the model website, witchmodel.org.

2.2 Risk of a catastrophic economic outcome

We introduce an endogenous probability of a catastrophic event by linking the probability of a very large loss in GDP to the increase in global average temperature above pre-industrial levels. The temperature increase is also endogenous to the model, which has a simple climate module linking forcing to emissions, which are determined by the energy mix chosen by the regions in the model. Catastrophic risk affects economic activities directly and utility indirectly. Decision makers, namely the regional social planners, interact strategically and do not cooperate on greenhouse gas emission reduction. They maximize their regional social welfare, defined over the expected realization of output actually available for consumption, which also depends on the size and distribution of the climate change damages. For each region *n*, at each point in time *t*, Eq. (1) describes the interaction between the expected damage net of adaptation (*CCDA*) and the total value of economic production (*YGROSS*):

$$YNET_{n,t} = \frac{1}{1 + CCDA_{n,t}} YGROSS_{n,t} \tag{1}$$

The expected damage in Eq. (2), *CCDA,* is a weighted sum of the non-catastrophic component (*CCD*) and of the catastrophic (*CCR*) realization. Weights are given by the probability of the catastrophic occurrence, $p(T_t)$:

$$CCDA_{n,t} = [1 - p(T_t)] \frac{1}{1 + ADAPT_{n,t}} CCD_{n,t} + p(T_t)\, CCR_{n,t} \tag{2}$$

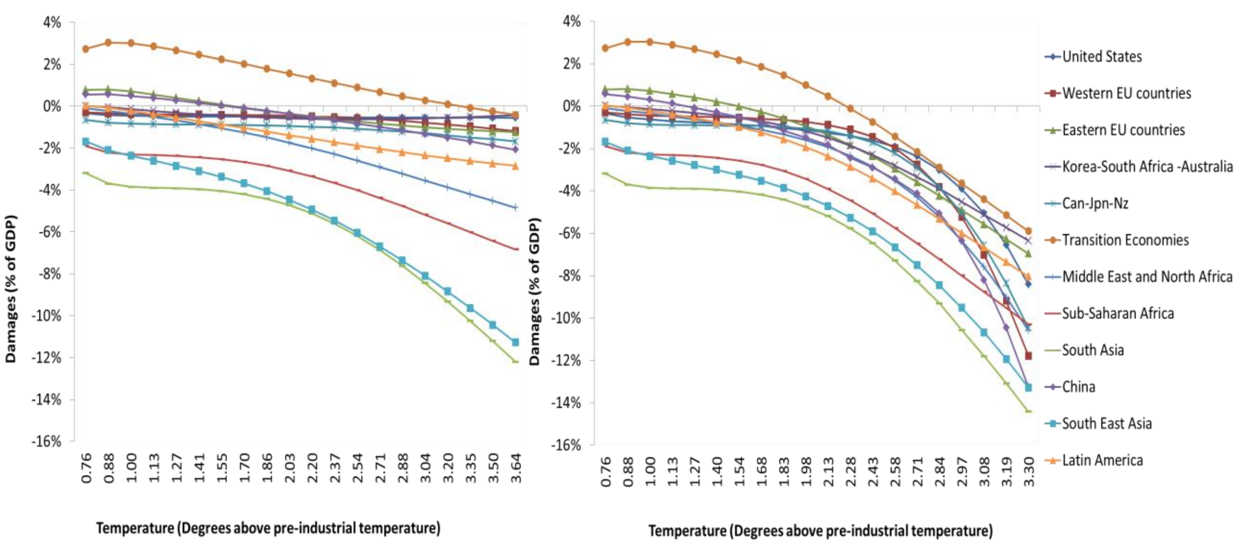
We assume that the catastrophic component of the expected damage in Eq. (2), *CCR*, is associated with 25% GDP loss in each region, when such catastrophe occurs. The non-catastrophic component is the standard damage described above. We assume that a catastrophe is outside the system coping range and therefore adaptation (*ADAPT*) only reduces the non-catastrophic damage component. The risk of the catastrophic economic loss can be reduced by controlling GHG emissions. Following Gjerde et al (1999), Bosello and Moretto (1999), and Bosello and Chen (2011), we describe the probability of the catastrophic event, $p(T_t)$ by a hazard rate that follows a Weibull distribution:

$$p(T_t) = 1 - \frac{1}{e^{\varphi\eta(T_t - T_0)^{1.5}}} \tag{3}$$

where $T_t - T_0$ is the temperature increase relative to the pre-industrial level, T_0. Eq. (3) states that keeping the atmospheric temperature at the T_0 level would eliminate the possibility of catastrophic events. The probability of a catastrophe grows when temperature increases above T_0. Each regional social planner can control the probability of the catastrophic event by decarbonizing the energy portfolio through appropriate investment in clean technologies, thus reducing emissions and temperature increase. In our cost-benefit analysis, the benefit of endogenously controlling temperature comes thus at the cost of lower short-run consumption. Optimizing agents choose the optimal balance of the two (see Section 3).

The relationship between temperature increase and catastrophic probability in Eq. (3) depends on the two parameters φ and η. The parameter η takes the value of 2.5 to maintain the convexity of the hazard rate function. The parameter φ is calibrated such that the probability of a catastrophic occurrence is 16% when the global average temperature increase hits 3°C above the pre-industrial period ($\varphi=0.021$). This value has been suggested by a number of recent studies that have elicited the opinion of experts about the likelihood of catastrophic outcomes or of the trespassing of tipping points (Lenton et al., 2008, Kriegler et al., 2009). In the model this occurs at the end of the century. Figure 1, left Panel depicts damages if the catastrophic event does not occur, while Figure 1, right Panel shows the expected damage in the presence of the catastrophic risk. Even if the catastrophic economic outcome is a 25% loss of regional GDP, the expected damages in 2100 vary between 6% and 14% of GDP.

Figure 1: Regional climate change damages in the AD-WITCH model without (left) and expected damage with (right) catastrophic risk



3. Results

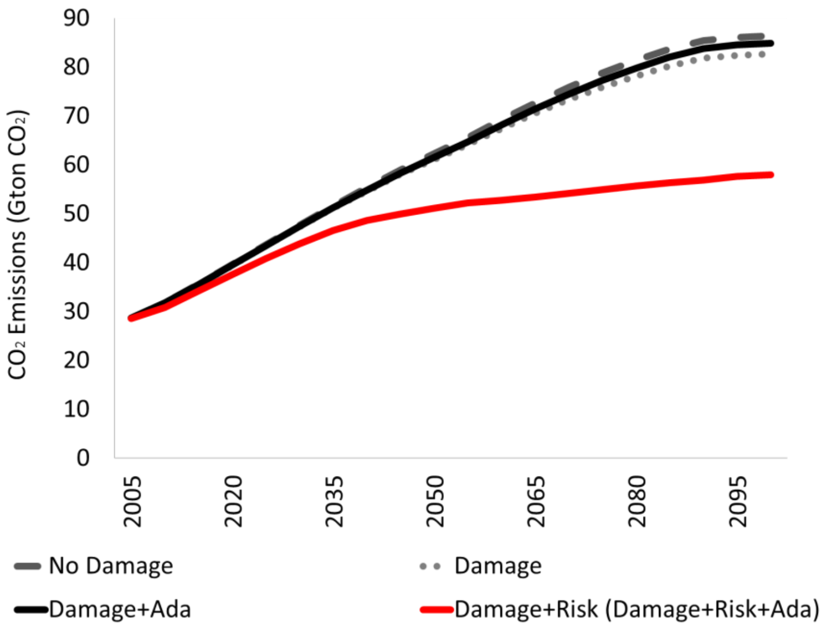
3.1 Mitigation and adaptation under climate risk

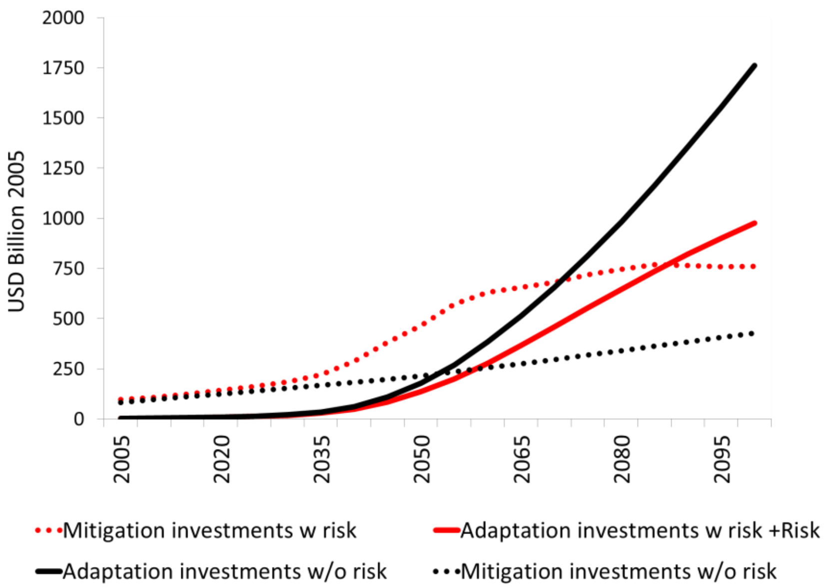
In a world without catastrophic risk and with no global agreement on climate policy, our numerical results confirm the findings of the theoretical and empirical literature discussed in the introduction. Figure 2, top panel, shows that the mitigation effort that would result from the cost-benefit analysis of each optimizing region is negligible and that the free-riding incentive dominates. Conversely, adaptation contributes almost entirely to damage reduction, especially after 2050. When regional planners internalize the risk of a catastrophic damage in their optimization choice, substantive abatement becomes optimal even in the absence of a global agreement. The perception of the risk of a catastrophe weakens free-riding incentives (Figure 2, top panel, red line). The optimal Nash abatement almost stabilizes CO_2 emissions, flattening after 2050 and dropping to 58 as opposed to 84 $GtCO_2$ in 2100. The resulting global emission profile is incidentally close to what a weak commitment to climate policy, such as a continuation of the Copenhagen Pledges throughout the century, would imply (Luderer et al. 2013).

Figure 2 (bottom panel) shows the allocation of investments between mitigation and adaptation. When regions perceive the risk of a climate catastrophe, increasing resources are shifted to mitigation, more precisely to investments in energy saving R&D, renewable energy sources, nuclear, and coal with Integrated Gasification Combined Cycle (IGCC) with carbon capture and sequestration (CCS). Globally, adaptation investments are reduced relative to the no-risk case because of the damage-reducing effect of higher mitigation and of the binding budget constraint. When internalizing the risk of large losses, mitigation investments become the main item throughout the century and adaptation reaches a budget allocation equal to that of mitigation in 2085 rather than in 2050.

The introduction of catastrophic risk modifies the size of the crowding-out effect between mitigation and adaptation. Adaptation reduces cumulative abatement by 48% and 1% throughout the century without and with risk, respectively. Mitigation reduces cumulative adaptation expenditure by 1% and 4.5% without and with risk, respectively. Some degree of reciprocal crowding-out between the two strategies remains because part of the mitigation effort still responds to the smooth climate-change damage component and continues to be influenced by adaptation measures, and vice versa.

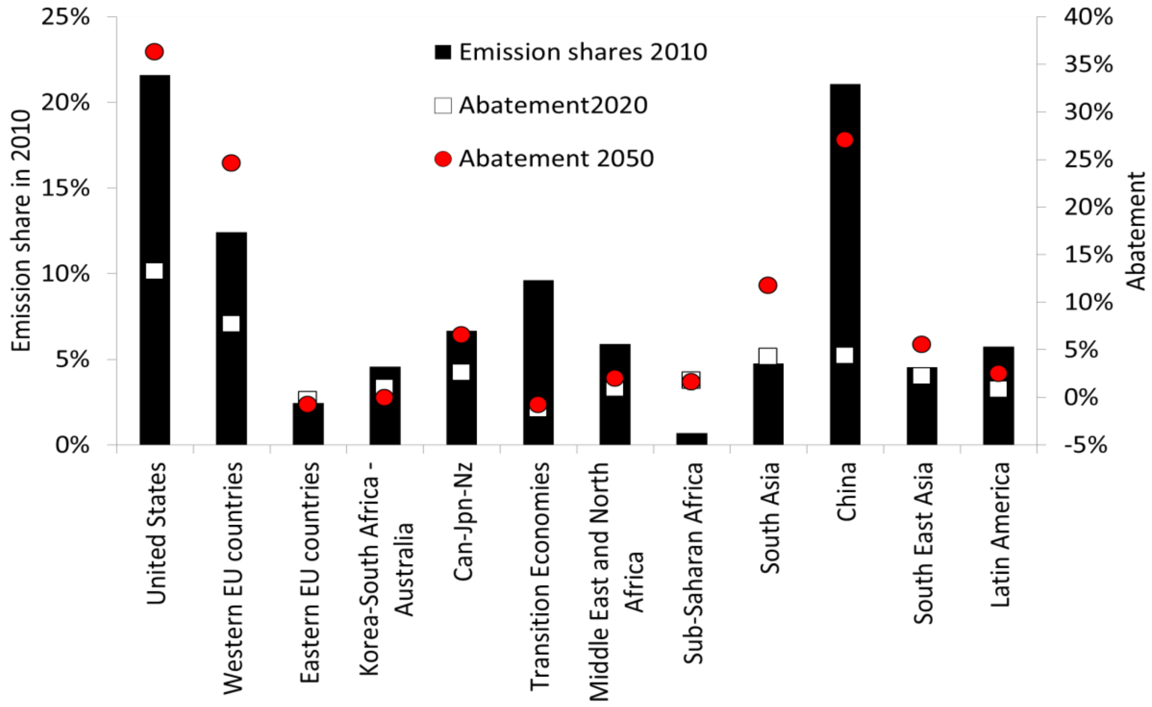
Figure 2. Impact of catastrophic risk on CO2 emissions (top panel), adaptation and mitigation investments (bottom panel), including wind, solar, nuclear, and coal IGCC with CCS power, energy efficiency R&D, and breakthrough R&D.





The introduction of the catastrophic risk induces a different distribution of the emission reduction effort. Given the non-cooperative setting, abatement is mostly driven by the effective ability of a country to reduce average global temperature, which directly controls the catastrophic risk. Figure 3 shows that maximum reduction of emissions occurs in major emitters in regard to the share of CO_2 emissions in 2010 (black bar). Greater abatement occurs in China, the United States, Western Europe, Canada-Japan-New Zealand and South Asia, whereas moderate reductions occur in the Middle East, North Africa and Latin America. As stated, the free-riding incentive is weakened but does not disappear completely. When the catastrophic risk augments mitigation, adaptation decreases in response to the reduced country-specific damage, though to a different extent in different countries. For instance, Europe increases its cumulative mitigation expenditure throughout the century by roughly the 57% and reduces its cumulative adaptation expenditure by the 34%. Conversely, the Middle East and North Africa increase their mitigation expenditures by the 5.8%, but still reduce their adaptation expenditures the 28%, since they also enjoy the climate benefits caused by the greater emission reductions effected in other countries.

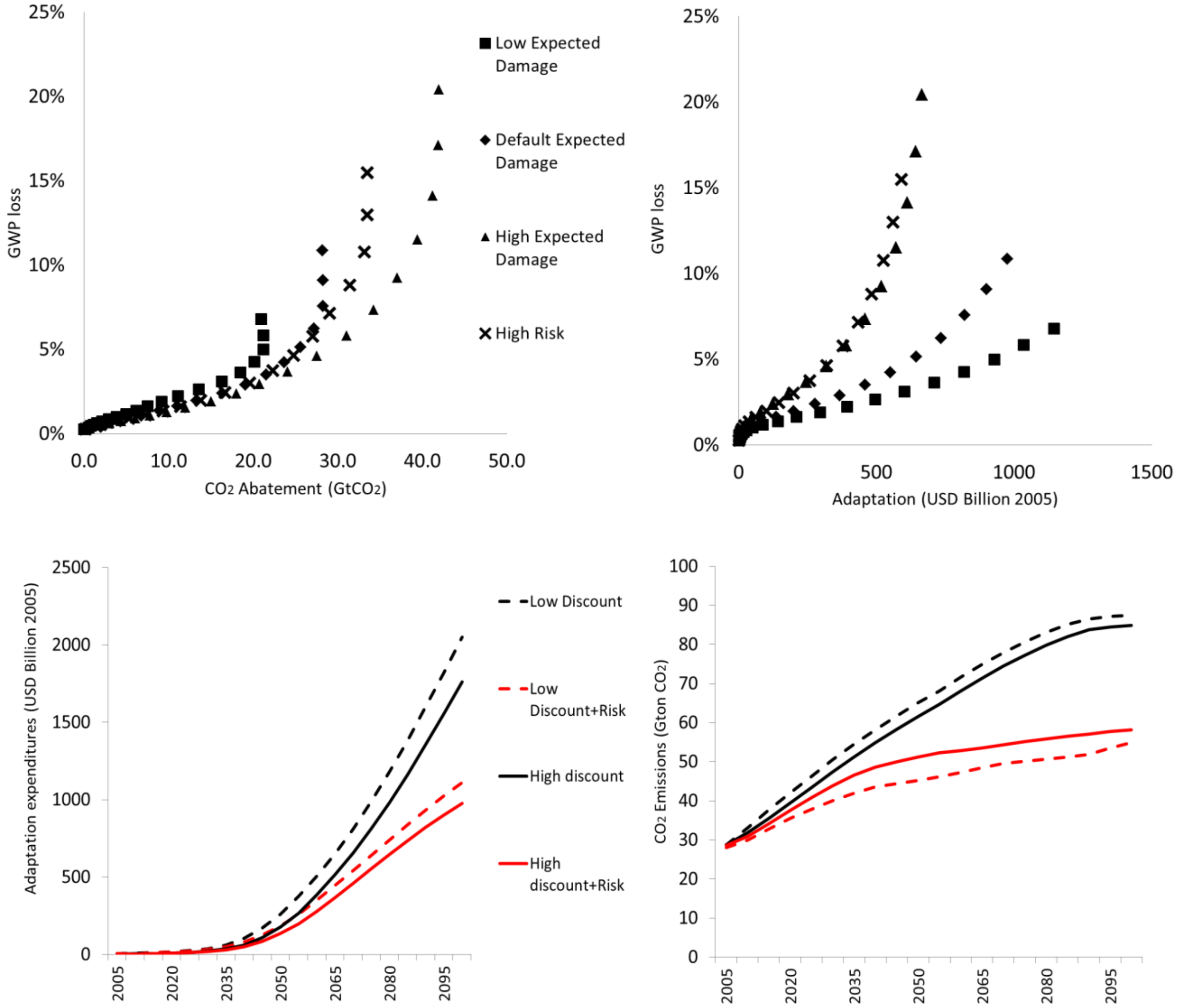
Figure 3. Regional abatement in 2020 and 2050 relative to the baseline without risk. Black bars show the 2010 regional emission shares.



In summary, in a world characterised by smooth and reversible climate damages, if countries can play strategically, mitigation is a marginal option. Although viable and welfare-improving, it is less cost-effective than adaptation and an exclusively residual strategy. Conversely, in a world with catastrophic risk, it becomes a key policy variable, irrespectively of its ability to reduce non-catastrophic damage, since it is the only strategy capable of reducing the probability of a catastrophic outcome.

Figure 4 examines the sensitivity of the trade-off between adaptation and mitigation to the discount rate, the catastrophic risk, and the catastrophic penalty. We find that, once catastrophic risk is introduced, lower discounting unambiguously implies more abatement and adaptation expenditure (Figure 4, lower panel). This result is particularly interesting, since, while standard in a cooperative framework, it is not obvious without cooperation. For instance, Bosetti et al. (2011) show that in a non-cooperative framework, changing assumptions on discounting have a limited influence on the optimal level of mitigation action. This is a direct consequence of the inability of individual regions to internalize the environmental externality. If it is true that a lower discount rate should favour mitigation as future damages gain in importance, at the same time it favours future consumption levels and thus emissions. Without the internalization of the negative externality caused by emissions, the two effects almost perfectly balance out, or the second even prevails. The higher probability associated with the catastrophic event or a higher catastrophic damage (High risk and high expected damage cases in Figure 4, upper panel) increases abatement while adaptation is crowded out. When the risk of a catastrophic event increases, the crowding-out of abatement induced by adaptation is in effect reduced to zero.

Figure 4. Top panels: sensitivity analysis of the size of catastrophic impact (low, default, and high expected damage) and of the size of catastrophic risk (high risk). Lower panels: sensitivity analysis of the discount rate.



3.2 Mitigation and adaptation: a strategic analysis

In a world with catastrophic risk, precautionary abatement becomes an optimal strategy even in the absence of an international global agreement. This section investigates whether a group of countries (OECD) could use adaptation transfers or unilateral commitment to adaptation expenditure as a strategic leverage to foster mitigation in another group of countries (the non-

OECD). We maintain the non-cooperative setting[2] and assume that only OECD countries perceive and react to catastrophic risk. Non-OECD countries react only to the non-catastrophic damage component. The idea is to simulate a situation in which OECD countries are not only inclined to strong domestic abatement, but are also willing to foster abatement in non-OECD by financing adaptation needs in non-OECD areas.

3.2.1 Unconditional adaptation transfers

In our first experiment we assume that the OECD countries finance all adaptation needs of non-OECD countries. The lump-sum transfer is divided among donors proportionally to the GDP share relative to the OECD total. The major donors are the USA and Western Europe, while the larger recipients are the Middle East and North Africa, Southeast Asia and Sub-Saharan Africa. The transfer grows over time, as adaptation needs in less developed countries rapidly increase after 2040, and peaks at 100 billion USD between 2055 and 2060.

Adaptation funds almost completely replace domestic adaptation in receiving countries, which in fact only slightly increases. Investments in physical capital and in mitigation activities (energy saving R&D and renewable technologies) are basically unaffected. The additional available budget is almost totally used for consumption. Discounted consumption throughout the century increases by 0.084% (486 billion USD) relative to the case with no transfers (Table 1). In other words, mitigation behaves quasi-linearly in non-OECD preferences. In our particular setting, when countries start from a non-cooperative optimum, the adaptation transfer does not crowd out domestic mitigation, but does crowd out domestic adaptation, even when adaptation and mitigation are substitutes[3]. Higher consumption and production implies slightly higher emissions (Figure 5), which cause slightly more damages and hence lower GDP (-0.00042%).

3.2.2 Conditional adaptation transfers and mitigation transfer

Transferred adaptation funds can only foster mitigation if a conditionality clause is included, stating that the adaptation fund will be delivered only in the presence of a binding, detectable mitigation commitment from the non-OECD countries. We consider the same adaptation transfer, but now non-OECD countries are required to invest a fraction of the transfer in renewable energy. We

[2] In fact, to highlight even clearer results, as compared to section 2, both the probability and the catastrophic penalties have been increased respectively to 50% and 99% of GDP, for a temperature increase of 3.6°C.

[3] A potentially different situation would be one in which, because of an adaptive capacity deficit and a resource constraint, developing countries implement sub-optimal (lower than needed) adaptation levels. In this case foreign and domestic adaptation can be expected to be additional. This issue, which will imply a change in the model setting, will be explored in future research.

analyse the implications of small and large transfers, and consider a range of fractions between 1/20 and 1, which changes the deal into a transfer for mitigation. In terms of welfare, which in AD-WITCH is a function of consumption, non-OECD countries would always benefit from this exchange, which covers their optimal adaptation costs. However, the conditionality clause reduces the consumption gain, relative to the unconditional transfer (Table 1). The condition imposes a sub-optimal level of renewable investments, which is larger than what non-OECD countries would optimally choose. Does this conditional transfer succeed in cutting emissions? The overall impact of the transfer onto non-OECD emissions is almost negligible, though it moves in the expected direction (Figure 5, left Panel).

The international financing of adaptation does not appear to be the most effective way of buying emission reduction in non-OECD countries. A legitimate question then is whether OECD countries could achieve better results by directly financing abatement in the non-OECD. Let us assume this would be possible, leaving aside for the sake of experiment all the transaction costs potentially involved. This is then considered in the last column (Transfer Mitigation in Table 1), where we assume that the transfer is directly invested by the OECD to support investment in renewable energy in the non-OECD. The non-OECD region experiences an increase in its investments in renewables from a current 12 billion USD to 66 billion USD in 2050, from a current 49 billion USD to 539 billion USD in 2100. Emission reduction in non-OECD is effectively higher, but still small (-69 $GtCO_2$ or -1.4% throughout the century). Furthermore, because of the strategic interaction between OECD and non-OECD countries, OECD countries compensate the additional reduction by the non-OECD countries with more emissions (relative to the unconditional transfer).

In terms of discounted consumption, although non-OECD countries would still be better off with a mitigation transfer than without, they would prefer a support to adaptation (Table 1). Indeed, the benefit from additional abatement is a public good, whereas the benefit from adaptation is fully appropriable. Moreover, adaptation funding is replacing what non-OECD countries would have done anyway, while mitigation funding is financing an additional sub-optimal effort. Interestingly, results are qualitatively different when GDP instead of consumption is considered, the major difference across the two indicators being obviously represented by investment patterns. Table 1 shows that adaptation transfers including a conditionality clause on mitigation are GDP-improving for both OECD and non-OECD countries. This positive (albeit small) effect is stronger the stronger the conditionality on investment in adaptation. It is triggered by the fact that in the WITCH model the cost of renewable energy is endogenous and falls with global Learning-By-Doing. Hence, the additional investments undertaken by non-OECD countries reduce the technology cost in the OECD countries as well, which benefit from the associated Learning-By-Doing externality. Furthermore, the slight reduction in global emissions caused by the transfer helps to mitigate climate change damages. All in all, this leads to small GDP gain relative to the no-transfer case (+0.0415% in non-OECD and +0.0265% globally). However, these benefits are not sufficient to compensate the consumption loss compared to the unconditional transfer.

Our results suggest partly countervailing messages. On the one hand, albeit in principle adaptation funding can be used by developed countries as a leverage to induce more mitigation in non-OECD countries, the effectiveness of this strategy is very limited. Here a clear mismatch of scales is highlighted: adaptation costs are much smaller than those required to decarbonize non-OECD economic systems. On the other hand, although the transfer would reduce consumption possibilities in the OECD, it would have a positive impact on their GDP, the more so when the transfer goes to financing mitigation (Table 1).

3.2.3 Unilateral commitment to adaptation in OECD countries

As a further experiment, we examine the effect of adaptation implemented in OECD countries on mitigation and adaptation in non-OECD countries. Following the ideas put forward by Auerswald et al. (2011) and Marrouch and Chaudury (2011) we want to test whether adaptation can be used as a strategic signal or leverage by a group of countries to induce more abatement in other countries. Specifically, we explore a unilateral increase in adaptation expenditure in the OECD between 10% and 200%, starting today (Figure 5, right panel). Since adaptation and mitigation are substitutes, abatement in OECD regions decreases. Cumulated OECD emissions increase by between 11.5 and 147 $MtCO_2$. As a reaction, abatement in non-OECD regions slightly increases and cumulated emissions decline by between 0.50 and 38.50 $MtCO_2$. Adaptation in non-OECD regions remains basically unchanged. Our results provide evidence to support Auerswald's intuition and confute Marrouch and Chauduri's point. Even if countries can adapt, a lower mitigation effort by one country or a group of them is compensated by more abatement outside the group. However, for this size of transfers, the effect on overall abatement is negative, and cumulative emissions on a global scale increase. This necessitates some caution regarding the practical possibility of using adaptation as a credible signal of low mitigation commitment in one country to induce mitigation in other countries.

Figure 5: CO2 cumulated emissions 2005-2100 in OECD (red bar) and non-OECD (grey bar) as difference relative to the no transfer case. The left panel shows the cases with unconditional and conditional transfers from the OECD countries to the non-OECD ones. The right panel shows the cases with a unilateral increase in adaptation in OECD countries between 10% and 200%.

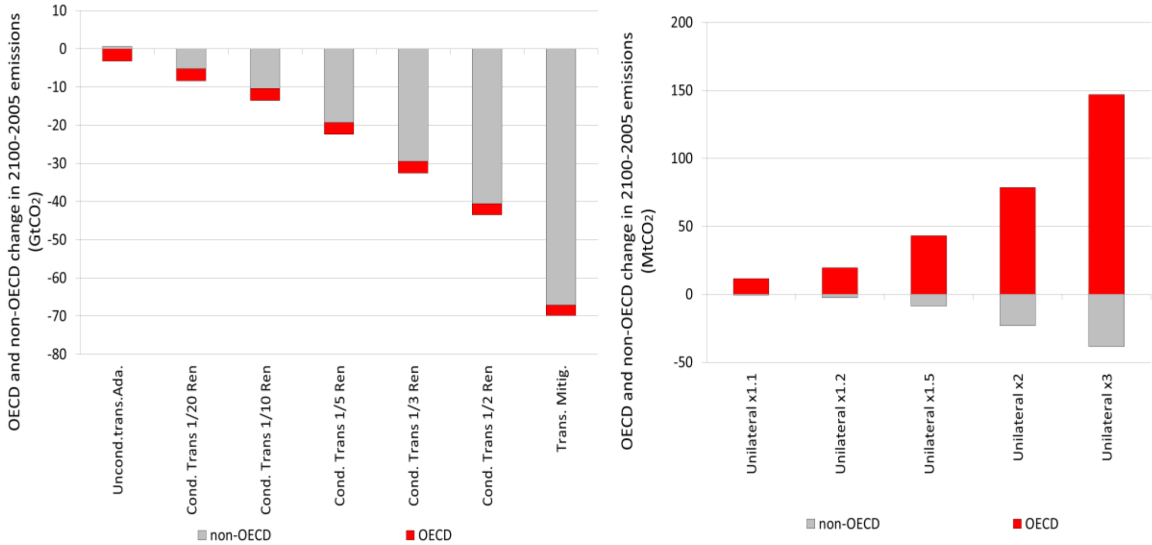


Table 1: GDP and consumption change relative to the no transfer case. Percentage point difference and USD Billion (Net Present Value over the century).

Percentage point difference (%) w.r.t. no Transfer		Unconditional Transfer Adaptation	Conditional Transfer 1/20 Renewables	Conditional Transfer 1/10 Renewables	Conditional Transfer 1/5 Renewables	Conditional Transfer 1/3 Renewables	Conditional Transfer 1/2 Renewables	Transfer Mitigation
GDP	World	0.0002%	0.0022%	0.0041%	0.0073%	0.0112%	0.0156%	0.0268%
	OECD	-0.0001%	0.0014%	0.0028%	0.0050%	0.0078%	0.0109%	0.0186%
	Non-OECD	-0.0004%	0.0028%	0.0056%	0.0107%	0.0167%	0.0236%	0.0415%
Consumption	World	-0.004%	-0.003%	-0.002%	-0.002%	-0.002%	-0.003%	-0.009%
	OECD	-0.0563%	-0.0542%	-0.0524%	-0.0493%	-0.0457%	-0.0416%	-0.0318%
	Non-OECD	0.0840%	0.0832%	0.0816%	0.0775%	0.0709%	0.0611%	0.0270%
USD Billion Difference w.r.t. no Transfer		**Unconditional Transfer Adaptation**	**Conditional Transfer 1/20 Renewables**	**Conditional Transfer 1/10 Renewables**	**Conditional Transfer 1/5 Renewables**	**Conditional Transfer 1/3 Renewables**	**Conditional Transfer 1/2 Renewables**	**Transfer Mitigation**
GDP	World	0.73	9.06	16.58	29.64	45.22	62.98	108.12
	OECD	-0.22	3.44	6.86	12.44	19.27	27.00	46.08
	Non-OECD	-3.00	19.72	39.68	76.12	118.71	167.65	294.94
Consumption	World	-11.42	-8.31	-6.54	-4.91	-5.28	-8.43	-28.13
	OECD	-109.92	-105.92	-102.45	-96.30	-89.20	-81.33	-62.10
	Non-OECD	485.65	480.63	471.61	448.08	409.59	353.30	155.78

Note: World and non-OECD figures do not include Transition Economies since in the simulation they neither receive nor give adaptation funds, being positively affected by climate change.

4. Conclusions

This paper contributes to the normative literature on mitigation and adaptation by framing the question of the optimal policy balance between these two strategies in the context of catastrophic climate risk. The analysis uses an integrated assessment model that accounts for the endogenous link between the probability of experiencing a catastrophic climate-related event and average global temperature increase.

The presence of catastrophic risk weakens the incentive to free ride and induces substantial mitigation effort even in a non-cooperative setting in which global cooperation on climate does not succeed. The policy balance is realigned from adaptation toward more mitigation, and the responsiveness of mitigation to changes in adaptation decreases. Compared to a world without climate catastrophes, risk reduces the substitutability between adaptation and mitigation because only mitigation can manage the catastrophic probability. Nonetheless, the strategic complementarity between mitigation and adaptation does not vanish. Even though adaptation does not influence the catastrophic probability, it is still a necessary complement to mitigation in addressing the residual damage not accommodated by the decentralized mitigation effort. Similarly, the trade-off between mitigation and adaptation persists: when adaptation increases, the need to mitigate the smooth part of climate change damages decreases. Therefore, even though greatly reduced, there remains a minimal crowding-out of mitigation by adaptation. These findings suggest that in a world characterized by catastrophic risk, mitigation is a key policy variable, as it is the only strategy able to limit the catastrophic risk. Mitigation should be justified on the basis of precautionary considerations and only marginally considering its capacity to reduce marginally increasing climate change damages. Adaptation should tackle the damage component that weak mitigation fails to accommodate because of the free-riding incentives.

Given these results, we then investigate whether unilateral or partial commitment to adaptation can be used as a leverage to increase abatement effort in third countries, always in a non-cooperative setting. We find that if the OECD countries financed all adaptation needs of non-OECD, such adaptation funding would significantly affect neither abatement nor adaptation. Domestic adaptation in non-OECD countries is displaced almost perfectly by international aid and mitigation remains unchanged. If the adaptation fund is conditional on undertaking specific mitigation actions at home, it can foster additional mitigation in less developed countries, though the effectiveness of this strategy remains very limited. On the one hand, the resources needed by the recipient countries to significantly decarbonize their production and energy system are much higher than the size of the transfer. On the other hand, in the chosen non-cooperative setting any additional abatement effort in non-OECD countries is strategically balanced by an increase in emissions in the OECD, which therefore erodes part of the benefit of the non-OECD mitigation. Even though a financial support to adaptation from richer countries would be insufficient to spur significant mitigation in developing countries, it could be beneficial for the donor countries. This happens if the transfer is specifically designed to foster investments in those technologies that, because of other market failures, are sub-optimal. We also evaluate whether a unilateral commitment by the OECD countries to adapt can induce more abatement in other countries. As a reaction, abatement in non-OECD regions effectively increases. However, the effect on overall abatement is negative, as cumulative world emissions increase. Adaptation transfers and strategic commitments to adaptation appear to be quite weak leverages for buying emission reduction in non-OECD countries, though adaptation transfers remain an important instrument for addressing the adverse distributional implications of climate change impacts. Moreover, our framework assumes that, in each model region, both adaptation and mitigation are implemented in an optimal fashion. The welfare implications of adaptation transfers can be different in second-best situations, in which for instance resource or capacity constraints lead to sub-optimal levels of adaptation.

Disclaimer

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References

Agrawala S, Fankhauser S (eds) (2008) Economic aspects of adaptation to climate change: costs, benefits and policy instruments. OECD, Paris

Agrawala S., Bosello F., C. Carraro , E. De Cian, E. Lanzi, K. De Bruin, R. Dellink (2010). "PLAN or REACT? Analysis of adaptation costs and benefits Using Integrated Assessment Models", OECD Environment Working Papers, No. 23, OECD Publishing.

Agrawala, S., Bosello F., C. Carraro , E. De Cian, E. Lanzi, K. De Bruin and R. Dellink (2011). "PLAN or REACT? Analisys of adaptation costs and benefits Using Integrated Assessment Models, *Climate Change Economics*, Vol.2 (3), 1-36.

Aldy J.E. and Viscusi W.K (2003), "The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World", *Journal of Risk and Uncertainty*, Volume 27, Number 1, 5-76,

Arrow, K. and A.C. Fisher (1974), "Environmental Preservation, Uncertainty, and Irreversibility", *The Quarterly Journal of Economics*, Vol. 88, No. 2: 312-319

Auerswald, Heike, Konrad, Kai A. and Thum, Marcel P., (2011), Adaptation, Mitigation and Risk-Taking in Climate Policy. CESifo Working Paper Series No. 3320.

Bahn, O., M. Chesney, and J. Gheyssens. 2010. The Effect of Adaptation Measures on the Adoption of Clean Technologies." Paper presented at the WCERE Congress, Montreal, 2010.

Barrett, S. (2010) "Climate Change and International Trade: Lessons on their Linkage from International Environmental Agreements", prepared for Conference on Climate Change, Trade and Competitiveness: Issues for the WTO, World Trade Organization, Geneva, 16-18 June 2010.

Balmford, Andrew, Pippa Gravestock, Neal Hockley, Colin J. McClean, and Callum M. Roberts (2004) The worldwide costs of marine protected areas, PNAS Vol. 101, no. 26.

Bigano A., Hamilton J.M. and Tol R.S.J. (2007), "The Impact of Climate Change on Domestic and International Tourism: A Simulation Study", *Integrated Assessment Journal* 7, 25-49.

Bondeau A., Smith P. C., Zaehle S. O. N., Schaphoff S., Lucht W., Cramer W., Gerten D., Lotze-Campen H., Muller C. and Reichstein M., (2007). "Modelling the role of agriculture for the 20th century global terrestrial carbon balance". *Global Change Biology*, 13, 679-706.

Bosello F. and Chen C. (2011), "Adapting and Mitigating to Climate Change: Balancing the Choice under Uncertainty", FEEM Note di Lavoro 550.2011.

Bosello, F., F. Eboli, R. Pierfederici. (2012***), "***Assessing the Economic Impacts of Climate Change. An Updated CGE Point of View***"***, FEEM Note di Lavoro, No. 2.2012.

Bosello F. and Moretto M. (1999) Dynamic Uncertainty and Global Warming Risk. FEEM Note di Lavoro. 80.99.

Bosello F., Carraro C., De Cian E. (2013). Adaptation Can Help Mitigation: An Integrated Approach to Post-2012 Climate Policy. Environmental and Development Economics, Vol 18, pp. 270–290.

Bosello, F., C. Carraro, and E. De Cian (2010). "Climate Policy and the Optimal Balance between Mitigation, Adaptation and Unavoided Damage", *Climate Change Economics*, Vol. 1, No. 2, 71–92.

Bosetti, V., C. Carraro, M. Galeotti, E. Massetti and M. Tavoni (2006), “WITCH: A World Induced Technical Change Hybrid Model”, *The Energy Journal. Special Issue on Hybrid Modeling of Energy-Environment Policies: Reconciling Bottom-up and Top-down* 13-38.

Bosetti, V., C. Carraro, R. Duval, A. Sgobbi and M. Tavoni (2009), “The Role of R&D and Technology Diffusion in Climate Change Mitigation: New Perspectives using the WITCH Model”, OECD Working Paper No. 664.

Bosetti, V., C. Carraro, E. De Cian, E. Massetti, M. Tavoni (2011). Incentives and Stability of International Climate Coalitions: An Integrated Assessment, Energy Policy 55 (2013) 44–56.

Buob S. and G. Stephan 2011.On the incentive compatibility of funding adaptation, NCCR Climate, Research Paper 2011/02.

Cai, Y., Judd, K. L., & Lontzek, T. S. (2013). The social cost of stochastic and irreversible climate change (No. w18704). National Bureau of Economic Research.

Ciscar, J.-C. (Ed.) (2009). Climate change impacts in Europe: final report of the PESETA research project. *JRC Scientific and Technical Research series*, EUR 24093 EN. Office for Official Publications of the European Communities: Luxembourg.

Criqui P., (2001), *POLES: Prospective Outlook on Long-term Energy Systems*, Institut d’Economie et de Politique de l’Energie, 2001, available on line at: http://webu2.upmf-grenoble.fr/iepe/textes/POLES8p_01.pdf

Criqui P., Mima S. and Menanteau P. (2009), *Trajectories of new energy technologies in carbon constraint cases with the POLES Model*, IARU International Scientific Congress on Climate Change, p. 16.

de Bruin K.C., Dellink, R.B. and R.S.J. Tol (2009), “AD-DICE: An Implementation of Adaptation in the DICE Model”, *Climatic Change*, Vol. 95: 63-81.

De Cian E., Bosetti V., Tavoni M. (2012). Technology innovation and diffusion in less than ideal climate policies. An assessment with the WITCH model. Climatic Change, Vol. 114, pp. 121-143.

Eboli F., Parrado R. and Roson R., (2010), "Climate Change Feedback on Economic Growth: Explorations with a Dynamic General Equilibrium Model", *Environment and Development Economics*, Volume 15 (5), pp 515 -533.

James, A., K.J. Gaston, and A. Balmford (2001), “Can we afford to conserve biodiversity?”, *BioScience*, Vol. 51 No. 1.

Emerton, Lucy, Joshua Bishop and Lee Thomas (2006). Sustainable Financing of Protected Areas. A global review of challenges and options. The World Conservation Union (IUCN), Gland, Switzerland

Feyen L. (2009), “Review of Literature on Impacts of Climate Change Infrastructure and Extremes”, Deliverable D2D.1, *ClimateCost* project.

Gjerde J., Sverre Grepperud, Snorre Kverndokk (1999), “Optimal climate policy under the possibility of a catastrophe”, *Resource and Energy Economics*, Volume 21, Issues 3–4.

Guillerminet M.L. and R. S. J. Tol (2008). Decision making under catastrophic risk and learning: the case of the possible collapse of the West Antarctic Ice Sheet. Climatic Change, Volume 91, Numbers 1-2, 193-209.

Hanemann, W.M. 2008. What is the Cost of Climate Change? CUDARE Working Paper No. 1027, University of California, Berkeley.

Hof AF, de Bruin KC, Dellink RB, den Elzen MGJ, van Vuuren DP 2009. The effect of different mitigation strategies on international financing of adaptation, *Environmental Science and Policy* 12: 832–843.

Hof AF, den Elzen MGJ, van Vuuren DP 2010. Including adaptation costs and climate change damages in evaluating post-2012 burden-sharing regimes, *Mitigation and Adaptation Strategies Global Change* 15:19–40.

Iglesias A., Garrote L., Quiroga S. and Moneo M., (2009), "Impacts of climate change in agriculture in Europe". *PESETA* FP6 project, available on line at: http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=2900.

Iglesias A., Quiroga S. and Garrote L. (2010), "Report Analysis for Europe", Deliverable D2B.2, *ClimateCost* project.

Ingham, A., Ma, J. and Ulph A.M. 2005. "Can Adaptation and Mitigation be Complements?" Working Paper 79, Tyndall Centre for Climate Change Research, University of East Anglia.

Ingham, A., Ma, J. and Ulph A.M. (2007), "Climate Change, Mitigation and Adaptation with Uncertainty and Learning", *Energy Policy* 35 (11): 5354-5369.

Intergovernmental Panel on Climate Change (IPCC), (2001) Climate Change 2001: Impacts, Adaptation and Vulnerability. Summary for Policy Makers, *World Meteorological Organisation. Geneva (2001)*

Kane, S. and J. Shogren (2000), "Linking Adaptation and Mitigation in Climate Change Policy", *Climatic Change* 45: 75-102.

Keller, K., Bolker, B. M., & Bradford, D. F. (2004). Uncertain climate thresholds and optimal economic growth. Journal of Environmental Economics and Management, 48, 723–741.

Kjellstrom T., Kovats R.S., Lloyd S.J., Holt T., Tol R.S.J., (2009), "The Direct Impact of Climate Change on Regional Labor Productivity", *Archives of Environmental & Occupational Health*, Vol. 64(4), 217-227.

Kovats R.S. and Lloyd S.J., (2011), "Climate Change Impacts on Health in Europe", Deliverable D2E.2, ClimateCost project.

Kriegler, E., Hall, J.W., H. Held, R. Dawson, H.J. Schellnhuber (2009), "Imprecise probability assessment of tipping points in the climate system", Proceedings of the National Academy of Sciences USA 1-6.

Lemoine, D.M., Traeger C.P., (2012), "Tipping Points and Ambiguity in the Economics of Climate Change", Working Paper 18230, http://www.nber.org/papers/w18230

Lenton, T.M., et al. (2008), "Tipping elements in the earth's climate system" Proceedings of the National Academy of Sciences USA 105:1786–1793.

Luderer G., Bertram C., Calvin K., De Cian E., Kriegler E . (2013). Implications of weak near-term climate policies on long-term climate mitigation pathways. Climatic Change, http://dx.doi.org/10.1007/s10584-013-0899-9.

Manne A. and Richard Richels (2005), "Merge: An Integrated Assessment Model for Global Climate Change, Energy and Environment", 175-189.

Marrouch, W. and Amrita Ray Chaudhuri (2011), "International Environmental Agreements in the Presence of Adaptation," Working Papers 2011.35, Fondazione Eni Enrico Mattei.

Nordhaus,W.D. 1994. *Managing the Global Commons: The economics of the greenhouse effect*. The MIT Press

Nordhaus,W.D. and J.G. Boyer 2000. *Warming the World: the Economics of the Greenhouse Effect*. The MIT Press

Nordhaus, W. (2007). Accompanying Notes and Documentation on Development of DICE-2007 Model: Notes on DICE-2007.delta.v8 as of September 21, 2007

Nordhaus, W. (2007), "A Review of the Stern Review on the Economics of Climate Change", *Journal of Economic Literature*, Vol. 45, No. 3.

Parry, M., O. Canziani, J. Palutikof, P. van der Linden, C. Hanson (eds.) 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report on Climate Change.* Cambridge University Press

Parry, M. (2009), "Closing the loop between mitigation, impacts and adaptation", *Climatic Change,* 96: 23–27

Pearce, D.W., Cline, W.R., Achanta, A.N., Fankhauser, S., Pachauri, R.K., Tol, R.S.J. and Vellinga, P.: (1996). The Social Costs of Climate Change: Greenhouse Damage and the Benefits of Control, in Bruce, J.P., Lee, H. and Haites, E.F. (eds.), *Climate Change 1995: Economic and Social Dimensions* - Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

Posner, R. A. (2004). Catastrophe: risk and response. Oxford University Press.

Roughgarden, T., & Schneider, S. H. (1999). Climate change policy: Quantifying uncertainties for damages and optimal carbon taxes. Energy Policy, 27, 415–429.

Stern, N. (2006), The Economics of Climate Change: The Stern Review, Cambridge University Press, Cambridge.

Tol, R.S.J. (2002), "Estimates of the Damage Costs of Climate Change" *Environmental and Resource Economics*, 1(21) 47-73.

Vafeidis A.T., Nicholss R.J., McFadden L., Tol R.S.J., Hinkel J., Spencer T., Grashoff P.S., Boot G. and Klein R.J.T., (2008), "A new global coastal database for impact and vulnerability analysis to sea-level rise", *Journal of Coastal Research,* 24, 917-924.

Van der Knijf J.M., Younis J. and de Roo A.D.P. (2010), "LISFLOOD: A GIS-based distributed model for river-basin scale water balance and flood simulation", *International Journal of Geographical Information Science,* 24(2), 189-212.

Warren et al. (2006), "Spotlighting impacts functions in integrated assessment", WP 91, Tyndall Centre for Climate Change Research.

Weitzman, M.L. (2009), "On Modelling and Interpreting the Economics of Catastrophic Climate Change", *Review of Economics and Statistics* 91, (1), 1-19.

Weitzman, M. (2001), "Gamma Discounting", *American Economic Review,* Vol. 91, No. 1.

Wright E.L. and Jon D. Erickson (2003), "Incorporating Catastrophes into Integrated Assessment: Science, Impacts, and Adaptation", Climatic Change, 3(57), 265-286.

Yohe, G., Andronova, N., & Schlesinger, M. (2004). To hedge or not against an uncertain climate future. Science, 306, 416–417.

Zickfeld K, et al. (2007), "Expert judgements on the response of the Atlantic meridional overturning circulation to climate change", *Climatic Change* 82, 235–265

Appendix.

Calibration of the damage functions. Data sources and methods

The AD-WITCH model used in the present study adopts the adaptation cost curves in Agrawala et al. (2010). This Appendix describes the calibration of the regional climate change damage functions, which builds on more recent data. Market damages are based on the results of the FP7 ClimateCost project (see Bosello et al. 2012). The project has quantified the physical and economic impacts of climate change on sea-level rise, energy demand, agricultural productivity, tourism flows, net primary productivity of forests, floods, and reduced work capacity because of thermal discomfort. All impacts, except those on floods and health, which focus on the EU, have been assessed for a number of macro regions covering the world. The joint macro-economic effect of the above climate change impacts, in terms of regional GDP changes, has been estimated by means of the computable general equilibrium (CGE) model ICES (Eboli et al., 2010). Therefore, the market damages included in the present study are net of autonomous adaptation. Non-market damages include an estimate of the potential ecosystem loss and of the non-market impacts on health. Both impacts have been evaluated by means of a willingness-to-pay approach. The next two sections describe in greater detail the methodologies used to evaluate market and non-market impacts.

Market damages

Estimates of coastal land loss due to sea-level rise are based on the DIVA model outputs (Vafeidis et al., 2008). DIVA (Dynamic Integrated Vulnerability Assessment) is an engineering model designed to address the vulnerability of coastal areas to rise in sea-levels. The model is based on a world database of natural system and socioeconomic factors for world coastal areas reported with a spatial resolution of 5°. The temporal resolution is 5-year time steps until 2100 and 100-year time steps from 2100 to 2500. Changes in natural as well as socio-economic conditions of possible future scenarios are implemented through a set of impact-adaptation algorithms. Impacts are then assessed both in physical (i.e. sq. Km of land lost) and economic (i.e. value of land lost and adaptation costs) terms.

Changes in tourism flows induced by climate change are derived from simulations based on the Hamburg Tourism Model (HTM) (Bigano et al., 2007). HTM is an econometric simulation model, estimating the number of domestic and international tourists by country, the share of international tourists in total tourists and tourism flows between countries. The model runs in time steps of 5 years. First, it estimates the total tourists in each country, depending on the size of the population and of average income per capita; then it divides tourists between those that travel abroad and those that stay within their country of origin. In this way, the model provides the total number of holidays as well as the trade-off between holidays at home and abroad. The share of domestic tourists in total tourism depends on the climate in the home country and on per capita income. International tourists are finally allocated to all other countries based on a general attractiveness index, climate, per capita income in the destination countries, and the distance between origin and destination.

Changes in average crops productivity per world region are derived from the ClimateCrop model (Iglesias et al., 2009; Iglesias et al., 2010). Crop response depends on temperature, CO_2 fertilisation and extremes. Water management practices are also taken into account. Spatially integrating all these elements, the model estimates climate change impacts and the effect of the implementation of different adaptation strategies. Responses of residential energy demand to increasing temperatures are derived from the POLES model (Criqui, 2001; Criqui et al., 2009), a bottom-up partial-equilibrium model of the world energy system, extended to include information on water resource availability and adaptation measures, which determines future energy demand and supply according to trends in energy prices, technological innovation, climate impacts and alternative mitigation policy schemes. The present version of the model considers both heating and cooling degree-days in order to determine the evolution of demand for different energy sources (coal, oil, natural gas, electricity) over the time-horizon considered.

Data on changes in net primary forest productivity *(NPP)* are provided by the LPJmL Dynamic Global Vegetation Model developed at the PIK – (Boundeau et al., 2007). The LPJ model, endogenously determines spatially explicit transient vegetation composition and the associated carbon and water budgets for different land-uses including forestry. It estimates the effects of climate change on forests (NPP) for all countries in the world, with or without carbon fertilisation effect on vegetation and the role of forest fires. Data on climate change impacts on river floods are based on results from the LISFLOOD model (Van der Knijff et al., 2009; Feyen, 2009). This is a spatially distributed hydrological model embedded within a GIS environment. It simulates river discharges in drainage basins as a function of spatial information on topography, soils, land cover and precipitation. This model has been developed for operational flood forecasting on a European scale, and it is a combination of a grid-based water balance model and a 1-dimensional hydrodynamic channel flow routing model. The LISFLOOD model can assess the economic loss in the EU27 countries per different macro-sectors: residential, agriculture, industry, transport and commerce, together with the number of people affected. The role of climate change, and of economic growth in determining the final losses can be disentangled. As opposed to other impact studies, LISFLOOD is an EU model, thus the non-EU regions remain outside the scope of its investigation.

Finally, climate change impacts on job performance in Europe are derived from Kovats and Lloyd (2011), who assess the change in working conditions due to heat stress produced by the increase in temperature, and their effects on labour productivity. By linking climate data, a combined measure of heat and humidity (the “Wet Bulbe Globe Temperature”), and effects on the human body (Kjellstrom et al., 2009), they are able to estimate the expected decrease in labour productivity for four European macro-regions (Western, Eastern, Northern and Southern). The authors also consider sectoral impacts by taking into account future changes in labour force distribution across sectors. Table AI compares the individual and joint effect on GDP that has been estimated by means of the CGE model ICES and Nordhaus (2007)’s estimates.

Non-market damages

Ecosystems and biodiversity losses induce welfare losses not directly priced by market transactions, such as the loss of recreational and amenity value of natural environments when they are enjoyed under free access, losses of option and existence values. To calibrate the ecosystem losses component, we follow a Willingness-To-Pay (WTP) approach, as in the MERGE model (Manne et al. 2005). In principle, an elicited WTP to avoid a given loss in ecosystems should encompass all their non-market values and therefore reasonably approximate the lost value in case they are not protected[4]. In MERGE the WTP, to avoid the non-market damages of a of 2.5°C temperature increase above pre-industrial levels, is 2% of GDP when per capita income is above 40,000 USD 1990. The 2% figure was the US EPA expenditure on environmental protection in 1995. An S-shaped relationship between per capita income and WTP is then used to infer the WTP for other regions. We follow a similar approach, though we use an updated proxy for the WTP, for which we consider the EU expenditure on environmental protection. The most recent Eurostat data referring to the public sector expenditure reports a total value in 2001 of 54 billion Euro, 0.6% of EU25 GDP, or of 120 Euro per capita[5]. This value encompasses activities such as protection of soil and groundwater, biodiversity and landscape, protection from noise and radiation, along with more

[4] In practice, the limitations of this approach are well known, and many criticisms have been raised against WTP and other stated preference approaches. However, the usual response is that in the end they represent the only viable way to capture existence values.

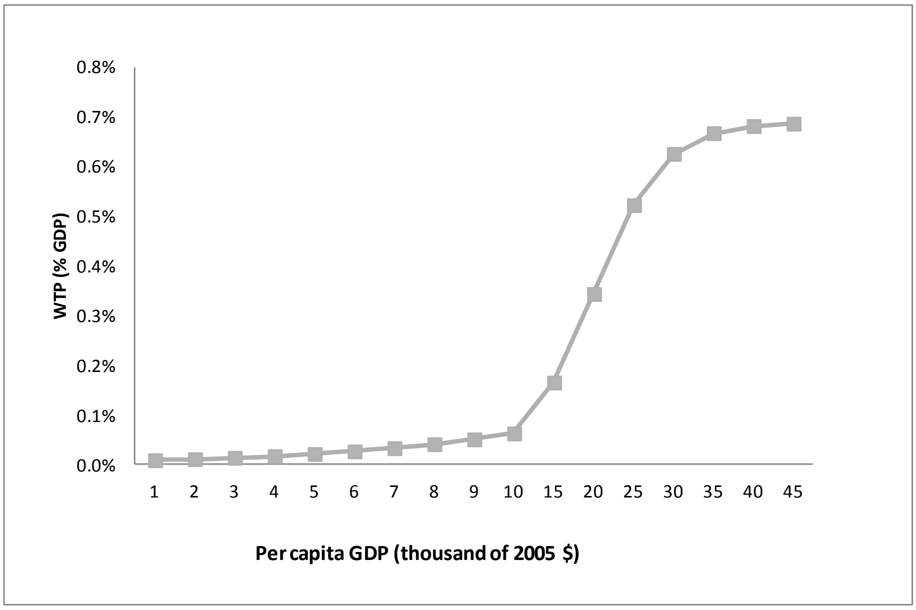
[5] “Environmental Protection Expenditure in Europe by public sector and specialized producers 1995-2002” http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-NQ-05-010/EN/KS-NQ-05-010-EN.PDF viewed on November 24th 2011.

general research and development, administration and multifunctional activities.We then use the expression reported in Warren et al. (2006), which links average per capita environmental expenditure and per capita income to extrapolate a relationship between WTP and per-capita income:

$$WTP_{n,t|t=2.5°C} = \gamma \Delta T_{n,t|t=2.5°C}{}^{\varepsilon} \frac{1}{1+100e^{(-0.23*GDP_{n,t|t=2.5°C}/POP_{n,t|t=2.5°C})}} \quad \text{(AI)}$$

In (AI) the parameters γ and ε have been calibrated to give exactly 0.6% of GDP when per capita income is 28,780 USD and ΔT=2.5°C. Figure AII shows the s-shaped relationship between per-capita income and WTP that has been used to compute the WTP in the different model regions, which is reported in Table AII.

Figure AII. Willingness to pay as a function of per capita GDP



Note: The black marker refers to the calibration point, a WTP equal to 0.6% for the EU income per-capita in 2001, $28,780.

Table AII also compares the resulting values with Hanemann (2008), who applies the same procedure, though he starts from a WTP estimates for the US equal to 0.1% of GDP; Nordhaus and Boyer (2000) as embedded in the RICE99 model, and by the MERGE model as described in Warren (2006).

Table AI. Market impacts of 1.92°C global average temperature increase (reference year 2050) on real GDP by region and impact: % change compared to the case with no temperature increase

	All impacts		Energy		Tourism		SLR		River Floods		Agriculture		Forestry		Health	
	Used this study	Nordhaus (2007)	Used this study	Nordhaus (2007)	Used this study	Nordhaus (2007)	Used this study	Nordhaus (2007)	Used this study	Nordhaus (2007)	Used this study	Nordhaus (2007)	Used this study	Nordhaus (2007)	Used this study	Nordhaus (2007)
USA	0.17	0.12	-0.01	0	0.18	0.22	-0.05	-0.08			0.05	-0.02	0.00			
MEUR	-0.15	-0.25	-0.05	0	0.07	0.33	-0.03	-0.35	-0.01	-0.19	0.07	-0.02	-0.01		-0.19	-0.02
NEUR	0.18	-0.25	-0.07	0	0.15	0.33	-0.11	-0.35	-0.01	-0.19	0.23	-0.02	0.00		0.00	-0.02
EEUR	-0.21	0.15	-0.02	0	0.10	0.28	-0.04	-0.01	-0.05	-0.08	-0.15	-0.02	-0.03		-0.03	-0.02
FSU	0.81	1.78	0.01	0.61	0.32	0.58	-0.03	-0.04			0.49	0.63	0.00			
KOSAU	0.09	0.48	-0.04	0.25	0.15	0.27	-0.04	-0.07			0.01	0.04	0.00			
CAJANZ	-0.09	0.02	-0.02	0	-0.10	0.24	-0.16	-0.21			0.19	-0.02	0.00			
NAF	-2.67	-0.97	-0.03	-0.25	-0.54	-0.19	-0.02	-0.02			-2.10	-0.51	0.01			
MDE	-0.83	-0.64	-0.19	-0.15	-0.42	-0.18	-0.10	-0.03			-0.10	-0.27	-0.03			
SSA	-1.50	-0.97	0.00	-0.25	-0.31	-0.19	-0.02	-0.02			-1.09	-0.51	-0.10			
SASIA	-3.10	-0.77	0.22	-0.22	0.04	-0.23	-0.32	-0.07			-3.02	-0.25	-0.02			
CHINA	0.20	-0.12	0.04	-0.25	-0.24	0.20	-0.03	-0.06			0.43	-0.02	0.00			
EASIA	-2.82	-0.60	0.01	-0.16	-0.36	0.03	-0.10	-0.07			-2.36	-0.40	-0.02			
LACA	-0.71	-0.58	-0.04	-0.22	-0.49	0.03	-0.05	-0.08			-0.11	-0.32	-0.01			

The extended names of the regions are: USA – United States, MEURO – Mediterranean Europe, NEURO – Northern Europe , EEURO - Eastern Europe, CAJANZ - Canada, Japan, New Zealand, CHINA - China and Taiwan, SASIA - South Asia, SSA - Sub-Saharan Africa, LACA - Latin America, Mexico, and the Caribbean, KOSAU - Korea, South Africa, Australia, FSU – Former Soviet Union, EASIA - South East Asia, MED- Middle-East, NAF - North Africa. The results presented in the table have been obtained by means of a model with a slightly finer regional disaggregation (14 instead of 12 regions) than that of the WITCH model. This is also the reason why the regional matching is imperfect.

Table AII. WTP for ecosystems protection related to a temperature increase of 2.5°C (% of regional GDP)

	AD-WITCH	Hanemann (2008)	Nordhaus and Boyer (2000)	(Merge as in Warren, 2006)
USA	0.69	0.10	0.10	2.00
Western EU	0.69	0.10	0.25	2.00
Eastern EU	0.69	0.10	0.10	2.00
KOSAU	0.69	0.10	0.10	1.99
CAJAZ	0.69	0.10	0.25	2.00
TE	0.50	0.08	0.05	1.47
MENA	0.31	0.05	0.05	0.89
SSA	0.01	0.002	0.10	0.04
SASIA	0.06	0.009	0.10	0.18
CHINA	0.61	0.09	0.05	1.76
EASIA	0.10	0.02	0.10	0.30
LACA	0.66	0.099	0.10	1.92
WORLD	0.49	0.07	0.10	2.00
USD Billion (2005)	1120	169		4569

The second type of impact refers to the changes in welfare related to modifications in health status[6]. The non-market costs related to changes in health status have been estimated by means of a value of statistical life approach (VSL). We derived the number of additional deaths related to climate-change from two sources. The first is the PESETA project (Ciscar et al., 2009). The PESETA research dedicated to the health impacts of climate change computed heat- and cold-related (cardiovascular and respiratory) deaths or avoided deaths for different degrees of warming (1°C, 2.5°C, and 3.9°C above pre-industrial levels) in Europe. The number of heat-related deaths is convex in temperature, while the number of avoided cold-related deaths is decreasing and concave. Hence, the relationship between net additional deaths and warming is n-shaped with a turning point at 2.5°C. We assumed this same relationship for all world regions. Heat- and cold-related diseases concern above all developed regions, while in developing regions large impacts will occur through vector-borne diseases, primarily malaria, dengue and schistosomiasis. For this aspect we extrapolated upon Tol (2002) estimating the number of deaths associated with 1°C of warming in different world regions. The study assumes that as per-capita income grows, mortality decreases until it disappears at a per-capita income level of 4,000 USD 2005. This implies that vector-born disease impacts will remain positive until 2070 only in Sub-Saharan Africa, until 2035 in South Asia, until 2015 in China, and until 2020 in East Asia.

[6] Climate-related health impacts are also associated with obvious market effects, directly measurable by changes in labour productivity, or in public and private health care expenditure. The focus here is instead placed on welfare losses associated with the disability or discomfort of living as an infirm person, which is a typical non-market aspect.

The moral implications aside, the money evaluation associated with loss of life will crucially determine the final economic assessment of climate–change-related health impacts and will introduce a degree of uncertainty-subjectivity very similar to that related to the assessment of ecosystem losses. Aldy and Viscusi (2003), surveying the literature on VSL, point to a fairly wide range of available estimates (see Box AI). Our choice was to assign each life the value of $ 1 million, which is in the upper range of estimates obtained with stated preference methodologies.

BOXAI. The Value of Statistical Life

According to Aldy and Viscusi (2003) the compensating wage method usually produces higher VSL in a range of 4-9 million USD. which entails a revealed preferences approach (hedonic wage) where the average risk of mortality is evaluated by a wage premium. This latter reflects the "wage-risk trade-offs" of workers with similar jobs in different environmental conditions. Estimates below the 5 million USD value usually come from studies using the Society of Actuaries data. These report wages from workers who have voluntarily chosen jobs that are an order of magnitude riskier than the average. There are also some studies yielding estimates beyond 12 million USD, but either these did not estimate the wage-risk trade-off directly or their authors reported unstable estimates. Estimates with this methodology are available only for small segments of the population, and usually refer only to current risk of accidental deaths (e.g. no deaths caused by air pollutants after a latency period are considered).

Estimates of roughly 1 million USD are produced by averting behavior approaches. These Stated Preference Methods directly ask individuals how much they would be willing to pay to compensate for a small reduction in risk. The lower estimates compared with compensating wage methods may reflect several characteristics of these studies that distinguish them from the labor market studies. First, some product decisions do not provide a continuum of price-risk opportunities (unlike the labor market, which does offer a fairly continuous array of wage-risk employment options), but rather a discrete safety decision. Second, the types of products considered in some studies may induce selection based on risk preferences. Third, several studies are based on inferred, instead of observed, price-risk trade-offs.

This methodology has been also applied in the PESETA study. A contingent valuation survey in which people of various ages – including elderly persons – have been asked to report their willingness to pay (WTP) for a reduction in their risk of dying has been conducted in UK, France and Italy. The results yielded exactly 1.1 million Euro.

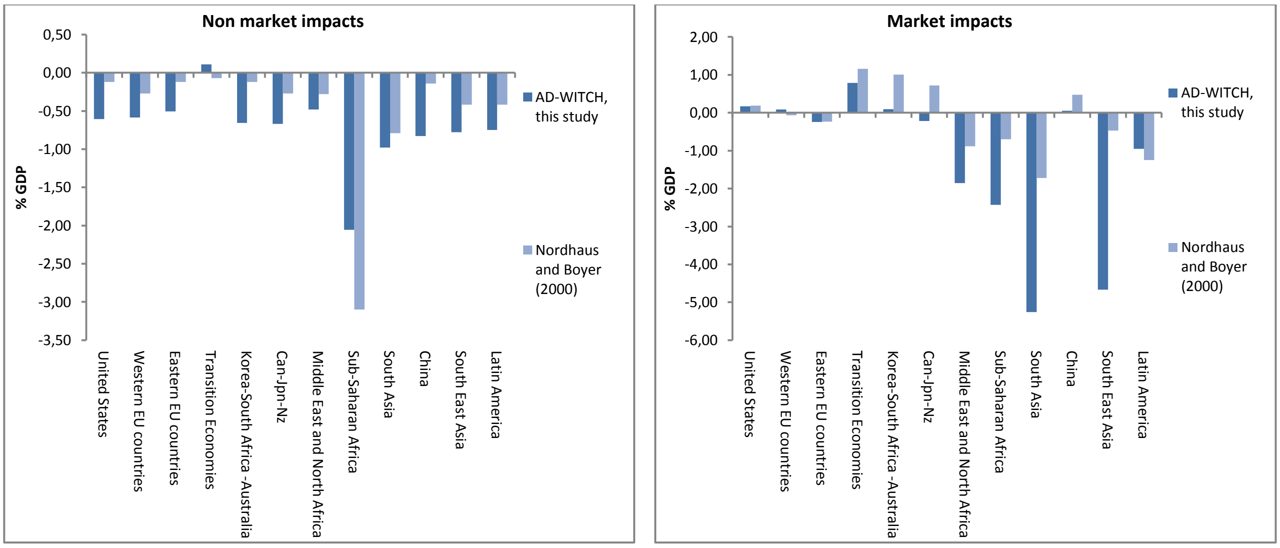
Table AIII reports the value obtained for the AD-WITCH world regions.

Table AIII. Climate change impacts on health. Economic estimates for a temperature increase of 1, 2.5, and 3.5°C (% of regional GDP)

°C	USA	Western EU	Eastern EU	FSU	KOSAU	CAJANZ	MENA	SSA	SASIA	CHINA	EASIA	LACA
1.0	0.294	0.332	1.206	2.652	0.156	0.042	-0.173	-3.423	-3.272	0.333	-1.521	0.019
2.5	0.076	0.098	0.171	0.591	0.028	0.016	-0.171	-1.592	-0.864	-0.225	-0.685	-0.090
3.5	0.085	0.112	0.202	0.647	0.030	0.018	-0.155	-0.519	-0.717	-0.233	-0.832	-0.087

Benefits are expected in cooler, richer regions, particularly Transition Economies and Eastern Europe, where decrease in cold-related mortality compensates increases in the heat-related one, and where vector-borne diseases are absent. Such a result is in contrast with Nordhaus (2007) and Nordhaus and Boyer (2000), since they assumed that any increased mortality in the summer is completely offset by the respective decrease in mortality from winter warming. Regions that suffer from vector-borne diseases face large economic impacts associated with health, but decreasing throughout time, as they get richer. Figure AIII compares the newly estimated impacts embedded in the AD-WITCH model with Nordhaus and Boyer (2000), showing the market and non-market components at the temperature calibration point (+2.5°C). Note that, for the sake of comparison, Nordhaus and Boyer (2000) figures for non-market impacts are net of the catastrophic damages and only refer to health, ecosystems and settlements.

Figure AIII: Estimated regional non market (left) and market (right) damages for a +2.5°C temperature increase above pre-industrial levels.



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