

The risk of delaying climate action

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Participants at the Paris Climate Conference COP21 agreed that global warming should be limited to 2°C. This would be the case if carbon concentrations could be stabilised at below 450 parts per million (ppm). However, simulations with climate models show that even at this level the risk of overshooting the 2°C limit is not negligible. From an economic point of view, it would be optimal to take early measures to reduce tail risks. To overcome public reluctance to make small sacrifices now to avoid substantial future damages, climate policies should be appropriately framed.

The Earth is warming up. According to NASA/GOSS, 17 of the 18 warmest years in the 136-year record all have occurred since 2001, with the exception of 1998. The year 2017 ranks as the second warmest on record, after 2016. This is almost certainly related to the growing presence of greenhouse gases, mostly due to human activities.¹ Recent research estimates that human-induced warming reached 0.93°C ($\pm 0.13^\circ\text{C}$; 5-95 percentile range) above pre-industrial levels in 2015, and is currently increasing at almost 0.2°C per decade.²

This had led to changes in the frequency of extreme weather events, such as increases in tropical cyclones, heavy precipitation, and periods of drought. In the insurance industry, weather-related catastrophe losses have increased by 2% each year since the 1970s in addition to changes related to accumulated wealth, inflation and population growth/movement.³ The re-insurance company Munich Re reported that total insured losses from natural disasters amounted to USD 135 bn in 2017, higher than ever before. Including uninsured losses this totalled USD 330 bn or 0.4% of world GDP.⁴ As temperatures continue to rise, losses from extreme weather could increase rapidly in a non-linear manner during the coming decades. The Stern Report estimates that without mitigation efforts, damages could reach 20% of world GDP by the end of the century.⁵

Growing concern of the consequences of climate change has made it possible to reach a milestone agreement among 196 countries at the COP21 in Paris in December 2015. The aim is to limit global warming to 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C. This should be done by reducing net emissions of greenhouse gases. The treaty has already been ratified by 175 parties, including the EU. Unfortunately, the US, world's largest producer of CO₂ gases announced in June 2017 to leave the agreement. For the moment, the treaty is not very restrictive and based on voluntary declared commitments, the so-called Nationally Determined Contributions (NDCs).

Even before the conclusion of the Paris climate deal, growth in global carbon emissions was slowing and clearly decoupled from GDP growth. The Global Carbon Project estimates that they increased by around 2% in 2017 after having stabilised at 36 Gt during the period 2014-2016. It is expected that emissions over the next few years will level off or only grow slightly, as countries implement their pledges.

However, more efforts are needed as, taken together, the NDCs are insufficient to reach the climate objectives of the Paris Agreement. Hence, in the coming decades, climate mitigation measures have to be stepped up. This may be much more difficult to achieve than in the past, as countries have first implemented the easy cuts, the so-called low hanging fruits such as the replacement of coal power stations by cleaner natural gas plants, nuclear reactors, PV solar or wind farms. In addition, countries have to spend more on climate adaptation to deal with the already observed effects of global warming.

Uncertainty about climate sensitivity

Over the past decades, considerable insight has been gained in the effect of carbon emissions on global warming and the economy by using sophisticated climate models. Nevertheless some important hiatuses remain, such as possible feedback effects and the possible existence of tipping points. The rising temperature can provoke serious economic losses through the negative impact on agriculture output, flooding, increased frequency of tornados and heavy precipitation, the rise in climate-related morbidity and migration.

The value of the long-term damage done by releasing an additional tonne of carbon dioxide (CO₂) in the atmosphere is called the Social Cost of Carbon (SCC). This concept is important in the design of climate policies. In a standard cost-benefit analysis, the marginal benefit of reducing carbon emissions should equal the SCC. The social cost of carbon is not readily observed but estimated, by so called Integrated Assessment Models (IAM), which link climate models with economic models. The three best known models are William Nordhaus' DICE model⁶, Richard Tol's FUND model⁷, and Christ Hope's PAGE model⁸. According to the US Environmental Policy Agency (EPA), the SCC amounted to USD 36 in 2015 (in 2007 dollars and a 3% discount rate

¹ The three main greenhouse gases are carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O). Other less prevalent greenhouse gases but with a far greater global warming potential are sulphur hexafluoride (SF₆), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs). In order to calculate the impact on global warming, all these gases are converted, according to their warming potential, into CO₂ equivalents or CO₂eq.

² Millar et al. (2017)

³ Millar et al. (2008)

⁴ Total losses, insured and uninsured, was even slightly higher in 2011, USD 354 bn (in 2017 prices), because of the Tohoku earthquake in Japan.

⁵ Stern, N. (2007)

⁶ Nordhaus (2016)

⁷ <http://www.fund-model.org/>

⁸ <http://www.climatecolab.org/wiki/PAGE>



Box

Climate sensitivity

The relationship between CO₂ and global warming is called climate sensitivity. Two types of climate sensitivity are used. The transient climate response (TCR) considers temperature changes that would occur if CO₂ levels increase by 1% (compounded) per year from pre-industrial levels (280 parts per million, ppm) until they double. This would take about 70 years. The TCR is the global temperature increase that would have occurred at that point in time.

Temperatures would still increase even if CO₂ levels would stabilise at double the pre-industrial level, as it takes a long time for the oceans to heat up. The equilibrium climate sensitivity (ECS) is the amount of warming achieved when the entire climate system reaches a stable temperature in response to a doubling of CO₂. This can take hundreds, if not thousands, of years.

Climate sensitivity can be estimated by using:

1. climate models
2. information from distant past climates, such as from the last ice age (palaeoclimatology).
3. data on how global temperature responds to the outbursts of large volcanoes.
4. recent climate trends.

Source: Colman and Braganza (2013)

for estimating the present value of future damages). Moreover, an increasing number of companies use an internal price for carbon pollution to weigh the risk and opportunities related to climate change. The Exxon Mobil Corporation uses USD 80 for a tonne CO₂ in 2040, which actually exceeds the EPA estimate for that year (USD 60).

Probability density function for climate sensitivity Stabilisation of CO₂eq concentrations at 560 ppm

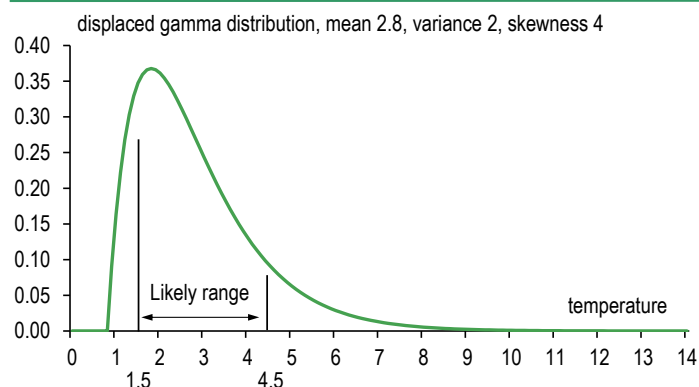


Chart 1

Source: BNP Paribas

A major uncertainty in the calculation of climate change damages is related to uncertainty about the magnitude of climate sensitivity (see box). The climate sensitivity rate λ , expressed in °C/(Watt/m²) is a

parameter that links the equilibrium temperature change T to the radiative forcing (RF) at carbon concentrations in the Earth's atmosphere (E):

$$T(\lambda, E) = \lambda * RF(E)$$

Climate scientists have obtained estimates for λ by running climate models thousands of times. The pattern that emerges is a right-skewed distribution similar to a lognormal or gamma distribution (see Lindsey, 2010). Few of the simulations result in less than 2 degrees of warming, but some result in significantly more than 4°C. Following Pindyck (2012) we have used a displaced gamma distribution (see Chart 1). The results are in line with estimations by the Intergovernmental Panel on Climate Change (IPCC), a UN sponsored body for the study of climate change. In its Fifth Assessment Report, the Panel estimates that the equilibrium climate sensitivity is likely in the range 1.5°C to 4.5°C, and very unlikely greater than 6°C.⁹ That range has persisted almost all of the past four decades.¹⁰

As policy makers would want to avoid major climate catastrophes, the right-hand tail of the distribution of T may matter most for them. It is what economists call "tail risks", the probability that equilibrium climate sensitivity will be above 4.5°C. It is very hard to get precise knowledge about the form of the tail, as, fortunately, extreme events fall well out of the range of experience. In such situations one has to rely on *a priori* beliefs in the form of a prior probability distribution.

The tail of the climate sensitivity distribution

CO ₂ eq/ppm	400	500	600	700	800	900
Pareto distribution						
Prob [$T \geq 5^\circ\text{C}$]	1.5	6.5	15	25	38	52
Prob [$T \geq 10^\circ\text{C}$]	0.2	0.83	1.9	3.2	4.8	6.6
Normal distribution						
Prob [$T \geq 5^\circ\text{C}$]	1.E-06	2	14	29	42	51
Prob [$T \geq 10^\circ\text{C}$]	1.E-30	1.E-10	1.E-05	0.1	0.64	2.1
Gamma distribution*						
Prob [$T \geq 5^\circ\text{C}$]	1.7	5.6	11.6	19.9	26.7	35.5
Prob [$T \geq 10^\circ\text{C}$]	0.0	0.0	0.3	0.8	1.9	3.4

Table 1

Sources: Weitzman (2011), *calculations BNP Paribas

Table 1 illustrates the problem. The higher the level at which carbon emissions stabilise, the greater the risk for catastrophic climate change. For the moment, the objective is to keep greenhouse gas concentration below 450 ppm. The average warming at that level is around 2°C and the risk that it will increase above 5°C is, at less than 5%, relatively low. However, assuming that the tail follows a gamma distribution, the probability that temperatures increase by more than 5°C would be higher than 10% if greenhouse gas concentrations exceed 580 ppm. For prudent policy makers, that would be a considerable risk. The

⁹ IPCC (2014). In the IPCC terminology, "likely" signifies a level of confidence of more than 66% and "unlikely" a level of less than 10%.

¹⁰ The 1979 Charney Report of the US National Research Council estimated this interval for the first time.



benefit of strong climate action can thus be viewed as an insurance premium against the risk of such a situation.

From global warming to future damages

The increase in global temperatures has a direct impact on GDP, in particular for agriculture output. Although a small increase might be beneficial for economies in moderate zones because of better harvests, globally output losses are likely to dominate because of production falls in the rest of the world. In addition, output will be damaged by changes in weather conditions, such as heavy precipitations in one place and long periods of drought elsewhere.

Distribution of warming costs by percentile of climate sensitivity

Percentile (midpoints)	Stabilisation at 450 ppm		Stabilisation at 550 ppm	
	Temperature °C	Damages %GDP	Temperature °C	Damages %GDP
2.5	0.8	0.0	1.0	0.0
7.5	1.0	0.0	1.2	0.0
12.5	1.1	0.0	1.4	0.1
17.5	1.2	0.0	1.5	0.2
22.5	1.4	0.1	1.7	0.4
27.5	1.5	0.2	1.8	0.6
32.5	1.6	0.3	1.9	0.9
37.5	1.7	0.4	2.1	1.2
42.5	1.8	0.6	2.2	1.6
47.5	1.9	0.8	2.4	2.2
52.5	2.1	1.2	2.5	2.9
57.5	2.2	1.6	2.7	3.7
62.5	2.3	2.1	2.9	4.9
67.5	2.5	2.9	3.1	6.3
72.5	2.7	3.8	3.3	8.2
77.5	2.9	5.2	3.6	10.8
82.5	3.2	7.2	3.9	14.6
87.5	3.5	10.5	4.3	20.6
92.5	4.1	16.7	5.0	31.8
97.5	5.1	35.1	6.3	64.7
Average	2.0	1.0	2.4	2.5

Table 2

Source: BNP Paribas

The results of stabilising greenhouse gas concentrations at 450 ppm and 550 ppm are summarised in table 2. If CO₂eq concentrations could be stabilised at 450 ppm, the temperature increase is likely between 1.5°C and 4°C. The mean value is 2°C, in line with the minimal objective of the Paris agreement. Moreover, it is very unlikely that global temperatures increase by more than 4°C (column 2). However, if greenhouse gas concentrations stabilise at 550 ppm, the picture is much bleaker. The mean increase in global temperatures is 2.4°C, but the

probability that temperatures increase by more than 4°C is 17.5% (column 4).

To analyse the severity of the damages, we could calculate the present value of the stream of losses. However, that would immediately pose the question about the discount rate to use. Following Quiggin (2017), we avoid this important question and evaluate the losses at some future date, say around the end of the century.

Damages are estimated by the loss function $L(\lambda, E)$, representing the percentage of GDP lost by the warming of the globe:

$$L(\lambda, E) = \{T(\lambda, E) - T_0\}^\kappa * L_0$$

where T_0 is the warming that can be sustained with minimal damages, L_0 a constant equal to the damages at T_0+1 and $\kappa > 1$, representing the convexity of the loss function. In our example, κ is set at 2.5.

The results are presented in Table 2 columns 3 and 5. If the world succeeds in keeping damages below 1.5°C, the aim of the Paris climate agreement, damages should be negligible. However, according to the IPCC, that is unlikely to happen. If greenhouse gas concentrations stabilise at 450 ppm and the average temperature increase is at 2°C, damages could be limited to around 1% of GDP. The IPCC warns that without additional efforts to reduce greenhouse gas emissions beyond those in place today, CO₂eq concentration levels could attain more than 1300 ppm by 2100 and the increase in global mean surface temperature could range between 3.7°C and 4.8°C. In such a scenario, losses could amount to around 20% of production without global warming. This is in line with the calculations in the Stern Review.

Can we wait?

A crucial question is how much income current generations are willing to sacrifice for the next generations in order to avoid catastrophic losses. Given the uncertainties, some argue that we should undertake a lot of action in order to make sure that global warming stays below 2°C. Others prefer waiting till more insight has been gained on the consequences of global warming to avoid unnecessary expenses.¹¹

A simple example two period model proposed by Summer and Zeckhauser (2008) may illustrate the problem. The two periods might be thought of as 10 year or 20 year periods. Environmental damages are experienced in the second period, due to greenhouse gases released in the first and second period.

In the absence of any abatement, emissions amount to 100 units in each period. The problem is to determine r_1 and r_2 , the abatements to be undertaken in period 1 and 2, respectively, expressed in percentages of total emissions. Emission reductions are not costless.

The cost function for either period is

$$C(r_i) = \gamma r_i^a$$

where $i=1,2$ and $a > 1$, implying increasing marginal costs and γ , a are constant.

¹¹ The problem is similar to the irreversible investment problem. See for example Dixit and Pindyck (1994).



Damages are determined by a stochastic binary variable d , which may be either high (H) or low (L) with equal probability. The mean value is 1, implying that $L=2-H$ and $1 \leq H \leq 2$.

At the end of the first period, the expected damages from emissions are learned, which will inform the level of reduction required in second-period emissions.

Losses at the end of period 2 are

$$L(r_1, r_2, d) = \{d(200 - r_1 - r_2)\}^q$$

The overall objective function at the start of period 1 is

$$\text{Minimize } \gamma r_1^a + 0.5 * (\gamma r_{2H}^a + \gamma r_{2L}^a) + 0.5 * \{[d(200 - r_1 - r_{2H})]^q + [d(200 - r_1 - r_{2L})]^q\}$$

Chart 2 shows the results for $q=1$ and different values of a , the parameter of the cost function. The lines demonstrate how the relative abatement effort in period 1, $R_1 = \frac{r_1^*}{(r_1^* + E([r_2^*]))}$ varies as a

function of uncertainty about damages in period 2 (H). Summers and Zeckhauser show that the results are very similar for $q=2$.

Early pollution abatement is optimal in case of high marginal costs and uncertain damages

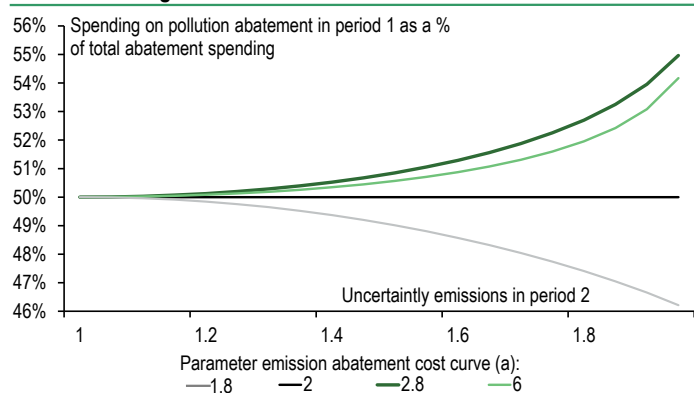


Chart 2

Source: BNP Paribas

An important question is whether more uncertainty leads to a larger or smaller fraction of total emissions reduction to be undertaken in period 1. Uncertainty is represented by the spread between H and L. It turns out that a , which determines marginal abatement costs, is a crucial parameter. If marginal abatement costs are low, it might be desirable to wait. However, if they rise rapidly ($a > 2$), as is assumed in most models, it becomes more attractive to do more abatement in the first period. The reason is that if damages turn out to be high, making all the abatement effort in the second period could become very expensive because of rising marginal abatement costs. In that case, it might be useful to prepare for climate change well before the effects of greenhouse gases are being felt.

Understanding tail risk

It is now widely agreed among climate scientists that the emission of greenhouse gases is the main driver behind the observed changes in global temperatures. What is less understood is how to deal with tail risks, rare events that have a catastrophic impact.¹² As we have seen, even when society succeeds in keeping the concentration of greenhouse gases below 450 ppm, the probability that temperature rises beyond 4°C, which could have catastrophic consequences, is not zero.

Economists often assume that people make rational decisions by maximizing a (collective) utility function. The psychologists Daniel Kahneman and Amos Tverski have studied human reactions. Their research shows that human decisions are likely to be directed by a set of inbuilt and largely intuitive mental shortcuts, what they call cognitive biases.¹³ They discovered that, unlike rational decision makers, people are more willing to gamble to avoid a loss than to obtain a benefit. In Kahneman's words: When offered the following: incur a loss of USD 900 for sure or take a 90% chance to lose USD 1000, then people take the gamble. But when offered the choice: Get USD 900 for sure or a 90% chance to get USD 1000, people opt for the sure reward of USD 900.

This sounds remarkably similar to the suggestion in the Nicolas Stern' report: "Using the results from formal economic models, the Review estimates that if we don't act, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever. If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20% of GDP or more. In contrast, the cost of action – reducing greenhouse gas emissions to avoid the worst impacts of climate change – can be limited to around 1% of global GDP each year."¹⁴ On these grounds, one may fear that people are willing to take a chance with climate change, rather than adapting their lifestyles.

Professor Jonathan Wiener identifies three main sources for the neglect of tail risks.¹⁵ The first source is **unavailability**. Research has shown that people tend to underweight the chances for common accidents and overweight the probability of severe accidents. Many people are more concerned about being involved in a plane crash or a terrorist attack than in a car accident. However, the former are much less common than often assumed. Moreover, serious accidents are often followed by inquests, which may result in new regulations to prevent a repeat. A mining accident might lead to a new set of underground safety rules. However, public health risks related to coal combustion, which actually claim a much higher death toll, are often underrated.

Despite their concern about serious accidents, the public is much less concerned about catastrophic risk, such as abrupt climate change, killer viruses, and large asteroid collisions. Policy makers have to set priorities in addressing all these dangers. For example, in 2009, despite

¹² This is sometimes called the "tragedy of the commons". See Wiener (2016).

¹³ Kahneman (2011)

¹⁴ Stern (2007), page 14

¹⁵ Wiener (2016)



warnings by public health authorities, an outbreak of H1N1 virus was shrugged off by the public. The reason for this attitude is a fortunate lack of experience of catastrophic risks. Movie theatres are among the few places where catastrophic risks are depicted. However, as movies are associated with amusement, this does little to heighten public awareness.

A second reason is the **large magnitude** of the impact of catastrophic risks. Research has been done in how much people are willing to pay for saving other people from risks. One would expect that the willingness would rise with the number of people involved. Researchers found indeed that the willingness rises, albeit at declining rate until it levels off. If the number of victims becomes very high, the willingness to pay declines. The psychologist Paul Slovic terms this “psychic numbing”¹⁶. A reason might be that people feel overwhelmed by the numbers. The public might have a strong emotional response to an identified individual, but not to a large and unidentified population. For this reason, NGOs often make use of a poster person in their funding campaigns. Lastly, the public may also be eager to combat an identified villain rather than a faceless natural disaster or a ubiquitous social problem.

A third reason for the neglect of tail risks is **under-deterrence**. Traditional legal systems have difficulties in handling mega-catastrophes. After a major disaster, institutions might break down, making it difficult to hold people responsible and force them to repair the damage. For this reason insurance against such mega disasters does not have any practical meaning. Policyholders do not want to pay premiums if they fear that the insurer will not be able to pay claims or even might not exist anymore after a mega disaster.

Framing climate policy

Public authorities have been much more aware of the reality of tail risks than the public at large. Since 1990, the US military authorities considered climate change as a “threat multiplier,” that could threaten operational effectiveness. In 2015, President Obama even identified climate change as one of the top strategic risks.¹⁷ This was subsequently scrapped from the list by President Trump in December 2017. In a 2014 report by the Center for a New American Security on the relation between national security and the risk of climate change, retired US general Gordon Sullivan notes: “Speaking as a soldier, we never have 100 percent certainty. If you wait until you have 100 percent certainty, something bad is going to happen on the battlefield.”¹⁸

A major challenge for climate policy is to overcome public resistance. As we have seen, people care much more about losses than about gains. However, keeping carbon concentrations at relatively safe levels may imply changes in lifestyle. Sacrifices have to be made for people living in poorer parts of the world to help them in investing in sustainable energy and in dealing with the already observed consequences of

climate change.¹⁹ Moreover, it is also about our willingness to invest for the coming generations. As long as climate change does not seem a very pressing problem, it is very tempting to become free-riders and let the coming generations make most of the effort in cutting back on greenhouse gas emissions. That would be a terrible mistake. For example, investment in energy infrastructure is an important determinant of carbon emissions in the decades to come. By investing now in sustainable energy sources we could considerably reduce greenhouse gases for future generations.

To convince the public of the need of avoiding climate change, environmental policies need to be appropriately framed. In the Stern Review, it is argued that for ethical reasons, intergenerational neutrality, the discount rate should be set close to zero for the optimisation of social welfare among generations. It is one of the reasons for the substantial differences between the Stern Review and earlier studies. This position has been heavily criticised. Nordhaus argued that the criterion of intergenerational neutrality is not as universal as the authors of the Stern Review would have us believe.²⁰ His main criticism is that this approach does not touch on structure of actual intertemporal decision-making. Each generation cannot decide for the coming generations how to act. Instead, he considers each generation as members of a relay team, “handing off the baton of capital to the next generation and hoping that future generations behave sensibly and avoid catastrophic choices by dropping or destroying the baton.” Summers and Zeckhauser (2008) make a similar argument by comparing policies to valuable antiquities, handed down between generations. “Each generation has the choice to sell the furniture but may think it may be optimal to continue, trusting that successive generations would see matters the same way.”

The Paris climate deal could be seen as a policy that can be handed down to the next generations. At the moment, the countries are negotiating on procedures for ratcheting up of the abatement objectives. A decision should be taken at the COP24 in Katowice (Poland) in December 2018. The Paris agreement and procedures (the so-called toolkit) are the policies that can be passed on to the next generations. Countries can drop out, as is already to be the case with the US, but they are also aware of their responsibilities. It will be extremely difficult to negotiate again a new carefully crafted document. Hence, it might be better to stick with the existing agreement and hope that the US will re-join at a later stage.

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¹⁶ Slovic (2010)

¹⁷ <http://nssarchive.us/wp-content/uploads/2015/02/2015.pdf>

¹⁸ CAN Military Advisory Board (2014)

¹⁹ In the Paris climate agreement, the developed country promised to make available funds amounting to at least USD 100 bn each year from 2020 onwards to assist the poorest country in adaptation and mitigation policies.

²⁰ See, for example, Nordhaus (2007).



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