The "doomsday" effect in climate policies. Why is the present decade so crucial to tackling the climate challenge?

Baptiste Perrissin Fabert[*] Etienne Espagne[†]
Antonin Pottier[‡] Patrice Dumas[§] Franck Nadaud[¶]

April 23, 2013

Abstract

In the last Conferences of the Parties, decision-makers have confirmed the long term objective of preventing a temperature increase greater than 2 °C. However, climate negotiations have not lead yet to a binding agreement. Assuming that such agreement is obtained, this paper aims at appraising whether decision makers' commitment to meet the 2 °C objective is credible or not.

Within the framework of an integrated assessment model, we consider that the global economy is confronted with a climate damage constraint characterized by a threshold effect which triggers non linearities in damages when temperature increase exceeds 2 °C. We run the model for a broad set of scenarios accounting for the diversity of "worldviews" in the climate debate.

We show that for a significant share of scenarios it is optimal to overshoot the threshold. This is interpreted as the outcome of a "doomsday effect" that makes it optimal for decision-makers to violate their commitment.

A second result is that the later mitigation efforts begin, the more difficult it becomes to prevent the overshoot. In particular, the number of "doomists" dramatically increases if mitigation efforts do not start by 2020.

In light of these results we argue that the window of opportunity for reaching the 2 °C objective with a credible chance of success is rapidly closing during the present decade. Further delay in finding a solution to the coordination problem critically undermines the credibility of the objective.

[*] Centre International de Recherche sur l'Environnement et le Développement (CIRED) E-mail : perrissin@centre-cired.fr

[†] CIRED

[‡] CIRED

[§] Centre International de Recherche Agronomique pour le Développement

[¶] CIRED

Contents

Video meliora proboque, deteriora sequor
"I see and approve of the better, but I follow the worse"

The Metamorphoses, Book 7
Ovid

1 Introduction

In the last Conferences of the Parties, decision-makers have confirmed the long term objective of preventing a temperature increase greater than 2 ℃ above pre-industrial levels. Diplomatic vagaries of the last twenty years have prevented the international community from reaching a binding climate agreement on such desirable target. This is partly due to the fact that decision-makers are stuck in a global prisonner's dilemma. Because of the common nature of the global climate, governments seek to avoid free-riding behaviors from their partners regarding mitigation efforts, and thus do not launch ambitious mitigation policy. Solutions out of the prisonner's dilemma are not unknown (Ostrom et al., 1999; Dietz et al., 2003), and there is some hope that the cooperative solution will eventually be reached. Our analysis focuses on the aftermath of an international agreement on climate policy. Once decisions-makers agree to act cooperatively, what can be expected of coordinated mitigation efforts? Will the declared 2 ℃ target be met or not?

To model this situation, we use RESPONSE, a simple Integrated Assessment Model (IAM). Before the starting date of mitigation policies, the global economy follows a business as usual scenario. Continuation of diplomatic divergences between countries postpone the beginning of mitigation efforts. After the starting date of mitigation policies, the economy follows a path that optimizes intertemporal global welfare under a climate constraint. We therefore assume that, after the international community has reached an agreement, the global economy is run by a unique benevolent planner, representing the now unanimous international community. The paper aims at appraising, in the aftermath of an ambitious climate policy agreement, whether decision makers' commitment to meet the 2 ℃ target is credible or not.

The climate constraint used in RESPONSE models the political agreement on the 2 ℃ target. It is characterized by a damage function with a threshold effect, located at 2 ℃. The damage function keeps climate damage low for temperature increase below 2 ℃, and makes it dramatically rocket when temperate increase exceeds the threshold. It is meant to match decision makers' representation of climate damage when they commit to keep temperature increase below 2 ℃. This commitment on a 2 ℃ target is partly based on IPCC (2007) findings, partly the results of a political process (Cointe et al., 2011).

In the literature, only few IAMs based on traditional Cost Benefit Analysis have been designed to seriously take into account the possibility of tipping points and thus of a dramatic climate catastrophe (Weitzman, 2009). Here, we build on Gjerde et al. (1999), Keller et al. (2004), and Lempert et al. (2006) who have explored the implications of introducing non-linearities of climate dynamics into conventional IAMs.

The 2 ℃ target is said credible if the global economy, run by the benevolent planner, does not exceed the 2 ℃ threshold. However, we do not know what are the underlying parameters of the economy that the benevolent planner will run. There is today a diversity of "worldviews" on key parameters of the climate debate, and we do not have good reasons to choose a particular set. Therefore we analyze the credibility of the 2 ℃ target for many combinations of a set of key technico-economic and climatic parameters (namely, global GDP growth, rate of technical progress, abatement costs, pure time preference, climate sensitivity).

We show that for a significant share of worldviews it is optimal to overshoot the threshold, unless climate damage is very high (above 20% of global GDP). This result is tantamount to a kind of "rationality trap" that we interpret as a "doomsday effect". Indeed even though decision-makers take into account a threshold function with strong climate damage, for some of them it is optimal to cross the threshold. We call them "doomists". The cost-effective approach (CEA) used by Keller et al. (2007) to estimate the cost of procrastination in climate policy prevents, by construction, any overshoot regardless of the costs. Cost-benefit analysis however (CBA) allows for the possibility of overshooting the temperature target (Ambrosi et al., 2003) and introduces some degree of flexibility in the temperature path.

In climate policy terms, CBA accounts for a "soft" commitment to meet the temperature target whereas CEA involves an absolute commitment. We interpret the number of "doomists" as an indicator of the credibility of the 2 ℃ target. The higher the number of doomists the weaker the credibility of the objective, as for a growing number of worldviews, it is not optimal to reach it.

To better understand this "doomisday effect", we identify by means of statistical methods the reasons for the rise of such phenomenon among the worldviews composing the climate debate. We discriminate among the key parameters mentioned above those which are more likely to drive to a "doomist" behaviour and conversely those which are more likely to hedge against this bleak effect. It turns out that climate sensitivity and the starting date of mitigation efforts are the most critical drivers.

Indeed any delay in mitigation efforts increases the cost of future drastic abatement required to comply with the temperature target, and also enhances the impact of the inertia of the climate system that could make a 2 ℃ temperature increase physically unavoidable because of past "commited" CO_2 emissions (Davis et al., 2010; Guivarch and Hallegatte, 2012).

We show then that the later the mitigation efforts begin, the more difficult it becomes to prevent the overshoot, as a growing number of worldviews are struck by the "doomsday effect". In particular, the number of doomists dramatically increases if mitigation efforts do not start by 2020, while it keeps relatively constant from 1990 to 2010.

Remind that mitigation efforts only start when coordination problems are solved. In light of these results we argue that the window of opportunity for credible commitment to respect the 2 ℃ target is rapidly closing during the present decade. While delay in the implementation of climate policies during the first 20 years of climate negotiations did not have much impact on the credibility of the target, reaching an agreement in the present decade has become critical to reach the temperature target. Ironically, it is at the very moment when the international community firmly reaffirms its commitment to the 2 ℃ target, that any further delay in finding a solution to the coordination problem undermines the most strongly the credibility of the objective.

In section 1, we focus on the modeling features of the representation of climate damage by decision-makers. Section 2 presents our methodology for building a population of scenarios that can account for the diversity of views expressed in the climate debate. Section 3 uncovers the drivers of the "doomist" strategy. Section 4 presents and discusses the results by estimating the extent of the "doomsday effect" among decision-makers. In particular, our results show that if no action is taken by the beginning of the decade, then the number of "doomists" will rise significantly in the present decade. This would critically undermine the credibility of the 2 °C target, if the international agreement were to be reached after 2020.

2 Modeling the representation of climate damage

RESPONSE models the global economy in a standard Solow-Ramsey framework, with capital accumulation and exogenous technical progress[1]. Before the international agreement, the global economy follows a business-as-usual scenario, there is no mitigation effort. After the agreement, the global economy follows an optimized path, the benevolent planner optimizes intertemporal welfare, taking into account climate damage.

The crucial point is to model how decision-makers picture the climate damage. International climate negotiations commonly refer to the 2 °C target as the politically acceptable temperature increase beyond which highly undesirable climate change may occur. We then assume that the benevolent planner pictures climate damage as exhibiting a significant jump around 2 °C. Accordingly, our damage function, expressed in percent of GDP, has a sigmoid form:

$$D(\theta_{A,t}) = \kappa\theta_{A,t} + \frac{d}{1 + \mathrm{e}^{(\theta_D - \theta_{A,t})/\eta}} \tag{2.1}$$

The damage function is plotted in figure 1: if the temperature increase $\theta_{A,t}$ overshoots the threshold θ_D, it triggers a strong increase d in climate damage during a non-linearity phase of duration η. In our runs, θ_D is set at 2 °C; the range η of the non-linearity phase is calibrated so that the jump in damage d unfolds its potential within the range [1.7 °C; 2.3 °C] of temperature increase. Note that, at θ_D, the non-linear portion of the damage reaches half of its full potential. In the sensitivity analyis, we consider several values for the size of the jump (see next section).

We call "doomist" behaviour the optimal strategy in which the benevolent planner overshoots the threshold θ_D. For a doomist benevolent planner, it is optimal, according to her worldviews, to enter the zone where catastrophic damage occurs. As an optimal strategy in a deterministic model, there is no uncertainty, surprise or wrong expectations involved in the "doomist" strategy. Either it is still rational to exceed the threshold because abatement efforts to prevent the overshoot are more costly, in terms of discounted utility, than high losses due to climate damage, or the threshold is bound to be crossed due to the inertia of the climate system. The "doomist" behaviour is thus a rational behaviour, as far as cost-benefit analysis is concerned.

[1] A comprehensive description of RESPONSE is provided in (Dumas et al., 2012) which is available at `http://www.centre-cired.fr/IMG/pdf/CIREDWP-201241.pdf`. See the supplementary appendix.

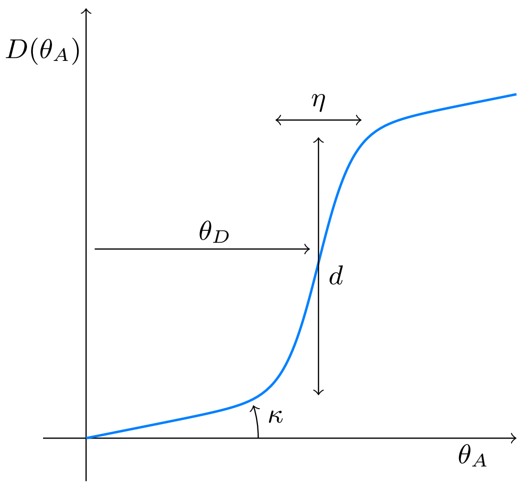

Figure 1: Sigmoid damage function D in RESPONSE. On the horizontal axis, θ_A stands for the atmospheric temperature increase relative to 1990 temperature in Kelvin. On the vertical axis, $D(\theta_A)$ represents climate damage in % of GDP. The non-linearity occurs around the temperature threshold θ_D, η is the width of the non-linearity phase, $d \geq 0$ is the size of the jump in damage, and κ is a linear trend of damage.

3 Methodology: accounting for a wide diversity of worldviews in the climate debate

In order to examine this "doomist" behaviour, we first build a population that accounts for the wide diversity of worldviews in the climate debate. A broad sensitivity analysis over five key parameters of RESPONSE, namely the rate of long term economic growth, the rate of pure time preference, the rate of technical progress, an index of abatement cost, and climate sensitivity, taking four equidistant values each within the ranges listed in table 1, allows us to build a population of $4^5 = 1024$ scenarios. The calibration of these parameters essentially rests on "beliefs" because there is no decisive argument for picking one value over another, and eventually the calibration results from an irreducible subjective choice within "objective" ranges provided by most advanced research (IPCC, 2007). The combination of beliefs in these parameters constitutes what we call a "worldview." All these worldviews are run with the same damage function described in section 1, for different levels of damage jump ranging from 0 to 50% of GDP.

Ranges of the rate of long term economic growth and climate sensitivity are based on estimates provided by the IPCC as well as some other recent studies suggesting higher values for climate sensitivity, with a skewed distribution (Stern, 2006; Roe and Baker, 2007; Weitzman, 2009). This is why we considered an extended range up to 6 °C. Ranges of pure time preference and abatement costs are drawn from the emblematic Stern/Nordhaus controversy

Table 1: Sensitivity analysis over 5 key parameters of RESPONSE taking 4 values within the following ranges

Growth rate	1% - 2.1%
Pure time preference	0.1% - 2.8%
Climate sensitivity	2 °C - 6 °C
Abatement linear cost (ζ)	\$0 /tCO_2 - \$101 /tCO_2
Technical progress on abatement cost (γ)	0.25% - 5.22% per year

which has polarized discussions on how to tackle the climate challenge[2]. Another point of contention between the two approaches outlined in a companion paper (Espagne et al., 2012), though it has remained almost unnoticed in the Stern/Nordhaus controversy, deals with abatement costs. Our abatement cost function is written at date t:

$$C_a(a_t) = \frac{1}{(1+\gamma)^t}\left(a_t\zeta + (BK-\zeta)\frac{(a_t)^\nu}{\nu}\right), \tag{3.1}$$

with γ the rate of technical progress, a_t the fraction of abatement, BK the backstop price, ζ is the marginal cost of first abatement ($C_a'(A_{t_0}=0)=\zeta$), and ν a power coefficient (set at 4).

While Nordhaus sets the price of the backstop technology (BK) at \$1,200 /tCO_2 in 2005 and an annual rate of technical progress of $\gamma = 0.25\%$ over the next century in order to reach a backstop price of \$950 /tCO_2 in 2100, Stern takes a much more optimistic view of the effect of technical progress on abatement cost. According to Stern, the mean cost of abatement will decrease from \$61 /tCO_2 in 2015 for an abatement level of 7.5 percent, to \$22 /tCO_2 in 2050, for an abatement level of 75 percent. For a backstop price set at \$1,200 /tCO_2 in 2005, such a view of mean abatement costs is consistent with an annual rate of technical progress of 5.22% and an additional linear cost in the abatement cost function of \$101 /tCO_2 in 2005.

For 26 levels of damage jumps in the range $0-50\%$ of GDP, we run RESPONSE with 1024 (4^5) scenarios, which produces as many optimal abatement trajectories. Among this population of scenarios we then focus on the world-views leading to a doomist behaviour for the le vel of jump in damage considered and various initial dates for the beginning of mitigation efforts. This allows us to better understand the rise of a "doomist" behaviour (see section 4) and how the credibility of 2 °C target is affected when mitigation efforts are postponed (see section 5).

[2]Comments following the Stern (2006) Review (Dasgupta, 2007; Nordhaus, 2007; Weitzman, 2007; Yohe and Tol, 2007) have mainly emphazised the impact of the so-called unusually low rate of pure time preference of 0.1% (which makes the discount rate used in Stern's runs amount to 1.4%) on Stern's recommendation of early and strong mitigation action. In turn, the "policy ramp" promoted by Nordhaus (2008) would be driven by a more conventional level of pure time preference (2.8%) leading to a discount rate of 4.1%.

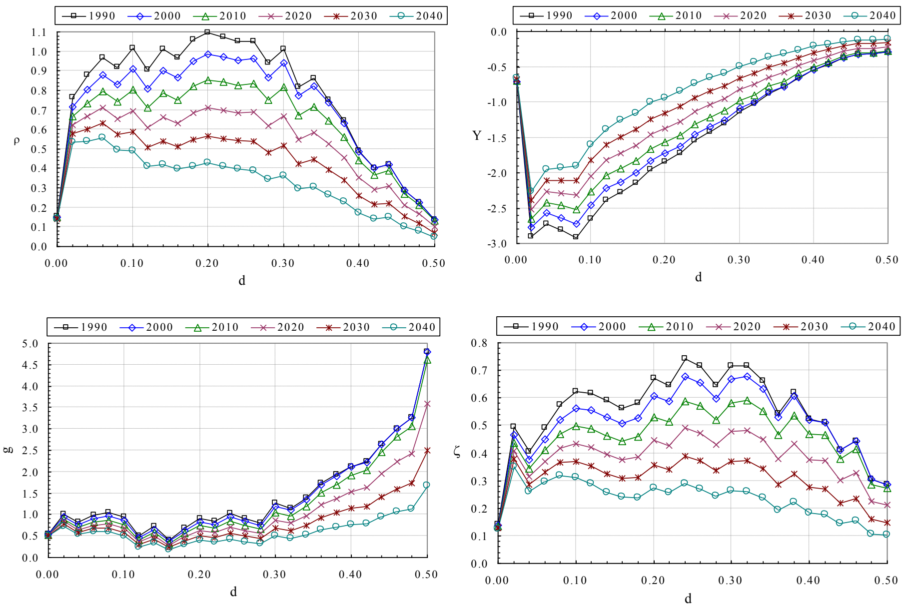

Figure 2: Evolution of the elasticities of pure time preference, technical progress on abatement technology, economic growth, and the marginal cost of first abatement

4 Uncovering the drivers of the "doomsday effect"

Table 2 lists all the "doomist" scenarios among all the scenarios we run. It clearly shows that such behaviour occurs for all levels of non linearities in damages, and for all starting date of mitigation efforts. Note however that when the jump is null, i.e. climate damage is reduced to its linear portion $\kappa\theta_{A,t}$, 94 percent of the scenarios lead to an overshoot of the temperature threshold. Describing these scenarios as "doomist" is not entirely appropriate since there is no serious threat. The figure simply indicates that the threshold will almost certainly be exceeded if only linear climate damage is anticipated. The same comment applies to cases with low jumps in damage which are not "frightening" enough to offset the cost of mitigation efforts to meet the 2℃ target.

In order to identify the drivers of the "doomsday effect" we estimate for all jumps in damage d, a logistic regression equation with 6 explanatory variables (the five key parameters that compose a worldview in addition to the starting date of mitigation efforts) and the dependant variable *doom* taking the value 1 when the 2℃ is overshot and 0 otherwise:

$$doom = \beta_0 + \beta_1\rho + \beta_2\gamma + \beta_3\zeta + \beta_4\vartheta + \beta_5 g + \beta_6 t_{begin},$$

with β_i the regression coefficients, ρ, the rate of pure time preference, γ, the technical progress on abatement technology, ζ the marginal cost of first

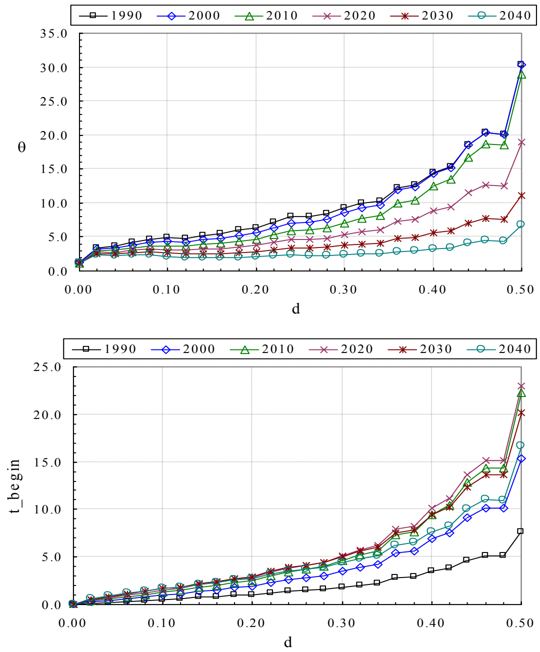

Figure 3: Evolution of the elasticities of climate sensitivity and the starting date of mitigation

abatement, ϑ the climate sensitivity, g the long term growth rate, and t_{begin} the starting date of mitigation efforts.

A separate estimation is computed for each value of the jump in damages, d, in 2% steps, providing thus 26 separate models. For each estimated logit model, elasticities were computed for each of the six starting dates of optimization t_{begin}. In a logit regression context, such elasticities are easily interpreted as the marginal impact of a given variable on the probability that a scenario is doomist. That is, the larger the elasticity, the bigger is the impact, and conversely if the elasticity is negative.

These elasticities were computed with the STATA 12 "margins" command by the delta method using numerical derivatives and the observed information matrix. Elasticities are computed for 26 values of d and 6 optimization dates for t_{begin} which give 156 elasticities per variable presented in figures 2 and 3.

The chart on the bottom left of figure 3 reads as follows: if the jump in damage is 10% and that mitigation efforts have started in 2000, then an increase of 1% of the discount rate increases the risk of being doomist by 0.6%. Figures 2 and 3 point out that technological progress on abatement cost reduces the risk of turning into doomist, while the other variables increase this risk. Figure 3 shows that climate sensitivity and the starting date of mitigation efforts are the two variables which have the greatest impact, in particular when jumps in damages are high. A one percent increase of the climate sensitivity when the jump in damage is 20% and the starting date of mitigation is 2020 makes the probability of turning into doomist increase by 5%. Note that the later the starting date of

Table 2: Evolution of the total number of "doomist" scenarios among the 1024 scenarios depending on the size of the jump in damage and the starting date of mitigation efforts

d	1990	2000	2010	2020	2030	2040
0.50	6	5	8	256	512	640
0.40	22	23	27	262	512	641
0.30	77	78	83	293	519	646
0.20	188	191	194	351	545	664
0.10	386	388	390	469	605	701
0.00	963	964	965	965	966	969

mitigation the lower the impact of an increase of the climate sensitivity. This is also true for the variables of growth and pure time preference. This is certainly due to the fact that postponing mitigation efforts keep less and less opportunity for not overshooting the 2 ℃ threshold, and therefore the impact on the risk of turning into a doomist is relatively greater when there is still a chance of meeting the temperature objective.

5 Results: Appraising the credibility of the 2 ℃ target across time

The aim of this section is to estimate in more details how the "doomsday effect" spreads with time and may eventually undermine the credibility of decision-makers' commitment to meet the 2 ℃ target. It brings us to the conclusion that the current 2010-2020 decade is crucial for climate policy to stand a chance of meeting the 2 ℃ target.

A static analysis of table 2 shows that the number of doomists decreases with the size of the jump regardless of the initial starting date of climate policy. This link is rather intuitive: the higher the shock of the damage, the higher the willingness to pay to hedge against the shock and thus to pay for precautionary mitigation efforts.

A dynamic analysis of figure 4, which displays results for only six levels of jump in climate damage, reveals that the number of doomists remains almost perfectly constant if mitigation policy is delayed from 1990 to 2010, since there are almost no additional doomists during this period. A dramatic increase in doomists then occurs during the 2010-2020 decade regardless of the size of the jump. This increase is all the more striking as it occurs after a two-decade plateau, while one could have expected a steady increase over the whole period. This upward trend of doomists is still noticeable during the following two decades.

These results suggest that if mitigation policies had started in the nineties or the early two thousands the 2 ℃ target would have been all the more politically credible and feasible since the number of doomists remained low and stable during this period. They also show that two decades may have been lost for implementing consensual climate policies.

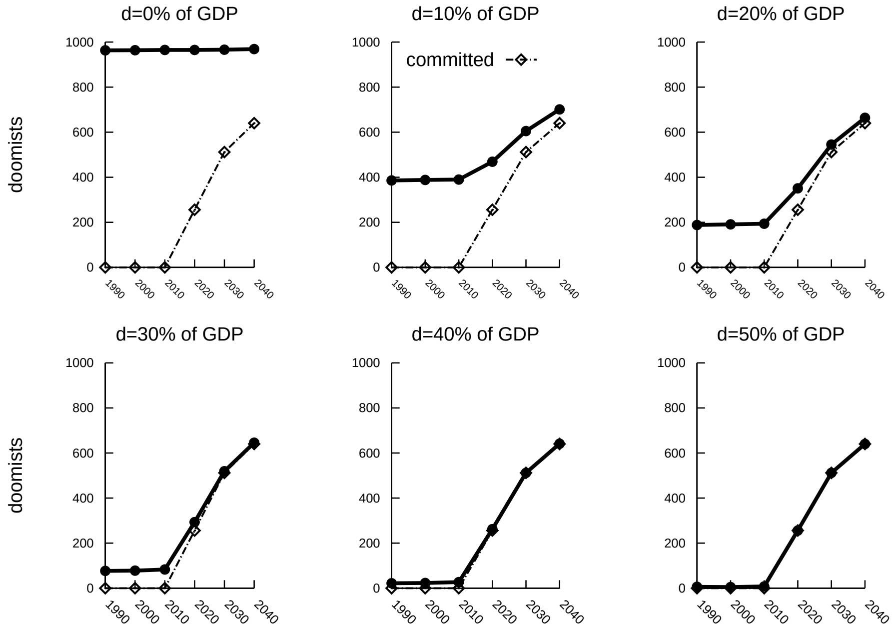

Figure 4: Evolution of the number of "doomists" depending on the size of the jump in damage and the starting date of mitigation efforts. The dashed line indicates the number of "committed doomists" among total "doomists"

Figure 4 also indicates that it becomes more and more difficult to avoid overshooting the 2 °C threshold as the beginning of mitigation efforts is postponed. The same analysis has also been carried out with temperature thresholds of 2.5 °C and 3 °C. We find the same type of results with however one or two decades of delay, depending on the temperature threshold (the higher the threshold, the later the occurrence of the doomist wave).

Note that the difficulty in preventing the overshoot is exacerbated by the inertia of the emission–temperature dynamics and the stock nature of GHG emissions. Indeed, figure 5 points out that if no mitigation efforts are undertaken by 2020, then past "committed" emissions, i.e. the stock of emissions accumulated by the starting date of mitigation efforts, inevitably lead to an overshoot of the 2 °C thresholds in some scenarios. This phenomenon becomes more pronounced with time, since delaying the beginning of the mitigation efforts increases the amount of committed emissions. In the extreme case where climate policy would not be implemented by 2040, virtually all of the decision-makers would be turned into "doomists" because of their "committed" emissions, regardless of the value of the jump in damage. Table 2 shows that, in this case, for more than 62 percent of the scenarios it would be too late to prevent the temperature increase from exceeding the 2 °C threshold, and therefore to prevent major climate damage from occuring.

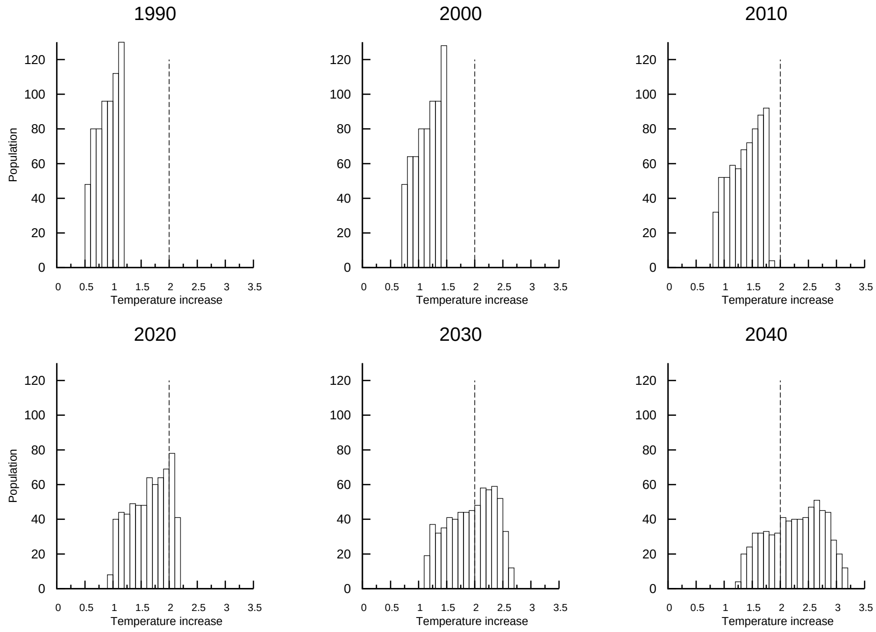

Figure 5: Distribution of temperature increases induced by "committed" emissions at different dates among 656 baseline scenarios, resulting from the combination of 4 different growth rates, 4 different discount rates and 41 possible climate sensitivities. Increasing the climate sensitivity density allows us to build a more accurate distribution of "committed" temperature increases than in the main sensitivity analysis that only takes into account 4 possible levels of climate sensitivity.

6 Conclusion

In this paper we show that taking into account non-linearities in climate damage has a significant impact on the optimal timing of climate policies and sheds light on the increasing difficulties with time to keep the opportunity to meet the 2 °C target that has been confirmed in last climate negotiations.

Among a broad set of scenarios accounting for the wide diversity of worldviews in the climate debate, we identify the main drivers of what we call the "doomsday effect" on decision-makers, that are beliefs on the climate sensitivity and the starting date of emission reduction. The "doomsday effect" effect either results from too high a level of "committed" emissions due to a delay in emission reductions and high levels of climate sensitivity, or a cost-benefit analysis that makes it optimal for rational deicsion-makers to resign themselves to overshooting the 2 °C threshold and then facing significant climate damage. We show that this effect occurs for any level of jump in damage and dramatically increases after the 2010-2020 decade, given that the later the mitigation efforts begin, the more difficult it becomes to prevent the overshoot.

The vagaries of the diplomatic process since the Rio Conference in 1992 have resulted in two "lost decades" for climate action. In light of these results, we believe that any further delay in reaching a clear international agreement will close the window of opportunity for meeting the 2 °C target with any reasonable chance of success. In fact, decision-makers may then become reluctant to implement ambitious climate policies since they will be in a position to believe it is too late to act and will be definitely struck by the "doomsday effect".

It is still time however to take stock of this thought experiment to keep on track with a future 2.5 °C or 3 °C target with a reasonable chance of success.

Acknowledgments

We have benefited from comments by Adrien Vogt-Schilb, Stéphane Hallegatte, Minh Ha-Duong. Responsibility for any errors is ours.

References

Ambrosi, P., Hourcade, J., Hallegatte, S., Lecocq, F., Dumas, P., and Ha-Duong, M. (2003). Optimal control models and elicitation of attitudes towards climate damages. *Environmental Modeling and Assessment*, 8(3):133–147.

Cointe, B., Ravon, P.-A., and Guérin, E. (2011). 2 °C: the history of a policy-science nexus. Working Papers IDDRI, n°19/11.

Dasgupta, P. (2007). Commentary: The Stern review's economics of climate change. *National Institute Economic Review*, 199(1):4–7.

Davis, S., Caldeira, K., and Matthews, H. (2010). Future CO2 emissions and climate change from existing energy infrastructure. *Science*, 329(5997):1330–1333.

Dietz, T., Ostrom, E., and Stern, P. (2003). The struggle to govern the commons. *Science*, 302(5652):1907–1912.

Dumas, P., Espagne, E., Perrissin-Fabert, B., and Pottier, A. (2012). Comprehensive description of the integrated assessment model RESPONSE. Working Paper CIRED.

Espagne, E., Perrissin-Fabert, B., Pottier, A., Nadaud, F., and Dumas, P. (2012). Disentangling the Stern / Nordhaus controversy: beyond the discounting clash. *Nota Di Lavoro*.

Gjerde, J., Grepperud, S., and Kverndokk, S. (1999). Optimal climate policy under the possibility of a catastrophe. *Resource and Energy Economics*, 21(3):289–317.

Guivarch, C. and Hallegatte, S. (2012). 2°C or not 2°C? *Global Environmental Change*, 3(1):179 –192.

IPCC (2007). *Climate change 2007: Mitigation. Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge University Press, Cambridge, UK and New York.

Keller, K., Bolker, B., and Bradford, D. (2004). Uncertain climate thresholds and optimal economic growth. *Journal of Environmental Economics and Management*, 48(1):723–741.

Keller, K., Robinson, A., Bradford, D., and Oppenheimer, M. (2007). The regrets of procrastination in climate policy. *Environmental Research Letters*, 2:024004.

Lempert, R., Sanstad, A., and Schlesinger, M. (2006). Multiple equilibria in a stochastic implementation of dice with abrupt climate change. *Energy economics*, 28(5):677–689.

Nordhaus, W. (2007). A Review of the "Stern Review on the Economics of Climate Change". *Journal of Economic Literature*, 45(3):686–702.

Nordhaus, W. (2008). *A question of balance*. Yale University Press.

Ostrom, E., Burger, J., Field, C., Norgaard, R., and Policansky, D. (1999). Revisiting the commons: local lessons, global challenges. *Science*, 284(5412):278–282.

Roe, G. and Baker, M. (2007). Why is climate sensitivity so unpredictable? *Science*, 318(5850):629.

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

Weitzman, M. (2007). A review of the Stern Review on the economics of climate change. *Journal of Economic Literature*, 45(3):703–724.

Weitzman, M. (2009). On modeling and interpreting the economics of catastrophic climate change. *The Review of Economics and Statistics*, 91(1):1–19.

Yohe, G. and Tol, R. (2007). The Stern Review: implications for climate change. *Environment: Science and Policy for Sustainable Development*, 49(2):36–43.