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Preface

The thesis is a collection of three papers focusing on the economics of natural disasters and climate change studies, each work investigate the topic from different perspectives and using the different tool.

In the first paper: “*Climate change, catastrophes and the Dismal Theorem: a critical review*” I review in depth the main studies in the field. In the second paper, “*Living on the Edge of the Catastrophe*”, I provide a theoretical model on policy design under risk of suffering a natural disaster. In the third paper, “*Environmental Disasters and Electoral Cycle: An Empirical Analysis on Floods and Landslides in Italy*”, I provide an empirical model linked to a political agency model, in order to address land policy (and consequently the soil sealing phenomena) in Italy during the last decades.

Through the first paper **Climate change, catastrophes and the Dismal Theorem: a critical review**, we provide an overview of the main studies about catastrophic scenarios and environmental policy in the presence of natural disaster risk related to climate change. The investigation is able to discuss how the literature has analysed these topics, modelling extreme case scenarios. Thus we focus on the main criticalities on the point such that the inter-generational equity, the debate around the use of a proper time rate preference and the consequent debate on the usefulness of Expected Utility theory in modelling catastrophic climate change with respect to the long time horizon. We focus on works have been able to provide answers and interesting policy recommendation and useful technicalities to use. This, reviewing also the most recent theoretically evolution on the assumption of rationality, investigating the newest papers entailing experimental approach.

The second paper **Living on the edge of the Catastrophe**, provides a theoretical model analysing environmental policy under uncertainty regarding the possibility of a natural disaster. We adopt a two-periods analytical model, to investigate two different institutional settings, one featuring a myopic social planner, choosing emissions in each time period to maximize current net benefits, and one featuring a forward-looking planner, who maximizes the expected net present

value of welfare across the two periods. The, uncertainty regards a threshold pollution level that, if violated, triggers a natural disaster. We conclude that under a myopic social planner welfare may increase or decrease over time, while in a non-myopic scenario welfare always increases across periods. Also, our model supports the idea that a myopic social planner pushes emissions closer to the edge of the natural disaster, but then, if the latter does not take place in the first period, benefits from having done that in terms of welfare in the second period. Introducing a stochastic decay rate, we also show that the environment may reward (punish) myopic behaviour ex post. Finally, the comparison between myopic and forward looking settings is not straightforward: this depends on a risk spreading vs. information learning trade off.

Throughout the third paper **Environmental Disasters and Electoral Cycle: An Empirical Analysis on Floods and Landslides in Italy**, we provide an empirical analysis on natural disasters concerning the potential drivers of regulators behaviour in the presence of risky actions. More specifically, we focus our attention on floods and landslides, and we select building permits as our measure of regulatory stringency.

We first build up a simplified theoretical framework based on public economics and political agency model, and then we derive theoretical results to be tested empirically. This is done by relying on a unique dataset covering Italy in the period 1995-2013 and containing information on soil sealing, building permits and natural disasters (floods and landslides), together with data on elections, at provincial level.

Our main conclusions suggest that the electoral cycle is an important driver of building permits: anticipated elections increase permits significantly while unanticipated ones do not. Further, a bad history in terms of disasters decreases permits, suggesting that such a bad history strengthens the relevance of “green” voters, but regulators and voters have “short memory”, as the impact vanishes after a relatively short time span.

Chapter 1

Climate change, catastrophes and Dismal Theorem: a critical Review.

Abstract

The aim of this paper is to provide an overview of the main studies about catastrophic scenarios and environmental policy in the presence of natural disaster risk related to climate change. We investigate how the literature has analysed these topics, modelling extreme case scenarios.

Throughout this review we want to investigate how the related literature has evolved during the recent years and how the historical evolution of climate change issue has influenced the academic studies (and viceversa).

We focus on two main criticalities: i) the intergenerational equity between present and future generations (Stern, 2006); ii) the time rate preference linked to the intergenerational equity, from the use of fat-tail and the consequent debate around the Dismal Theorem (Weitzman, 2009) to the debate around the usefulness of Expected Utility theory.

Keywords: Catastrophe, Uncertainty, Environmental Policy, Risk, Natural Disaster.
JEL Classification: Q54

1.1 Introduction

In the last decades the literature on climate change risk, and overall on environmental policy, has significantly increased. Since the Kyoto agreement, the general consensus about the climate change issue (which is not always granted) along with the rising policymakers' effort, focused the attention on this topic and on the studies on extreme events.

Indeed, the common consensus around the topic is rapidly changing and, at the institutional level the effort to design a proper policy aiming to avoid the worst impacts of climate change has increased over time. This is testified by the lively debate surrounding the most recent conferences

of parties¹. The main issues revolve around the implementability of policy and the reliability of future previsions.

Thus, the literature is adopting both a theoretical and a technical focus: on the theoretical side it is not straightforward to justify the political cost due to an environmental policy; a more technical level the probability structure to be used in modelling future catastrophic scenario is controversial.

Regarding the political cost there are two mains debatable points: the inter-generational equity, and so the opportunity to engage in policies increasing the well-being of future generations (Stern, 2006), (Weitzman, 2009); the social equity, meaning the opportunity to impose costs of policy only to the rich countries or also to the poorer ones (Dasgupta, 2007).

Focusing on the first issue, every paper or report investigating catastrophic scenarios linked to climate change has to provide analysis assuming or recommending a political viable intergenerational policies (Ackerman et al., 2009, Dietz et al., 2007, Stern, 2006, Sterner and Persson, 2008, Tol and Yohe, 2006, 2007, Weitzman, 2009).

Consequently, a very controversial issue in the literature regards the value of discount factor between present and future utility (pretty always present and future generation), together with the assumption of a stochastic discount factor (Weitzman, 2009).

These unresolved problems are due to the existence of more than one source of uncertainty: the future preferences (future utility), the potential for environmental damage due to climate change, the probability of extreme events and the severity of the extreme events.

The pure time rate preference, and so the discount factor, is one of the most debated issues in this decade. This is so because the discount factor involves several theoretically disputable points.

According to this, before going deeper in to the debate about the Dismal Theorem (hereby, DT), (Weitzman, 2009) we will investigate how the approach on modelling discounting in the climate change literature has been modified after the Stern Review (Stern, 2006).

Weitzman (2009), uses a fat-tailed function in order to estimate the risk of a climate catastrophe, this leads to the result that it is necessary to conduct extremely expensive environmental policies in order to be “safe”. The effect on the literature has been shattering, and the paper attracted many critiques, mainly technical but also regarding the conclusions and policy recommendations provided.

The rest of the paper is organized as follows, any section has a paper as landmark and discusses the debate around that paper: in section 2, we discuss the Stern Review (Stern, 2006), deemed by

¹See, for example COP21 and related materials: <http://www.cop21paris.org/>

most scholars a sort of handbook of the economics of climate change; in section 3 we will present the DT (Weitzman, 2009) commenting the technical choices of the author; section 4 is focused on the critiques against the DT and the debate on this; in section 5 we will present the most recent work paying attention to the recent (and future) debate stressing the Expected Utility theory (hereby, EU theory) and the assumption of rationality; section 6 concludes giving remark and suggestion for future works.

1.2 Stern Review and debate

Since the beginning of the current century, there has been an increasing interest in the field of catastrophic scenarios with a particular focus on climate catastrophes. The breakdown of Kyoto agreement and the general consensus about the climate change issue from populations, academia and governments has guided the research on this topic.

Thus, many studies providing interesting policy recommendations has been made along these years. The most important work about climate change catastrophic scenario and natural disaster studies, and overall about environmental policies and analysis, is the one by Stern and published by the U.K. government: *The Economics of Climate Change: The Stern Review* (Stern, 2006).

The reason why a government decides to finance a similar study is to avoid the same mistakes done through the Kyoto agreement.

It is interesting, indeed, to remember the *DICE-Model* made by Nordhaus (1993) and the title of the paper that follows the same assumption framework *Requiem for Kyoto: An Economic Analysis of the Kyoto Protocol*².

The Stern Review is a huge study on the risk and policies around the climate change issue. The aim of the Review is to lay down the basis for future research about climate policy and to discuss the divergences in the different models implemented in the economics analysis.

The academic debate regarding the climate change effect is focused on the uncertainty about the future scenario and the policy expenditure in order to avoid the worst-case scenarios. The Stern Review is focused exactly on these aspects. Indeed, Stern (2006) provides simulations, under different assumptions frameworks, about the standard inter-temporal welfare function $W = U(C_0) + \beta E [U(C_i)]$. Thus he asserts that, modelling the catastrophic climate change, the discount rate (β represents the

² Nordhaus and Boyer (1999).

discount factor) has to be extremely low due to the large inter-temporal horizon (C_i is consumption by future generations), as otherwise we would underestimate the catastrophic scenario. This assumption faced some scepticism, first of all from [Weitzman \(2007\)](#) and also some others authors like [Henderson \(2007\)](#), [Carter et al. \(2007\)](#) and [Tol and Yohe \(2007\)](#).

The other controversial point of the academic debate regards the expectation $E(\cdot)$ of future utility. The analysis about the right assumption framework to use in a climate policy model, few years after, has conducted to the DT ([Weitzman, 2009](#)) and it is still not over.

The Stern review provides clear answers entailing a policy prospective. A debatable point of the assumptions framework utilized is related to the discount factor, giving a great importance to the future generations' utility.

As argued by the author, this choice entails a policy recommendation: *“future generations should have a right to a standard of living no lower than the current one”*³, which follows from the concept of sustainability. Thus, in order to model it, Stern uses a very low discount rate r defined as $r = \delta + \eta g$, where δ is the pure discount rate, η is the elasticity of the growth rate path, $g = \frac{\dot{c}}{c}$ and, consequently, the discount factor is given by $\beta = e^{-rt}$.

This particular assumption has faced many objections in the academia. [Weitzman \(2007\)](#) argues that, according to the model provided by Stern, it should be necessary to save the entire present endowment in order to mitigate the losses. Weitzman, in fact, plugging the values of r , δ and η used by [Stern \(2006\)](#) in a balanced growth path, underlines the result regarding the saving rate: $s = \frac{r-\delta}{\eta r}$. Using the values of δ and r assumed by [Stern \(2006\)](#) the simulation gives a $s \approx 100$ per cent of saving and through this [Weitzman \(2007\)](#) asserts that to use $\delta \approx 0$, $\eta \approx 1$ is a non-conventional assumption, too strong with respect to the mainstream economics, and involves an “unconvincingly” policy recommendation. [Dietz et al. \(2007\)](#), defending the Stern Review, argue that introducing technological progress the implied saving rate would change.

[Dasgupta \(2007\)](#) highlights another important point of discussion, analysing the distinction between δ and η , that is “crucial”, according to the author, because if the first affects the intergenerational distribution, the second involves the distribution among agents of the same generation. Thus, [Dasgupta \(2007\)](#) makes a note of the evidence that [Stern \(2006\)](#) uses an extremely egalitarian view of the intergenerational distribution but an extremely non-egalitarian view between richer and poorer countries.

³ [Stern \(2006\)](#) page 42.

An accurate analysis on parameters values is made by [Stern and Persson \(2008\)](#) that conduct a deep observation of every Stern's choice:

- With respect to δ , [Stern and Persson \(2008\)](#) note that high value for the pure rate of time preference, implicitly suggests policies making extinction more likely to occur. Thus, also according to Stern and Persson, Stern uses a “*very egalitarian view of intergenerational distribution*” but this does not seem to be a mistake.
- Regarding η , the utility of growth, [Stern and Persson \(2008\)](#) argue that “*it is ironic that Stern has been accused of using too low value for η when he has used a value of one*”. In fact, in standard real business models, η is close to zero and it is straightforward to think of a concave utility function.
- Finally, concerning g for the authors ask on the possibility that Stern uses a growth rate which is too high and, moreover, they wonder if it is licit or not to use an eternal growth in a similar analysis⁴.

Controversies regarding the parameter's values aside, [Weitzman \(2007\)](#) criticizes how [Stern \(2006\)](#) faces the uncertainty regarding the future value of r : $E(r)$. Stern uses a linear combination between a high value and a low value of r , and then he solves $\frac{1}{2}e^{r_1} + \frac{1}{2}e^{r_2}$. Even though, the value obtained is acceptable, Weitzman criticizes the expectation, proposing to use a set of subjective probabilities $\sum p_i$ of the value of the discount rate r_i . Thus, he obtains $r(t) = -\frac{\ln \sum p_i e^{-r_i t}}{t}$, that declines monotonically over time to an asymptotic limit for $r(\infty) = \min_i \{r_i\}$. Hence, the Weitzman's conclusion is: “*Stern is right for the wrong reasons*”.

Indeed, regarding the Ramsey formula used by Stern, Weitzman suggests to treat the growth rate g as a normal random variable: $g \sim N(\mu, \sigma^2)$, where σ^2 is the known variance, obtaining $r^f = \delta + \eta\mu - \frac{1}{2}\eta^2\sigma^2$. Actually, to use a random variable in order to represents the growth rate gives fair importance to the volatility as compared to the interest rate.

Overall, [Weitzman \(2007\)](#) discards some aspects of the “political document” known as Stern Review⁵ because these are too strong and given by strong theoretical assumptions, that are not easily testable empirically. While this may be true, it is possible to move the same objection also to

⁴ Regarding this point, Stern and Persson lament the academic discredit of the “limit to growth theory” ([Meadows et al., 1972](#)), and the Malthusian “absurd” idea that if the planet is finite an eternal exponential growth could be a problem ([Malthus, 1798](#)).

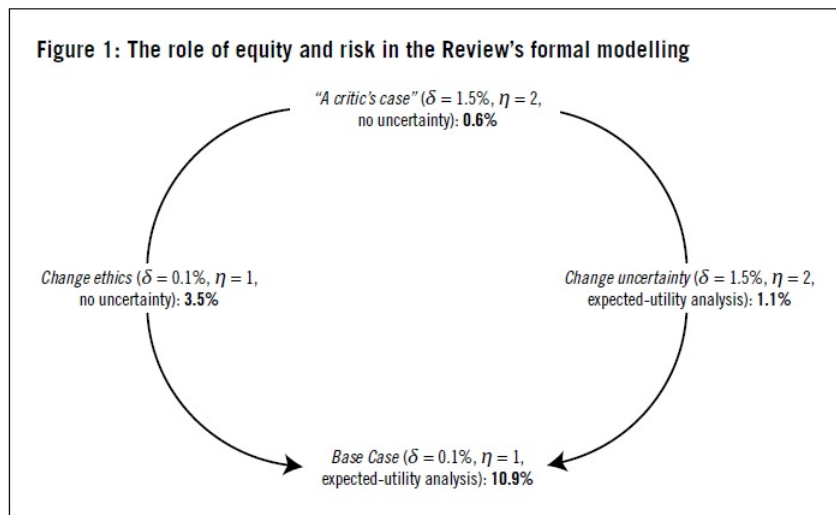
⁵ [Weitzman \(2007\)](#) page 723.

the modification proposed by Weitzman.

On this ground, the analysis proposed by Dietz is extremely interesting; [Dietz et al. \(2007\)](#) argue that the ethical considerations regarding the responsibilities among generations, necessarily “boil down” the model into a very simplistic one. The point is the same for any value chosen: “*how do we, as a generation, value benefits to collective action to protect the climate for generations a hundred or more years from now?*” and taking into consideration the fact, that the damage due to the climate change could affect the future growth, so that also the values of g is not straightforward.

Undoubtedly, the link between the evaluation of risk and inter-generation ethics is not univocal.

Figure 1.1. Consumption Choice along two time periods, [Dietz et al. \(2007\)](#).



A critic's case: [Nordhaus \(2006\)](#)
Base Case: [Stern \(2006\)](#)

[Figure 1.1](#) shows two extreme views present in the literature: [Nordhaus \(2006\)](#) and [Stern \(2006\)](#) and it is added to this two intermediate simulations. In the underside part of the figure, indeed, it is represented the estimation made by the Stern Review asserting that climate change will involve more than ten per cent of loss in global mean consumption per-capita.

At the top of the illustration there is an example of study in which the effects of climate change are taken into consideration in an optimistic way (considering the risk) and using a smaller coefficient concerning the utility of the future generations: [Nordhaus \(2006\)](#) in which $\delta = 1.5\%$ and $\eta = 2$. Moreover, in that paper there is not (or very little) uncertainty. [Dietz et al. \(2007\)](#) argue that within a similar simulation it is not possible to justify any policy action because, according to the chosen parameter values the estimated damage is only 0.6% of the current consumption.

Dietz et al. (2007) focus their attention on the more sensitive aspect of the Stern framework of analysis, making two additional simulations. The first, entailing “a larger ethical weight” but omitting uncertainty, and the second one introducing uncertainty, but using the same parameters used by Nordhaus (2006). In that case, the cost of climate change increases with respect to Nordhaus (2006) but not significantly. This, because “*the interaction between risk and ethics ... is crucial*”⁶.

Although it is licit to assert that some assumptions imposed by Stern (2006) are “political” it, is also possible to make this critique for any assumption framework chosen. In fact, the authors of this critique receive the same kind of comments after a couple of years (it is the case of critiques on the Weitzman’s DT).

Notwithstanding the doubts, the critiques and the controversies, the Stern Review obtained a widespread attention by the academia, by supranational and national institutions.

Moreover, even the idea that Stern overestimates the climate risk (Tol and Yohe, 2006) is contradicted by some papers, an interesting example of this being Ackerman et al. (2009). They use the same assumptions of Stern (2006) changing some parameters considered to be too “optimistic”, concluding that the climate damage for the future is bigger than the one computed by the Review in terms of future loss of GDP. According to their paper, the climate damage is estimated as a loss of 10.8% with respect to the current GDP in 2100, whereas Stern has estimated this loss at 2.2%.

The authors over three important parameters differently: the threshold of a climate catastrophe⁷, the probability of it⁸ and the damage function⁹. Thus, Ackerman et al. (2009) conclude that Stern (2006) does not inflate the damage and estimate correctly the cost of climate change.

The academic debate regarding the technical aspects of the Stern Review covers, more or less, every part of the assumption framework. It is so unequivocal that the Stern Review is a breaking point in environmental policy analysis, as it. “*(...) has come to symbolize something of a dividing line in the evolution of the common appreciation of the climate problem. (...) the Stern Review is the first major, official economic report to give climate change a really prominent place among global problems*”. (Sterner and Persson, 2008)

⁶ Dietz et al. (2007) page 245.

⁷ Stern uses a Monte Carlo simulation in order to establish a threshold temperature (degree above the present one) that must be reached before catastrophic events becoming possible. Stern (2006): < 2, 5, 8 >; Ackerman et al. (2009): < 2, 3, 4 >.

⁸ Meaning that there is a rate at which the probability of having a catastrophe increases along with the increasing in the temperature. Monte Carlo simulation, Ackerman et al. (2009): < 1, 10, 20 >; Ackerman et al. (2009): < 10, 20, 30 >.

⁹ In Stern (2006) the damages function is given by aT^N , where a is an uncertain parameter that is allowed to vary in the Monte Carlo analysis. He set the values as < 1, 1.3, 3 >, whereas Ackerman et al. (2009) as < 1.5, 2.25, 3 >.

The controversy around the conclusions and estimations has been widespread, the kind of integrated assessment model used (called PAGE2002) has been involved in many other papers also covering different environmental fields (an example could be [Alberth and Hope \(2007\)](#)).

The PAGE2002 is able to follow all the damages caused by climate change as described by the third IPCC Report ([UNFCCC, 2001](#)). Recall that the most recent UN reports was not yet produced in 2006¹⁰ and the ones produced after, followed the Stern framework¹¹.

[Hope \(2006\)](#) summarizes that the PAGE2002 is an update of the PAGE95 integrated assessment model ([Plambeck and Hope, 1996](#)) able to investigate all the following aspects: *Emissions of the primary greenhouse gases, CO₂ and methane, including changes in natural emissions stimulated by the changing climate; The greenhouse effect; Cooling from sulphate aerosols; Regional temperature effects; Non-linearity and transience in the damage caused by global warming; Regional economic growth; Adaptation to climate change; The possibility of a future large-scale discontinuity.*

In order to deeper analyse the modelling of PAGE2002, the appendix of [Hope \(2006\)](#) provides a great synthesis.

One aspect that will be deeply stressed during the same years, regards the probabilistic features of the model; through Stern spreads the level of uncertainty in the his model, according to Weitzman and many others authors (...) it is not enough. The point is an endemic one: every study on catastrophic scenarios has to analyse also situations with a small probability of realization. Moreover, the different sources of uncertainty and the limits to information justify the use of “fat-tailed” probability.

Thus, three years after Weitzman will derive his DT ([Weitzman, 2009](#)) and the debate that will rise will be widespread.

1.3 Dismal Theorem and recent literature

As argued above, in the recent years the literature production about environmental economics, catastrophic scenarios and policy against natural disaster opportunity has increased. This, thanks to a general awareness about the issue, for the predicted failure¹² of Kyoto agreement and also thank to the Stern Review (2006), already discussed.

The many sources of uncertainty have been, and still are in nowadays academic debate, one of

¹⁰ UNFCCC (2007) and UNFCCC (2014).

¹¹ http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5447.php

¹² Nordhaus (1993).

the most controversial points. [Barrett \(2013\)](#) work is one of not many example of a paper that investigates the uncertainty behind the level of pollution (or lack of pollution control) that causes a natural disaster. The author analyses the uncertainty by using a uniform and a Gaussian random variable in order to analyse the level of pollution that could determine a catastrophe or not, according to this assumption any increase in emissions unit provides a higher risk to cause a disaster.

His paper, concerns the climate treaties among countries. An interesting conclusion by [Barrett \(2013\)](#) is that the severity of the possible disaster does not affect the Nash equilibria of the model.

Another unresolved debate present in the literature regards the appropriate welfare framework in order to evaluate the environmental policy, especially about the climate change. One stimulating work about this, is the one by [Heal \(2009\)](#) that conducts an analysis about the different tools used in the literature in order to investigate climate change policy.

A key point of academic discussion, as investigated in the previous section, is the discount rate. As we show, [Stern \(2006\)](#) argues that the pure rate of time preference (PRTP) is extremely low, and there exists a widespread discussion about this issue.

[Heal \(2009\)](#) agrees on the perspective that it is also important to study the elasticity among goods; moreover, he stresses the role of uncertainty investigating the solutions proposed by [Stern \(2006\)](#) and [Nordhaus \(2007\)](#). According to [Heal \(2009\)](#), in fact, *“Uncertainty is one of the dominant facts in any analysis of climate change”*. The point is that in the field there are different sources of uncertainty, that regard the magnitude of possible catastrophe, which kind of pollution could cause it.

Straightforward, any study entailing the possibility of having a natural disaster has to face the uncertainty about this possibility and about the information available to the agents facing the issue.

Entailing the possibility of having a catastrophe requires a deep analysis of events having a negligible probability to occur. This stresses the normal tools of *EU theory*, that mostly is not sensitive to small probability events.

The point carried out in relation to some environmental problems is exactly what make sensitive EU theory not to low probability, high value events. For instance, economic issues posed by climate change involve the need to investigate, under uncertainty, the best policy for low-probability events with high-impact catastrophic consequence. [Weitzman \(2009\)](#) focuses his work on this.

The main point of [Weitzman \(2009\)](#), is to show *“that the economic consequences of fat-tailed structural uncertainty (...) can readily outweigh the effects of discounting in climate-change policy*

analysis". This is done using a framework which differs from models of uncertain catastrophes where the uncertainty has form of a know thin-tailed Probability Density Function (here by, PDF). Indeed, the author provides a model with fat-tailed PDF, which are the consequence of the link between the thick-tailed probability, stemming from the evidence, and the thick-tailed probability represented by the likelihood function.

The particular feature of [Weitzman \(2009\)](#) work, is the discount factor. Since he used a two time periods theoretical model, he has chosen to use a stochastic discount factor instead of a fixed rate. The stochastic discount factor used by Weitzman is defined as the ratio between future expected marginal utility $E[U'(C)]$ and the current one $U'(1)$, considering also the pure rate time preference β : $M := \beta \frac{E[U'(C)]}{U'(1)}$.

According to the [Weitzman \(2009\)](#) framework of analysis, through this stochastic factor M , it is possible to derive the marginal rate of substitution between present and future consumption of a certain infinitesimal unit δ . The conclusion is that this stochastic discount factor M tends to infinity.

The author obtains this, starting from three main assumptions¹³:

- i) The coefficient of relative risk aversion $\eta(c) := -c \frac{U''(C)}{U'(C)}$ is strictly greater than zero as $c \rightarrow 0$.*
- ii) The consumption growth rate $y := \log C$ is distributed according to a probability density function $h(y|s) = \frac{1}{s} f(\frac{y-\mu}{s})$, where f is a normalizable function, μ is a know location parameter, and s is an uncertain scale parameter. Weitzman interprets s as a "generalized climate sensitivity parameter" (...).*
- iii) The prior on s is of the form $p(s) \propto s^{-k}$, where $k > 0$, and you are given a finite number n of independent observation y_n of the random variable y .*

The first assumption (*i*), as is summarized by [Millner \(2013\)](#), is simply a form of risk aversion; the second one (*ii*) is an assumption used to represent the consumption growth linked to climate change, straightforward Weitzman adopts a stochastic form; the third assumption (*iii*) regards the uncertainty on climate sensitive.

Thus, the author concludes that the consumption will decline in a "catastrophic" way $y \rightarrow -\infty$, whereas, the stochastic discount factor tends to infinity (DT):

- a) The posterior distribution for y , $q(y|y_n) \propto \int_0^\infty h(y|s) \Pi_n h(y_n|s) p(s) ds$ scales like $|y|^{-(n+k)}$ as $y \rightarrow -\infty$.*

¹³ The Dismal theorem is provided by [Weitzman \(2009\)](#) work, this summary of the assumptions and conclusions is given by [Millner \(2013\)](#).

b) *The stochastic discount factor $M \rightarrow \infty$.*

The conclusion (a) is substantially the central result of the DT, the consumption growth declines to $-\infty$, because the PDF $h(y|s)$ depends on a prior $p(s)$, which depends, negatively, on a $k > 0$.

As argued, this work is a big innovation in modelling the risk of a catastrophe related to climate change and the reaction in the academia has been significant. The idea of a CBA entailing a fat-tailed risk is not widely accepted, also because this involves an expensive and quick policy reaction. This is so, even though it is commonly accepted that the policy should be oriented to reduce the probability to experiment a catastrophe in the future.

Moreover, the author (due to the strong critiques made against the assumptions of the DT), provides interesting reasoning on the use of the framework here analysed, observing the probability to assign of the climate change response to GHG change, namely the equilibrium climate sensitivity (“a good example of a know unknown”¹⁴). Thus, in a subsequent work [Weitzman \(2011\)](#) argues that results can depend on seemingly random decisions about how to model tail probabilities; specifically, we use a Pareto PDF or a normal one. It is true, indeed, that using the same probability of [UNFCCC \(2007\)](#), there is a great difference in upper tail behaviour between the Pareto and the Normal distribution. This, adds to the fact that only on this point there are at least two sources of uncertainty: the change in temperature ([Table 1.1](#)) and the sensitivity to GHG emissions ([Table 1.2](#)).

Table 1.1. $Prob[S \geq \hat{S}]$ for fat-tailed Pareto and thin-tailed Normal distributions

$\hat{S} =$	$3^{\circ}C$	$4,5^{\circ}C$	$6^{\circ}C$	$8^{\circ}C$	$10^{\circ}C$	$12^{\circ}C$
$Prob_P[S \geq \hat{S}]$	0,5	0,15	0,06	0,027	0,014	0,008
$Prob_N[S \geq \hat{S}]$	0,5	0,15	0,02	0,003	$7 * 10^{-7}$	$3 * 10^{-10}$

[Weitzman \(2011\)](#) p. 279

On [Table 1.2](#), \hat{S} is the temperature increasing threshold analysed and the values shown represent the probability that the threshold is violated. The following table represent the link between emissions and temperature increase. According to the different probability structure assumed, Pareto = $Prob_P(\cdot)$ = fat-tails and Normal distribution = $Prob_N(\cdot)$ = thin-tails. How the *ppm* of CO_2 affects the increasing of temperature? Straightforward, it is uncertain, and the author is able to show how

¹⁴[Weitzman \(2011\)](#) page 277.

(and why), using fat-tailed distribution the outcome is more worrisome (Byrnes, 2015). For any value of *ppm* Weitzman (2011) shows the probability to violate some ($5^{\circ}C$ or 10° threshold, as follows.

Table 1.2. Probabilities of exceeding $T = 5^{\circ}C$ and $T = 10^{\circ}C$ for given $G = ppm$ of CO_2e

G	400	500	600	700	800	900
<i>MedianT</i>	1,5°	2,5°	3,3°	4,0°	4,5°	5,1°
<i>Prob_P[T ≥ 5°C]</i>	1,5%	6,5%	15%	25%	38%	52%
<i>Prob_N[T ≥ 5°C]</i>	10 ⁻⁶	2,0%	14%	29%	42%	51%
<i>Prob_P[T ≥ 10°C]</i>	0,20%	0,83%	1,9%	3,2%	4,8%	6,6%
<i>Prob_N[T ≥ 10°C]</i>	10 ⁻³⁰	10 ⁻¹⁰	10 ⁻⁵	0,1%	0.64%	2,1%

Weitzman (2011) p. 279

Generally, the debate affects, mainly, the mathematical tools and assumptions used in the DT, not the underlying principles. Thus, in the presence of fat-tailed outcomes and strong risk aversion, it is not possible to use the standard EU theory, because the probability of catastrophic events does not decline sufficiently rapidly to compensate for risk aversion. On the other hand, it remains crucial to include the deep structural uncertainties concerning catastrophic outcomes, influencing plausible applications of any Cost-Benefit analysis to the economics of climate change for the foreseeable future.

1.4 Critiques to Dismal theorem

The interpretations and the assumptions of Weitzman (2009) paper had faced a significant debate (it is possible to count more than one thousand citations)¹⁵. In fact, according to a relevant branch of the environmental literature, the dismal theorem has not great relevance regarding the climate problem and the modelling strategy proposed by Weitzman is not useful in order to conduct a cost-benefit analysis.

We can summarize the assertions against the DT assumptions' framework along three lines: *i)*

¹⁵ Horowitz and Lange (2014), Karp (2009), Nordhaus (2011) and others.

The assumption that does not allow to endowment transfer (Horowitz and Lange, 2009); *ii*) The fact that infinite marginal willingness to pay does not imply total willingness to pay is infinite (Karp, 2009); *iii*) The use of a CRRA utility function (Arrow and Priebsch, 2014).

Horowitz and Lange (2009) show that it is possible to apply the Weitzman's model only in the cases in which it is not possible to shift wealth from the present to future. This is a strong limit of the Weitzman's model, and even though many papers give different kinds of critiques, this remains a central point.

In fact, the impossibility to do investment during the first time period affects the expected value of the stochastic discount factor. The authors, using the same model but considering the explicit investment decision, obtain quite different results. According to this, they conclude that (...) *the optimal expected marginal rate of substitution between current and future consumption is finite (...)*. This is the main difference within the authors' methodology and the one by Weitzman (2009).

As argued above, the difference from Weitzman (2009) is that the investment decision is explicit. Thus, in the second time period there will be $C_1(S) + R(p, s)$, where $R(p, s)$ is the return to p ¹⁶ investment decided during the first time period. Thus, Horowitz and Lange (2009) do not obtain $\beta \frac{E[U'(C_1(S))]}{U'(1)} = \infty$ as optimal investment choice if it exists a technology which is able to transfer an asset into the future¹⁷. In fact, even if we assume optimal choice $p = 0$ we have that $\beta \frac{E[U'(C_1(S))]}{U'(1)} = \frac{1}{R'(0)}$, contradicting Weitzman (2009) straightforwardly.

The point is that the Weitzman (2009) work proceeds along the Bayesian paradigm¹⁸, as, he uses a likelihood function in order to investigate the behaviour of the random variable. According to this framework of analysis the conclusion regarding an infinite marginal rate of substitution is obvious.

The critiques made by Karp (2009), follows the same idea. In fact, also Karp highlights this point of analysis concluding that the likelihood function entailing the intra-generational conflict arising from climate change policy could be exaggerated under two circumstances: (a) if it is not possible to change the composition of investment between man-made input and natural capital; or (b) if the investment decisions are not able to internalize neither future nor present damages¹⁹.

Karp (2009) conducts an analysis of consumption along two time periods, studying the consump-

¹⁶ $0 < p < 1$ where the entire consumption is normalized to 1.

¹⁷ Horowitz and Lange (2009): Proposition 1, page 4.

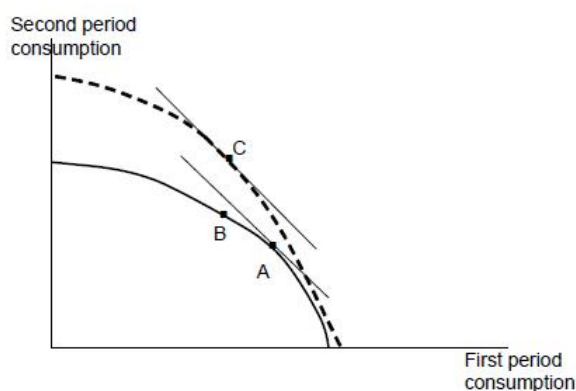
¹⁸ Millner (2013)

¹⁹ Karp (2009), page 27.

tion's possibility frontier (Figure 1.2). According to Karp, the internalization of present damage and the opportunity to abate during the future time period (i.e. the possibility to consume abatement), provokes a shifting of the curve (the consumption possibility frontier) to the right from the plain to the dotted curve. According to this, the discount rate has a key role in order to take the decision to abate or not. The first best C, entails a positive amount of abatement during both time periods. The point is that in this first best the investment decision during the first time period claim emissions during the second one, thus the emissions decision is not exogenous. This is so, because, in this setting, the current generation bequest to the future man-made input and the possibility to abate (to consume abatement), while in the present period it is possible to internalize the damage. So, Karp (2009) critiques the DT, due to the fact that the embedded assumptions do not permit to design a long-run policy.

Thus, the author argues also that if the agent takes the emission during the second time period

Figure 1.2. Consumption Choice along two time periods, Karp (2009).



Point A: Constrained optimum with abatement set equal to 0.

Point B: BAU equilibrium

Point C: First Best with abatement

as exogenous (or if it is not possible to internalize the present emissions), the equilibrium is given by point B. Specifically, Karp²⁰ does not critique the entire DT, rather he agrees that uncertainty about the distribution of a random variable can significantly increase overall uncertainty about this random variable, leading to a much higher risk premium, but he strongly argues against the interpretation of DT according to which society should be willing to make essentially any sacrifice to transfer a unit of certain consumption into the future. Roughly for the same reasons, both Karp

²⁰Karp (2009), page 17.

(2009) and Horowitz and Lange (2009) have criticized also the fact that Weitzman shows his result in terms of marginal willingness to pay instead the total.

Horowitz and Lange (2009) criticize the DT by using the same CRRA function coherently in the Weitzman (2009) work, in order to investigate the temporal substitution of consumption along two time periods: $U(C) = \frac{C^{1-\eta}}{1-\eta}$ where the future consumption is a random variable that captures uncertainty about her value.

The Nordhaus (2011) paper argues against the DT in a different way. In fact, the main point of debate regards the absence of policy in the DT. According to the author, in the Weitzman modelling this influences the conclusion toward a pessimistic one because there is not the opportunity for the policymaker to do something in order to avoid the catastrophic scenario: “*Weitzman discusses many implications of the dismal theorem, but one of the most striking is its destructive effect on benefit cost analysis, particularly for climate change*”.

Indeed, the author recognizes the importance of the DT in terms of helping to identify when tail events are significant; but, it is doubtless that Weitzman assumes a complete (and strong) inability of society to learn and act in time.

Regarding this, with the aim of supporting his theory, Weitzman (2011) argues that the huge time required by the system to naturally remove extra atmospheric CO_2 (Solomon et al., 2009) represents the evidence of ineffectiveness of any policy.

1.5 What’s Future in Climate Change Research and Policy underlying Catastrophic’ Scenarios

Nowadays, the challenges previously described, have been important in order to design the new global strategy undertaken by the policy makers²¹. Undoubtedly, the scientific approach and the simulation regarding the future outcomes have been seriously considered.

This is an additional reason in order to face the fact that EU is fragile with respect to heavy-tailed distributional assumptions²². Specifically, Ikefuji et al. (2015) provide a general theoretical framework, leaving probability distribution unrestricted. The authors follow, at the same time, the

²¹Paris agreement: <https://unfccc.int/resource/docs/2015/cop21/eng/109r01.pdf>

²²(Ikefuji et al., 2015)

idea that it is reasonable to use fat-tail to model future consumption and observe that there is a limit to present consumption effort in terms of present policy (or in other words, the insurance cannot have an infinite price).

The authors rise objections to the mainstream EU theory axiomatization by [Von Neumann and Morgenstern \(1944\)](#) and [Savage \(1956\)](#), without discrediting the DT and arguing that it is appropriate questioning if EU theory is an appropriate theory for normative analysis on catastrophic risk. Indeed, they use a pretty similar (to Stern and Weitzman) inter-temporal welfare function $W(C_0, C_1) = U(C_0) + \frac{1}{1+\rho} E[U(C_1)]$, assuming that it is possible to transfer endowment from the present to the future. Thus, the future wealth depends on the state of nature of time $t = 1$: $W_1 = (W_0 - C_0)e^{A\epsilon_1}$, where ϵ_1 is the risk associated with a given probability distribution under \mathcal{P} (the shape of the probability function is given by the assumptions made).

Consequently, [Ikefuji et al. \(2015\)](#) assert that the representative agent faces catastrophic consumption risk at the future time $t = 1$ when ϵ_1 is heavy-tailed to left under the (objectively or subjectively) given probability measure \mathcal{P} . In fact, deriving the optimal consumption bundle, the inter-temporal marginal rate of substitution will be given by: $P_{C_1^*}(C_1^*) = \frac{U'(C_1^*)}{(1+\rho)U'(C_0^*)}$; so, it exists at least the option to postpone current consumption because in the future there could be the need for a catastrophic consumption (a sort of self-insurance). Straightforward, if the rate of substitution is finite or not, depends on the assumption regarding the risk aversion²³.

Specifically, if the relative risk aversion is non-negative, and non-decreasing for any positive consumption, and the absolute risk aversion is non-increasing for any positive consumption, then the expected inter-temporal marginal rate of substitution is finite: $E(P) < \infty$. The authors object to [Weitzman \(2009\)](#) only the fact that the DT is based on ex-ante incompatible model specification; asserting that, it is possible to use EU theory to conduct similar modelling.

Thus, [Ikefuji et al. \(2015\)](#) provide a utility function of present and future consumption avoiding fragility to distributional assumptions. Note, the authors observe that “*only the Savage’s axiomatization of EU is valid*”; they did not say the same, regarding Von Neumann Morgenstern axiomatization.

Notwithstanding the recent evolution of the debate around the EU framework, it is also becoming of interest the new framework of analysis focusing on the rationality assumption.

[Chanel and Chichilnisky \(2013\)](#) conduct an interesting experiment asking (two time, the first

²³[Ikefuji et al. \(2015\)](#): page 309, Proposition 5.2.

on 1998 and the second one during the 2009): “Imagine that you are offered the opportunity to play a game in which you must choose and swallow one pill out of 1 billion identical pills. Only one contains a lethal poison that is sure to kill you, all the other pills being ineffective. If you survive (i.e. you swallow one of the 999.999.999 ineffective pills), you receive a tax-free amount of 152.450 €. Are you willing to choose one pill and to swallow it?”

The experiment has been repeated two times and the authors investigate also the reasoning of answer change (if the individual are rich or poor, if they are educated or not, if they have child or not, etc...). Straightforward, the results of experiment contradict the EU theory because the interviewed people overestimate the risk. Substantially, this result follows the [Posner \(2004\)](#) idea: *“a very low probability of materializing, but that if does materialize will produce a harm so great and sudden as to seem discontinuous with the flow of events that preceded it”*. Thus, a possible and innovative solution proposed by [Chanel and Chichilnisky \(2013\)](#), is to use a discontinuous function to link to any state of word in order to provide “The Topology of Fear” ([Chichilnisky, 2009](#)).

Of course, this is the future of any analysis regarding this field, even though the “normal” EU theory will remain a fundamental basis. The new frontier of economics science, that is breaking the wall of rationality, could provide interesting results regarding human behaviour.

An emblematic real example, of this, is the fear of a terrorist attack, that is higher with respect to the fear of a car crash. In a rational view this is absurd, however, the reason for this behaviour is common knowledge. In the first case, in fact, the victims and the perpetrators are easily identifiable, in the second case, they are not. The policy makers behave consequently, after 9/11 air-traffic was banned in the entire US and the growth of victims of car crashes was higher than the victim of the world trade center attack ([Sunstein, 2007](#)). Also for the climate change risk the perpetrator is not identifiable, so population is oriented to underestimate this risk, and the economics science has to provide answers also regarding this point; it is not sufficient suggest to policy makers what to do, it is important also to explain why there is not people consensus regarding climate change policy.

Undoubtedly, the new approaches recently used in other economics fields will be extremely useful on this ground; even during 1990s (but at time, it was only a niche of literature), somebody asserted that people behave not rationally in front of risk of catastrophe ([Coursey et al., 1993](#)). [Sunstein \(2007\)](#) investigating how people and governments manage the worst case scenarios, reports experimental work in which the individuals underestimate the risk (so they treat it having value of as 0) when the probability of having a catastrophe is below a certain threshold, whereas when

this probability exceeds the threshold people are willing to pay a big amount in order to defend themselves from this eventuality. Thus, if the people do not ignore the huge risk, they overestimate it; this is exactly what Coursey et al. said in 1993.

1.6 Conclusions and Suggestions

The great importance of the literature related to climate change and to the possibility to incur in catastrophic scenarios, is commonly recognized both in the academia and in the institutional environment.

Indeed, the catastrophic climate change and the long time horizon (i.e. 2100) imply many responsibilities to the researcher who is investigating the field; some works have been able to provide answers and interesting policy recommendation like [Stern \(2006\)](#); instead, [Weitzman \(2009\)](#) rises a great academic debate around his DT. The use of fat-tailed probability by [Weitzman \(2009\)](#), attracted many critiques, but also an important debate regarding the different sources of uncertainty and how to deal with them.

Finally, it is not possible to conclude any survey on catastrophic climate change without stressing the entire EU theory and his sixty years of existence. The human behaviour in front of the possibility to suffer a global disaster entails some features that, undoubtedly, a stochastic discount factor is not able to capture. Thus, for the future, we expect experimental and behavioural tools to be important in order to understand the actions chosen by individual, insurance companies, lobbies and governments.

Bibliography

- [1] ACKERMAN, FRANK, ELIZABETH A. STANTON, CHRIS HOPE, AND STEPHANE ALBERTH (2009): “Did the Stern Review underestimate US and global climate damages?”, *Energy Policy*, Vol. 37, pp. 2717–2721. Available at: <http://www.sciencedirect.com/science/article/pii/S0301421509001529>.
- [2] ALBERTH, S. AND C. HOPE (2007): “Climate modelling with endogenous technical change: stochastic learning and optimal green house gas abatement in the PAGE2002 model”, *Energy Policy*, Vol. 35, No. 3, p. 1795–1807. Available at: <http://www.sciencedirect.com/science/article/pii/S0301421506002540>.
- [3] ARROW, KENNETH J. AND MARCEL PRIEBSCHE (2014): “Bliss, Catastrophe, and Rational Policy”, *Environmental & Resource Economics*, No. 58, pp. 491–509. Available at: <http://link.springer.com/article/10.1007/s10640-014-9788-6>.
- [4] ARROW, K.J. (1974): “The use of unbounded utility functions in expected-utility maximization: Response”, *The Quarterly Journal of Economics*, Vol. 88, pp. 136–138. Available at: <http://qje.oxfordjournals.org/content/88/1/136.full.pdf>.
- [5] ARROW, K.J. (2009): “A note on uncertainty and discounting in models of economic growth”, *Journal of Risk and Uncertainty*, Vol. 38, pp. 87–94. Available at: <http://link.springer.com/article/10.1007/s11166-009-9065-1>.
- [6] BARRETT, SCOTT (2013): “Climate Treaties and Approaching Catastrophes”, *Journal of Environmental Economics and Management*, Vol. 66, pp. 235–250. Available at: <http://www.sciencedirect.com/science/article/pii/S0095069612001222>.
- [7] BUCHHOLZ, W. AND M. SCHYMURA (2012): “Expected utility theory and tyranny of catastrophic risks”, *Ecological Economics*, Vol. 77, pp. 234–239. Available at: <http://www.sciencedirect.com/science/article/pii/S092180091200119X>.
- [8] BYRNES, D. (2015): “Extreme Value Theory and Backtest Overfitting in Finance”, *Bowdoin College*, No. 5. Available at: <http://digitalcommons.bowdoin.edu/honorsprojects/24/>.
- [9] CAMERON, L. AND M. SHAH (2013): “Risk-taking behavior in the wake of natural disaster”,

- NBER Working Paper Series*, No. 19534. Available at: <http://www.nber.org/papers/w19534>.
- [10] CARTER, ROBERT M., C. R. DE FREITAS, INDUR M. GOKLANY, DAVID HOLLAND, AND RICHARD S. LINDZEN (2007): “Climate Science and the Stern Review”, *World Economics*, Vol. 8, No. 2, pp. 161–173. Available at: <http://www.world-economics-journal.com/Climate%20Science%20and%20the%20Stern%20Review.details?AID=290>.
- [11] CHANEL, O. AND G. CHICHILNISKY (2013): “Valuing life: Experimental evidence using sensitivity to rare events”, *Ecological Economics*, Vol. 85, pp. 198–205. Available at: <http://www.sciencedirect.com/science/article/pii/S0921800912001164>.
- [12] CHICHILNISKY, G. (2000): “An axiomatic approach to choice under uncertainty with catastrophic risks”, *Resource and Energy Economics*, Vol. 22, p. 221–231. Available at: <http://www.sciencedirect.com/science/article/pii/S0928765500000324>.
- [13] CHICHILNISKY, G. (2009): “The topology of fear”, *Journal of Mathematical Economics*, Vol. 45, pp. 807–816. Available at: <http://www.sciencedirect.com/science/article/pii/S0304406809000639>.
- [14] COURSEY, D. L., G. H. MCCLELLAND, AND W. D. SCHULZE (1993): “Insurance for low-probability hazards: A bimodal response to unlikely events”, *Journal of Risk and Uncertainty*, Vol. 7, No. 1, pp. 95–116. Available at: <http://link.springer.com/article/10.1007/BF01065317>.
- [15] DASGUPTA, PARTHA (2007): “Commentary: The Stern Review’s Economics of Climate Change”, *National Institute of Economic Review*, No. 199, pp. 4–7. Available at: <http://ner.sagepub.com/content/199/1/4.1.full.pdf+html>.
- [16] DIETZ, S., D. ANDERSON, N. STERN, C. TAYLOR, AND D. ZENGHELIS (2007): “Right for the Right Reasons. A final rejoinder on the Stern Review”, *World Economics*, Vol. 8, No. 2, pp. 229–258. Available at: <http://www.world-economics-journal.com/Right%20for%20the%20Right%20Reasons.details?AID=292>.
- [17] HALLEGATTE, STÉPHANE (2014): *Natural Disasters and Climate Change. An Economic Perspective*. Available at: <http://elibrary.worldbank.org/doi/abs/10.1596/1813-9450-6216>.

- [18] HEAL, G (2009): “Climate economics: a meta-review and some suggestions for future research”, *Review of Environmental Economics and Policy*, Vol. 3, No. 1, pp. 4–21. Available at: <http://reep.oxfordjournals.org/content/3/1/4.full.pdf+html>.
- [19] HENDERSON, DAVID (2007): “Governments and Climate Change Issues: The case for rethinking”, *World Economics*, Vol. 8, No. 2, pp. 183–228. Available at: <http://www.world-economics-journal.com/Governments%20and%20Climate%20Change%20Issues.details?AID=291>.
- [20] HOPE, CHRIS (2006): “The Marginal Impact of Co2 from PAGE2002: An Integrated Assessment Model Incorporating the IPCC’s Five Reasons for Concern”, *The Integrated Assessment Journal*, Vol. 6, No. 1, pp. 19–56. Available at: http://journals.sfu.ca/int_assess/index.php/iaj/article/view/227.
- [21] HOROWITZ, J. AND A. LANGE (2009): “What’s wrong with infinity - A note on Weitzman’s Dismal Theorem”, *Symposium*. Available at: <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.578.888&rep=rep1&type=pdf>.
- [22] HOROWITZ, JOHN AND ANDREAS LANGE (2014): “Cost benefit analysis under uncertainty? A note on Weitzman’s dismal theorem”, *Energy Economics*, Vol. 42, No. C, pp. 201–203. Available at: <http://www.sciencedirect.com/science/article/pii/S014098831300296X>.
- [23] IKEFUJI, M., R.J.A. LEAVEN, J.R. MAGNUS, AND C. MURIS (2015): “Expected utility and catastrophic consumption risk”, *Insurance: Mathematics and Economics*, Vol. 64, pp. 306–312. Available at: <http://www.sciencedirect.com/science/article/pii/S0167668715001006>.
- [24] KARP, LARRY S. (2009): “Sacrifice, Discounting and Climate Policy: Five Questions”, *CESifo Working Paper Series*, No. 2761. Available at: http://ideas.repec.org/p/ces/ceswps/_2761.html.
- [25] MALTHUS, THOMAS (1798): *An Essay on The Principle of Population*: J. Johnson. Available at: <http://www.esp.org/books/malthus/population/malthus.pdf>.
- [26] MEADOWS, DONELLA H., DENNIS L. MEADOWS, JORGEN RANDERS, AND WILLIAM W. BEHRENS (1972): *Limits to Growth*: Universe Books. Available at: <http://www.clubofrome.org/report/the-limits-to-growth/>.

- [27] MILLNER, ANTONY (2013): “On welfare frameworks and catastrophic climate risks”, *Journal of Environmental Economics and Management*, Vol. 65, No. 2, pp. 310–325. Available at: <http://www.sciencedirect.com/science/article/pii/S0095069612001209>.
- [28] NORDHAUS, WILLIAM AND JOSEPH G. BOYER (1999): “Requiem for Kyoto: An Economic Analysis of the Kyoto Protocol”, *The Energy Journal*, Vol. Volume 20, No. Special Issue, pp. 93–130. Available at: <http://EconPapers.repec.org/RePEc:aen:journl:1999si-a05>.
- [29] NORDHAUS, WILLIAM D (1993): “Optimal Greenhouse-Gas Reductions and Tax Policy in the DICE Model”, *The American Economic Review*, Vol. 83, No. 2, pp. 313–17. Available at: http://www.jstor.org/stable/2117683?seq=1#page_scan_tab_contents.
- [30] NORDHAUS, WILLIAM D (2006): “The Stern Review on the Economics of Climate Change.”, *NBER Working Paper 12741*. Available at: <http://www.nber.org/papers/w12741>.
- [31] NORDHAUS, WILLIAM D (2007): “A Review of the Stern Review of the economics of climate change”, *Journal of Economic Literature*, Vol. 45, No. 3, pp. 686–702. Available at: <https://www.aeaweb.org/articles?id=10.1257/jel.45.3.686>.
- [32] NORDHAUS, WILLIAM D (2011): “The Economics of tail events with an application to climate change”, *Review of Environmental Economics and Policy*, Vol. 5, No. 2, pp. 240–257. Available at: <http://reep.oxfordjournals.org/content/5/2/240.full.pdf+html>.
- [33] PARSON, EDWARD A (2007): “The Big One: A Review of Richard Posner’s Catastrophe: Risk and Response”, *Journal of Economic Literature*, Vol. 45, No. 1, pp. 147–213. Available at: <https://www.aeaweb.org/articles?id=10.1257/jel.45.1.147>.
- [34] PINDYCK, ROBERT S. (2011): “Fat Tails, Thin Tails, and Climate Change Policy”, *Review of Environmental Economics and Policy*, Vol. 5, No. 2, pp. 258–274. Available at: <http://reep.oxfordjournals.org/content/5/2/258.full.pdf+html>.
- [35] PLAMBECK, ERICA AND CHRIS HOPE (1996): “PAGE95: An updated valuation of the impacts of global warming”, *Energy Policy*, Vol. 24, No. 9, pp. 783–793. Available at: <http://www.sciencedirect.com/science/article/pii/030142159600064X>.
- [36] POSNER, RICHARD (2004): *Catastrophe: Risk and Response*: New York. Available

- at: <https://books.google.it/books?id=NXLiBwAAQBAJ&dq=posner+catastrophe+risk+and+response&lr=>.
- [37] SAVAGE, L. J. (1956): “The Foundations of Statistics”, *Journal of the American Statistical Association*, Vol. 51, No. 276, pp. 657–659. Available at: http://www.jstor.org/stable/2281495?seq=1#page_scan_tab_contents.
- [38] SOLOMON, S., G.K. PLATTNER, R. KNUTTI, AND P. FRIEDLINGSTEIN (2009): “Irreversible climate change due to carbon dioxide emissions”, *Proceedings of the National Academy of Sciences*, Vol. 106, No. 6, pp. 1704–9. Available at: <http://www.pnas.org/content/106/6/1704.full.pdf>.
- [39] STERN, NICHOLAS (2006): *The Economics of Climate Change*: London: H. M. Treasury. Available at: http://webarchive.nationalarchives.gov.uk/20100407172811/http://www.hm-treasury.gov.uk/stern_review_report.htm.
- [40] STERNER, THOMAS AND U.MARTIN PERSSON (2008): “An Even Sterner Review: Introducing Relative Prices into the Discounting Debate”, *Review of Environmental Economics and Policy*, Vol. 2, No. 1, pp. 61–76. Available at: <http://reep.oxfordjournals.org/content/2/1/61.full.pdf+html>.
- [41] SUNSTEIN, CASS R. (2007): *Worst-Case Scenarios*: Harvard University Press. Available at: <http://www.hup.harvard.edu/catalog.php?isbn=9780674032514>.
- [42] TOL, RICHARD S. J. AND GARY W. YOHE (2006): “A Review of the Stern Review”, *World Economics*, Vol. 7, No. 4, pp. 233–250. Available at: <http://www.world-economics-journal.com/A%20Review%20of%20the%20Stern%20Review.details?AID=262>.
- [43] TOL, RICHARD S. J. AND GARY W. YOHE (2007): “A Stern Reply to the Reply to the Review of the Stern Review”, *World Economics*, Vol. 8, No. 2, pp. 153–159. Available at: <http://www.world-economics-journal.com/A%20Stern%20Reply%20to%20the%20Reply%20to%20the%20Review%20of%20the%20Stern%20Review.details?AID=289>.
- [44] UNFCCC (2001): *IPCC Third Assessment Report*. Available at: http://www.grida.no/publications/other/ipcc_tar/.

- [45] UNFCCC (2007): *IPCC Fourth Assessment Report*. Available at: <https://www.ipcc.ch/report/ar4/>.
- [46] UNFCCC (2014): *IPCC Fifth Assessment Report*. Available at: <https://www.ipcc.ch/report/ar5/>.
- [47] VON NEUMANN AND MORGENSTERN (1944): *Theory of Games and Economic Behavior*: Princeton NJ. Available at: <http://press.princeton.edu/titles/7802.html>.
- [48] WEITZMAN, M. L. (2007): “A Review of The Stern Review on the Economics of Climate Change”, *Journal of Economic Literature*, Vol. 45, No. 3, pp. 703–724. Available at: <https://www.aeaweb.org/articles?id=10.1257/jel.45.3.703>.
- [49] WEITZMAN, M. L. (2011): “Fat-Tailed Uncertainty in the Economics of Catastrophic Climate Change”, *Review Environmental Economics and Policy*, Vol. 5, No. 2, pp. 275–292. Available at: <http://reep.oxfordjournals.org/content/5/2/275.full.pdf+html>.
- [50] WEITZMAN, M.L. (2009): “On Modelling and Interpreting the Economics of Catastrophic Climate Change”, *The Review of Economics and Statistics*, Vol. 91, No. 1, pp. 1–19. Available at: <http://www.mitpressjournals.org/doi/pdf/10.1162/rest.91.1.1>.

Chapter 2

Living on the Edge of the Catastrophe

Abstract

The aim of this paper is to provide a theoretical model in order to analyse environmental policy under uncertainty regarding the possibility of a natural disaster. We adopt a two-periods analytical model, to investigate two different institutional settings, one featuring a myopic social planner, choosing emissions in each time period to maximize current net benefits, and one featuring a forward-looking planner, who maximizes the expected net present value of welfare across the two periods. As in [Barrett \(2013\)](#), uncertainty regards a threshold pollution level that, if violated, triggers a natural disaster. We conclude that under a myopic social planner welfare may increase or decrease over time, while in a non-myopic scenario welfare always increases across periods. Also, our model supports the idea that a myopic social planner pushes emissions closer to the edge of the natural disaster, but then, if the latter does not take place in the first period, benefits from having done that in terms of welfare in the second period. Introducing a stochastic decay rate, we also show that the environment may reward (punish) myopic behaviour ex post. Finally, the comparison between myopic and forward looking settings is not straightforward: this depends on a risk spreading vs. information learning trade off.

Keywords: Catastrophe, Uncertainty, Environmental Policy, Risk, Natural Disaster.

JEL Classification: Q54, O13, Q38

2.1 Introduction

Uncertainty is an unavoidable issue related to several environmental problems. It is therefore the subject of a significant amount of literature, starting from the seminal contributions by [Weitzman \(1974\)](#), [Robert and Spence \(1976\)](#) and many others. In his contribution on price vs. quantities, [Weitzman \(1974\)](#) was the first to compare environmental policy instruments in the presence of uncertainty, showing that uncertainty on the benefits side does not seem to matter in environmental policy design: only the uncertainty on the costs side matters. More recent papers, as among others [Stavins \(1996\)](#), show instead that “refining” Weitzman model can lead to significantly different outcomes in terms of socially desirable policy design; more specifically, [Stavins \(1996\)](#) asserts that

uncertainty on the benefits side can indeed trigger a social loss, if cost and benefit uncertainty is correlated.

In many studies, uncertainty affects the amount of damage that the emissions cause; [Tarui and Polasky \(2005\)](#) work, is an example of this. In their paper, the authors introduce a multi period environmental policy model under uncertainty and investigate the socially desirable environmental policy design assuming that the policy makers can learn new information about environmental damages between different periods. In such a way, uncertainty plays a role not only in the chosen instrument, but also in the chosen timing of the policy. More precisely, [Tarui and Polasky \(2005\)](#) provide a game-theoretic model of pollution regulation with endogenous technology adoption and learning involving a policymaker and a polluting firm. The authors compare taxes and standard policy under discretion or rules and they develop a welfare analysis. The timing of intervention, rules or discretion, affects the acquisition of new information by regulator. Under discretion, the regulator resolves the uncertainty before designing the policy, instead, under rules, the regulator designs the policy before resolving the uncertainty.

We depart from the above cited literature by modelling a two periods regulatory setting where an environmental authority chooses the strictness of environmental policy. The environmental authority can be myopic (maximizing social welfare in each time period) or forward looking (choosing emissions in the first period accounting for all the consequences of her choices on both periods). In both cases, the strictness of environmental policy in the first and second periods is chosen under uncertainty; on the other hand, we take a rather extreme view of uncertainty, namely we model the possibility of a natural disaster to take place if a (stochastic) threshold is exceeded by pollution levels in any of the two periods. In such a way, our paper is close to [Tarui and Polasky \(2005\)](#) in terms of analytical structure. We however simplify it without accounting for technology adoption, while we keep the possibility of learning across the two periods. As we will clarify in the paper, modelling environmental damages as a natural disaster (of a yes or no character) allows us to investigate previously not assessed issues arising in choosing the optimal timing of environmental policy. Other papers related to our work are mostly linked to the role played by uncertainty (obviously) and to the modelling of natural disasters, including climate change.

[Newell and Pizer \(2003\)](#) analyse the role played by uncertainty in determining the costs of global climate change policy. Pollution is treated as a stock externality that involves uncertainty regarding its amount and its direct damage. Moreover, the authors compare the price and quantity based

policies, then applying their results to climate change intervention. Costello and Karp (2004) entail uncertainty on the abatement cost function and focus on the possibility of learning and strategic behaviour by the regulated firm.

In the papers listed above, and in general in the literature, uncertainty usually affects costs, the damage function or both of them. Even those studies in which a catastrophic scenario is uncertain, at least one agent knows the causality between human activities and natural disasters. On the other hand, we focus on the case of uncertainty on the environmental damages side, but we work with an uncertain threshold level, that if violated, causes a catastrophic event.

There are very few examples of papers dealing with uncertainty about the magnitude of a threshold level triggering an environmental disaster. Barrett (2013), among the very few, analyses uncertainty by using both a uniform random variable and a Gaussian probability distribution function. On the other hand, Barrett's work is focused on the impact of the uncertain threshold on the (in)succes of climate treaties.

In our paper, we borrow the uncertain threshold treatment from Barrett (2013), and analyse its consequences in terms of desirable policy design in a setting *a la* Tarui and Polasky (2005). We depart from Barrett (2013), as we do not focus on climate related disasters. Indeed, the simple way in which uncertainty is modelled in our paper makes it more suitable for more "local" environmental disasters, such as weather accidents, floods or toxic pollutants.

More specifically, we model a two periods setting featuring a firm generating emissions in each period and subject to regulation by an authority in charge of maximizing social welfare. As already outlined, the authority can be myopic or forward looking. In our stylized model, pollution generates linear benefits but also increases the level of emissions, that accumulate and possibly contribute to reach an uncertain threshold triggering an environmental disaster. The disaster can take place in the first period (in which case it generates a social loss for both periods, which adds to the loss of benefits in the second period) or in the second period (in which case it generates a social loss only in the same period). We limit our case to a very simple command and control policy, to keep matters as readable as possible. Also, to focus on our main issue, we disregard the environmental damages related to pollution which are not related to the risk of the natural disaster. Our model features a peculiar kind of learning; namely, the information obtained between the first and the second period if the environmental disaster does not take place is a positive function of the risk ran during the first period. In other words, the more I pollute in the first period, the closer I get to the

uncertain threshold (which is bad), but the more I learn about the threshold (if the disaster does not take place) between the first and the second period (which is likely to improve welfare). This is a particular feature that is not present in the literature, but it is extremely close to reality. The idea is to model the incentive of the regulator and the firm to go as close as possible to the borderline of the catastrophe in order to discover where is the line between the disaster and safety. This implies an incentive to increase emissions in the first period that we label as “*dangerous learning*”, which is linked to the existence of an absorption capacity by the environment related to the pollutant at stake, and introduces an additional source of interest in the debate on the desirable timing of environmental policy.

The outline of the paper is as follows. Section 2 presents the basic structure of the model. Section 3 argues the nature of the uncertainty. Section 4 develops the model under myopic and non-myopic preference structure. Section 5 entails the comparison between the two preference structures. A numerical example is also presented in this section. Section 6 stresses the parameters of the model through a comparative statics. Section 7 adds to the model a stochastic learning and compares it with the basic model. Section 8 concludes.

2.2 The Model

We model a two periods setting (with $i = 1, 2$) where a social planner aims at maximizing a social welfare function which is composed by the benefits linked to emissions in each time period and by the social cost of a possible natural disaster. Thus, there is a benefit in each period $i = 1, 2$ and a social cost X that arises if the disaster takes place. Emissions are generated by a regulated firm featuring benefits $B(\cdot)$. We model the firm in the simplest possible way, by assuming that it wishes to emit any arbitrarily large level, so that the actual firm’s emissions are given by the target e_i set in each period $i = 1, 2$ by the environmental authority.

The disaster could occur during the first period (in which case it generates damages in both periods), during the second one or never. The possible social loss X related to the natural disaster is associated with the probability $F(e_1)$ (i.e. the probability that the disaster occurs in the first period) or $F(e_1, e_2)$ (i.e. the probability that the disaster happens in the second period). The specific structure of the probability linked to the possible catastrophe is central to the paper and

will be described in details in the next section. A regulated firm generates emissions.

The timing of intervention depends on the structure of the objective function of the environmental authority. We distinguish two cases: a myopic preference function and a non-myopic one, according to the related literature. Indeed, following Kurz (1987): “*Myopic decision rules refers to... preferences depending ...only upon the values of the exogenous variable at time i , disregarding any information about future conditions of the economic environment*”.

Thus, in the case of myopic preferences there will be an objective function only depending on benefits and damages in each period $i = 1, 2$. This implies that in the first time period the regulator chooses e_1 to maximize: $[1 - F(e_1)] B(e_1) + [F(e_1)] [-X]$, whereas, during the second time period any variable regarding the first time period is treated as exogenous and the authority chooses e_2 to maximize: $[1 - F(e_1, e_2)] B(e_2) + [F(e_1, e_2)] [-X]$.

Instead, with a forward looking, or non-myopic, framework, emissions’ decision are simultaneously taken at time $i = 1$, so that the environmental authority chooses e_1 and e_2 to maximize: $[1 - F(e_1)] B(e_1) + [1 - F(e_1)] [1 - F(e_1, e_2)] B(e_2) + [F(e_1)] [-X - X(1 + \delta)^{-1}] + [1 - F(e_1)] [F(e_1, e_2)] [-X(1 + \delta)^{-1}]$.

Straightforward, with non-myopic preference, we have to consider several cases: the case in which the disaster does not occur during the first period (probability $[1 - F(e_1)]$); the case in which the disaster occurs during the first period (with probability $F(e_1)$) and then it generates damages along the two time periods, the corresponding present value of damages being $-X - X(1 + \delta)^{-1}$, where δ is the discount rate; the case in which the disaster does not occur during the first time period but it occurs during the second one (probability: $[1 - F(e_1)] F(e_1, e_2)$) and then it generates the damage only during the second time period $-X(1 + \delta)^{-1}$; finally, the case in which the disaster does not occur during both time periods (with probability $[1 - F(e_1)] [1 - F(e_1, e_2)]$).

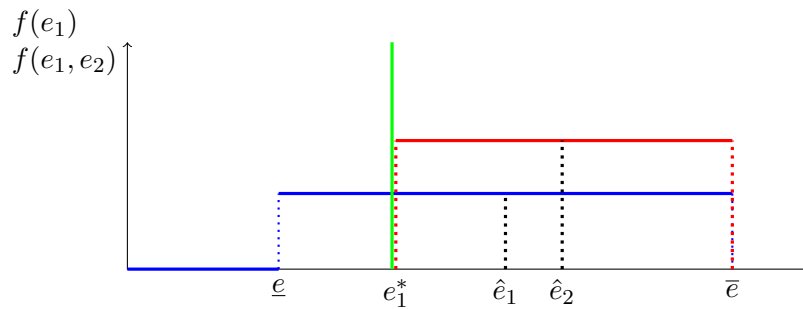
2.3 Uncertain Threshold

In this section we focus on the random link between emissions and the probability of a natural disaster to take place. We assume the simplest possible distribution function for the critical random level (label it e^c) of the emissions threshold, i.e. we assume that e^c is uniformly distributed and, more specifically, $e^c \sim U(\underline{e}, \bar{e})$.

If $e^c < e_1$, then the environmental disaster takes place during the first time period, whereas in the case $e^c \geq e_1$, the environment is preserved (at least, during the first period). Hence, the probability of having an environmental disaster during the first period is given by $Pr[e^c < e_1] = F(e_1)$. If the environmental disaster does not take place in the first period, and if we label e_1^* as the optimal emissions in the same period, then the distribution of the uncertain threshold is updated between the first and the second time period, so that the updated distribution in the same period for e^c is such that $e^c \sim U(e_1^*, \bar{e})$. In other words, the emissions produced during the first period become the lower-bound of the uniform random threshold during the second time period. The updating taking place between the first and the second period is due to the fact that the environmental authority learns that the threshold is not in the interval (\underline{e}, e_1^*) and, consequently, any emissions in the interval disappear from the random variable domain. The specific feature of this (simple) learning process is that it is more effective the larger the emissions level in the first period. For this reason, we label it “*dangerous learning*”.

Using a graphical approach in order to present the random variable, we will have a PDF during the second period which is thicker because the variance has decreased (Figure 2.1). Obviously, the probability of each potential (remaining) level of the threshold will increase; also the entire function moves to the right because the lower bound of possible endurable emissions shifts from \underline{e} to e_1^* .

Figure 2.1. Uncertain Threshold Level

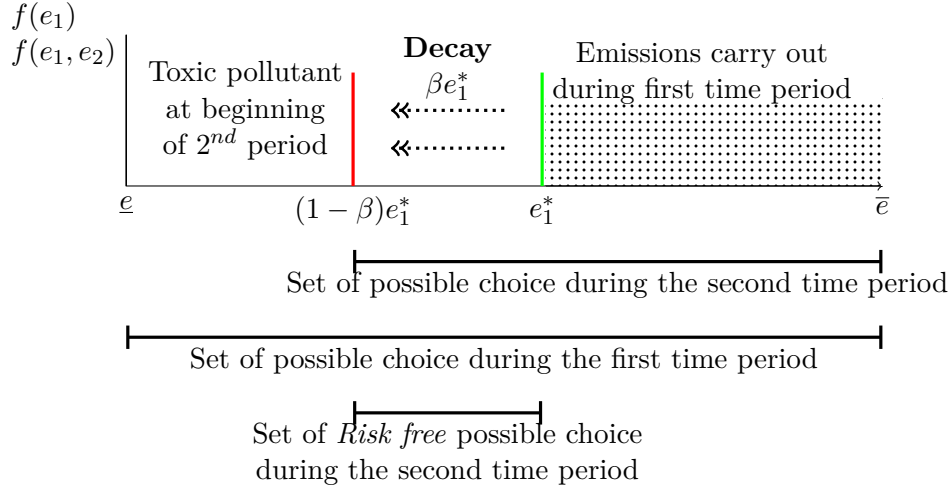


The blue curve shows the PDF during the first period, while the red curve shows the PDF during the second one.

An additional assumption, to improve the realism of the model, is that a decay rate $\beta \in (0, 1)$ exists such that a quota of the pollutant does not contribute to reaching the uncertain threshold in the second period. In other words, there is an absorption rate between the first and the second period, so that at the beginning of the second time period only $(1 - \beta)e_1^*$ units of pollution are accumulated into the environment. Thus, during the second time period, the set of emission levels that do not trigger an environmental disaster increases by βe_1^* , and these emissions are “free of risk”

in the sense that they can be emitted in the second period with a 100% certainty that they will not trigger the disaster. We label these emissions as “risk free emissions” $e_2^{RF} = \beta e_1^*$, which are a sort of “prize” for any risk experienced during the first time period by increasing emissions. This can

Figure 2.2. Emissions’ accumulation and decay β



be expressed in analytical terms as follows: $Pr [e^c < (1 - \beta)e_1^* + e_2 | e_2 < \beta e_1^*] = F(e_1, e_2)_{e_2 < \beta e_1^*} = 0$. The set of “risk free” emission levels described above are as shown in the [Figure 2.2](#). The dotted area of the figure represents the set of emission levels that are indeed subject to a risk of disaster during the second time period, of course if the disaster itself has not taken place during the first period.

From the above assumptions, we can therefore conclude that the probability to exceed the uncertain threshold, triggering in such a way the disaster, is as follows:

$$F(e_1) = \begin{cases} 0 & \text{for } e_1 < \underline{e} \\ \frac{e_1^* - \underline{e}}{\bar{e} - \underline{e}} & \text{for } \underline{e} < e_1 < \bar{e} \\ 1 & \text{for } e_1 > \bar{e} \end{cases}$$

and the corresponding density function is given by:

$$f(e_1) = \begin{cases} 0 & \text{for } e_1 < \underline{e} \\ \frac{1}{\bar{e} - \underline{e}} & \text{for } \underline{e} < e_1 < \bar{e} \\ 0 & \text{for } e_1 > \bar{e} \end{cases}$$

This structure is exactly the same used by [Barrett \(2013\)](#). On the other hand, we focus on a

two time horizon, so that the first period emissions and the decay rate affect the random variable structure in the second period: as already outlined, the emissions carried out during the first period, e_1^* , become the new lower bound of the domain of the random threshold level. Hence, the probability to trigger a natural disaster during the second time period is influenced by the emissions carried out during the first time period: $F(e_1, e_2) = Pr [e^c < (1 - \beta)e_1 + e_2 | e^c > e_1^*]$. As a result, during the second time period the random variable is characterized by the following Cdf:

$$F(e_1, e_2) = \begin{cases} 0 & \text{for } e_2 < e_1^* \\ \frac{e_2 - \beta e_1^*}{\bar{e} - e_1^*} & \text{for } e_1^* < e_2 < \bar{e} \\ 1 & \text{for } e_2 > \bar{e} \end{cases}$$

and by the following Pdf:

$$f(e_1, e_2) = \begin{cases} 0 & \text{for } e_2 < e_1^* \\ \frac{1}{\bar{e} - e_1^*} & \text{for } e_1^* < e_2 < \bar{e} \\ 0 & \text{for } e_2 > \bar{e} \end{cases}$$

2.4 Solving the Problem

2.4.1 Myopic Behaviour

As already outlined, to keep results as neat as possible we focus on the simplest possible shape for the benefits and environmental damages related to emissions, namely, we assume fixed environmental disaster costs X and linear benefits $B(e_i) = e_i$. Under a myopic behaviour, the environmental authority maximizes net expected welfare in each period.

First Time Period

According to the assumptions previously described, the first period objective function is given by:

$$\begin{aligned} \max_{e_1} & \left\{ \left[\frac{\bar{e} - e_1}{\bar{e} - \underline{e}} \right] e_1 + \left[\frac{e_1 - \underline{e}}{\bar{e} - \underline{e}} \right] [-X] \right\} \\ & \text{s.t. : } e_1 \geq 0 \end{aligned} \tag{2.1}$$

The corresponding Lagrangian function is as follows:

$$L : \left[\frac{\bar{e}-e_1}{\bar{e}-\underline{e}} \right] e_1 + \left[\frac{e_1-\underline{e}}{\bar{e}-\underline{e}} \right] [-X] + \lambda_1 e_1$$

First-Order Conditions require:

- i) $\left[-\frac{e_1}{\bar{e}-\underline{e}} + \frac{\bar{e}-e_1}{\bar{e}-\underline{e}} - \frac{X}{\bar{e}-\underline{e}} + \lambda_1 \right] e_1 = 0$ with $-\frac{e_1}{\bar{e}-\underline{e}} + \frac{\bar{e}-e_1}{\bar{e}-\underline{e}} - \frac{X}{\bar{e}-\underline{e}} + \lambda_1 \leq 0$ and $e_1 \geq 0$
ii) $\lambda_1 e_1 = 0$ with $\lambda_1 \geq 0$ and $e_1 \geq 0$

As a result, we can have an interior solution, featuring $\lambda_1 = 0$ and $e_1^M = \frac{\bar{e}-X}{2} > 0$, and a corner solution, featuring $\lambda_1 = \frac{X-\bar{e}}{\bar{e}-\underline{e}} > 0$ and $e_1^M = 0$. Thus, the emissions' choice depends on the random variable's parameter \bar{e} and on the possible social loss X .

Second Time Period

Under myopic behaviour, the objective function of the environmental authority in the second period is the same as in the first one; the only (indeed relevant) difference is the updating in the random variable:

$$\begin{aligned} \max_{e_2} \left\{ \left[\frac{\bar{e} - (1-\beta)e_1 - e_2}{\bar{e} - e_1} \right] e_2 + \left[\frac{e_2 - \beta e_1}{\bar{e} - e_1} \right] [-X] \right\} \\ \text{s.t. : } e_2 \geq 0 \end{aligned} \quad (2.2)$$

The Lagrangian function is given by:

$$L : \left[\frac{\bar{e} - (1-\beta)e_1 - e_2}{\bar{e} - e_1} \right] e_2 + \left[\frac{e_2 - \beta e_1}{\bar{e} - e_1} \right] [-X] + \lambda_2 e_2$$

Along the same lines of the first stage, the solution to the above problem implies, after some straightforward calculations, an interior solution, such that $\lambda_2 = 0$ and $e_2^M = (1+\beta) \left[\frac{\bar{e}-X}{4} \right] > 0$, and a corner solution such that $\lambda_2 = -\frac{\bar{e} - (1-\beta)e_1 - X}{\bar{e} - e_1} > 0$, and $e_2^M = 0$.

As a result, focusing on interior solutions, $e_2^M < e_1^M$, i.e. during the second time period emissions are lower than in the first period¹.

This is so because the probability of experiencing a natural disaster raises from the first to the second time period, as we have shown in the previous section (see, again, [Equation 2.1](#)).

It is also interesting to investigate a bit further the role of what we have labelled as “dangerous learning”, strictly linked with the decay rate β . In the extreme case where no pollution carries over from the first to the second time period (i.e. $\beta = 1$), then the environmental authority will be able to set an emission target larger than e_1^M in the second period featuring perfect certainty that the

¹Indeed, it is easily shown that $e_1^M > e_2^M$: $\frac{\bar{e}-X}{2} > (1+\beta) \left[\frac{\bar{e}-X}{4} \right]$ if $1 > \beta$, which is true by assumption.

first e_1^M emissions will not trigger any disaster. More broadly, the larger the decay rate, the more “fruitful” is learning, the larger the emissions level will be in the second time period².

Finally, notice that, as expected, the decay rate β does not affect the amount of emissions during the first time period: $\frac{\partial}{\partial \beta} e_1^M = 0$. This is the main consequence of the assumed social planner myopia.

2.4.2 Non-Myopic Behaviour

As argued above, a forward-looking social planner choose emissions levels of both time periods to maximize the expected net present value of social welfare. As a result, the forward looking social planner will indeed consider the impact of the chosen first period emissions on the structure of the random variable during the second time period. Also, and clearly, the non myopic planner anticipates that, if the disaster takes place in the first period, it will affect both time periods. The social planner’s objective function in the forward looking scenario is therefore given by:

$$\begin{aligned} \max_{e_1, e_2} & \left\{ \left[\frac{\bar{e} - e_1}{\bar{e} - \underline{e}} \right] e_1 + \left[\frac{e_1 - \underline{e}}{\bar{e} - \underline{e}} \right] [-X - X(1 + \delta)^{-1}] + \left[\frac{\bar{e} - (1 - \beta)e_1 - e_2}{\bar{e} - \underline{e}} \right] e_2(1 + \delta)^{-1} \right. \\ & \left. + \left[\frac{e_2 - \beta e_1}{\bar{e} - \underline{e}} \right] [-X(1 + \delta)^{-1}] \right\} \\ \text{s.t.} & : e_2 \geq 0 \\ & e_1 \geq 0 \end{aligned} \tag{2.3}$$

The Lagrangian for this constrained maximization problem is as follows:

$$L : \left[\frac{\bar{e} - e_1}{\bar{e} - \underline{e}} \right] e_1 + \left[\frac{e_1 - \underline{e}}{\bar{e} - \underline{e}} \right] [-X - X(1 + \delta)^{-1}] + \left[\frac{\bar{e} - (1 - \beta)e_1 - e_2}{\bar{e} - \underline{e}} \right] e_2(1 + \delta)^{-1} + \left[\frac{e_2 - \beta e_1}{\bar{e} - \underline{e}} \right] [-X(1 + \delta)^{-1}] + \lambda_1 e_1 + \lambda_2 e_2$$

First-Order Conditions require:

- i) $\left[-\frac{e_1}{\bar{e} - \underline{e}} + \frac{\bar{e} - e_1}{\bar{e} - \underline{e}} - \frac{X[1 + (1 + \delta)^{-1}(1 - \beta)]}{\bar{e} - \underline{e}} - \frac{e_2(1 + \delta)^{-1}(1 - \beta)}{\bar{e} - \underline{e}} + \lambda_1 \right] e_1 = 0$ with $[\cdot] \leq 0$ and $e_1 \geq 0$
- ii) $\left[-\frac{e_2(1 + \delta)^{-1}}{\bar{e} - \underline{e}} + \frac{\bar{e} - (1 - \beta)e_1 - e_2}{\bar{e} - \underline{e}}(1 + \delta)^{-1} - \frac{X(1 + \delta)^{-1}}{\bar{e} - \underline{e}} + \lambda_2 \right] e_2 = 0$ with $[\cdot] \leq 0$ and $e_2 \geq 0$
- iii) $\lambda_1 e_1 = 0$ with $\lambda_1 \geq 0$ and $e_1 \geq 0$
- iv) $\lambda_2 e_2 = 0$ with $\lambda_2 \geq 0$ and $e_2 \geq 0$

After some tedious but straightforward calculations, we can conclude that, focusing on the interior

²Straightforward, $\frac{\partial}{\partial \beta} e_2^M = \frac{\bar{e} - X}{4} > 0$ for the interior solution.

solutions³: $e_1^{NM} = \frac{[2-(1+\delta)^{-1}(1-\beta)]\bar{e}-[2+(1+\delta)^{-1}(1-\beta)]X}{4-(1+\delta)^{-1}(1-\beta)^2}$, and $e_2^{NM} = \frac{(1+\beta)[\bar{e}-X]+X(1+\delta)^{-1}(1-\beta)}{4-(1+\delta)^{-1}(1-\beta)^2}$.

The main difference with respect to the myopic behaviour is that here, the social planner “shifts” emissions from the first to the second time period. In other words, we obtain a result which is reversed with respect to the myopic case, namely⁴ $e_1^{NM} < e_2^{NM}$.

2.4.3 Corner Solutions

Before moving on the comparison of the results obtained in the myopic and forward looking scenario, we will devote this subsection to a discussion of the corner solution arising in the forward looking case, and to their comparison with those arising in a myopic setting.

With myopic preferences, the corner solution reflects the scenario in which the social planner decides not to emit, namely $e_{1,2}^M = 0$. Mathematically, this occurs if $X > \bar{e}$: in this scenario, the social planner prefers to stop production because she is not willing to bear the risk of a potentially very damaging disaster (see [Figure 2.3](#)). Thus, if a corner solution arises in the first time period, i.e. $X > \bar{e}$ then it is also $e_2^M = 0$. On the other hand, if there are positive emissions during the first time period, then emissions are positive also in the second: $e_{1,2}^M > 0$ if $X < \bar{e}$. This could be expected, as learning implies that some “risk free” emissions can be exploited during the second period.

The impossibility of a scenario in which null second period emissions and positive ones during the first period arise (both in the myopic and non myopic case) can be derived mathematically: such a corner solution would imply:

$$\left\{ \begin{array}{l} e_1^{NM} = \frac{\bar{e}-X[1+(1+\delta)^{-1}(1-\beta)]}{2} \\ e_2^{NM} = 0 \\ \lambda_2 = - \left[\frac{(1+\beta)\bar{e}+[2+\beta-(1+\delta)^{-1}(1-\beta)^2]X}{\bar{e}-\underline{e}} \right] (1+\delta)^{-1} \end{array} \right.$$

but it is straightforward to show that $\lambda_2 \not\geq 0$, which violates the Khun-Tucker conditions. It is on the other hand possible to have parameters values such that (in a forward-looking setting)

³corner solutions will be discussed in the next subsection.

⁴ $e_1^{NM} < e_2^{NM}$ if $[2-(1+\delta)^{-1}(1-\beta)]\bar{e}-[2+(1+\delta)^{-1}(1-\beta)]X < (1+\beta)[\bar{e}-X]+X(1+\delta)^{-1}(1-\beta)$, which requires $-\left[\beta+(1+\delta)^{-1}(1-\beta)\right]\bar{e}-(1-\beta)X < 0$, that is always true.

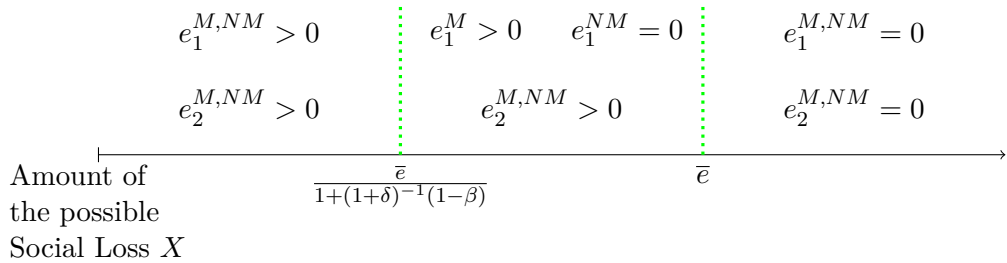
positive emissions arise during the second time period while emissions are set to 0 in the first one. Such a solution would indeed imply the following conditions:

$$\left\{ \begin{array}{l} e_1^{NM} = 0 \\ e_2^{NM} = \frac{\bar{e}-X}{2} \\ \lambda_1 = -\frac{[2-(1+\delta)^{-1}(1-\beta)]\bar{e}-[2+(1+\delta)^{-1}(1-\beta)]X}{2(\bar{e}-\underline{e})} \end{array} \right.$$

In the non-myopic case, the social planner takes into consideration that a natural disaster taking place in the first period would also generate damages also in the second period, incurring in loss with net present value $-X - X(1 + \delta)^{-1}$ instead of $-X$ arising in the myopic case. As a consequence, the threshold for the social loss X taking the forward looking social planner to stop emissions in the first period is lower than in the myopic case (see **Figure 2.3**). Production will not stop also in period 2 only if the value of X is sufficiently small. Summing up, production will stop in the first period but there will be positive emissions in the second if $\frac{\bar{e}}{[1+(1+\delta)^{-1}(1-\beta)]} < X < \bar{e}$, and then $e_2^{NM} > 0$, with $e_1^{NM} = 0$.

Finally, if $X > \bar{e}$ then the social planner will simply stop emissions and production, due to the

Figure 2.3. Corner solutions



very large magnitude of the possible natural disaster, as we could expect. More specifically, we will have in this case:

$$\left\{ \begin{array}{l} e_1^{NM} = 0 \\ e_2^{NM} = 0 \\ \lambda_1 = \frac{X[1+(1+\delta)^{-1}(1-\beta)]-\bar{e}}{\bar{e}-\underline{e}} \\ \lambda_2 = \frac{X-\bar{e}}{\bar{e}-\underline{e}}(1+\delta)^{-1} \end{array} \right.$$

2.5 Myopic vs. Non-Myopic Behaviour

We now turn to compare the results under the two assumed scenarios, focusing on interior solutions. We can easily conclude that the myopic social planner chooses to emit more than the forward looking one in the first period, while the reverse holds in the second period. In fact, we obtain that⁵ $e_1^M > e_1^{NM}$, while⁶ $e_2^M < e_2^{NM}$. Also, we can show that overall accumulated emissions are larger under a myopic preference structure: $e_2^M + (1 - \beta)e_1^M > e_2^{NM} + (1 - \beta)e_1^{NM}$. According to these results the probability to experience a disaster is larger in a myopic setting only during the first time period, whereas, the probability to experiment the natural disaster, with a forward-looking behaviour is larger during the second time period. Albeit most of these results could be expected, their driving forces (at least in part) rest on (to our knowledge) underinvestigated mechanics.

In order to help the interpretation of results, we provide a numerical example; the adopted parameter values are as shown in [Table 2.1](#). We choose a not too high value for the social cost of a possible disaster X (as compared to the maximum level of emissions \bar{e}); otherwise we would have a corner solution (see [Figure 2.3](#)). Also, for simplicity, we choose a null lower-bound of emissions (without loss of generality), and standard interest rate and decay rate. The corresponding equilibrium values are as reported in [Table 2.2](#)

Table 2.1. Numerical Example: Parameters

Parameter name	Description	Value
X	Social Cost of a possible natural disaster	10
\bar{e}	Upper-bound of toxic emissions	30
\underline{e}	Lower-bound of toxic emissions	0
δ	Interest rate	0.05
β	Decay rate and learning parameter	0.1

As already outlined, the probability of experimenting a natural disaster in the second time period is lower under myopic preference, as compared with the forward-looking preference structure. This is due to the fact that the myopic agent takes “advantage” of her short sightedness during the

⁵ $e_1^M > e_1^{NM}$ requires $\frac{\bar{e}-X}{2} > \frac{[2-(1+\delta)^{-1}(1-\beta)]\bar{e}-[2+(1+\delta)^{-1}(1-\beta)]X}{4-(1+\delta)^{-1}(1-\beta)^2}$, which holds if $(1 + \delta)^{-1}(1 - \beta)[(1 + \beta)\bar{e} - (\beta - 3)X] > 0$. This is always the case, as $(1 + \delta)^{-1}(1 - \beta) > 0$ by assumption, and $(1 + \beta)\bar{e} - (\beta - 3)X > 0$ because $0 < \beta < 1$.

⁶ $e_2^M < e_2^{NM}$ requires $(1 + \beta) \left[\frac{\bar{e}-X}{2} \right] < \frac{(1+\beta)[\bar{e}-X]+X(1+\delta)^{-1}(1-\beta)}{4-(1+\delta)^{-1}(1-\beta)^2}$ which can be easily shown to hold, as $0 < X(1 + \delta)^{-1}(1 - \beta)$.

Table 2.2. Numerical Example: Results

e_1^M	e_2^M	$e_2^M + (1 - \beta)e_1^M$	$F(e_1^M)$	$F(e_1^M, e_2^M)$	$1 - F_1^M$	F_2^M
10	5.5	14.95	0.333	0.225	0.15	
e_1^{NM}	e_2^{NM}	$e_2^{NM} + (1 - \beta)e_1^{NM}$	$F(e_1^{NM})$	$F(e_1^{NM}, e_2^{NM})$	$1 - F_1^{NM}$	F_2^{NM}
1.77	9.203	10.796	0.059	0.32	0.301	

first time period, exploiting the “dangerous learning” during the second one. In others words, the myopic planner, not accounting for the second period impact of its choices, finds it convenient to trample on the border of the cliff because only in this way she can get closer to discover where the “border” is.

We conclude this section by calculating different possible social welfare calculations, related to each period as well as to aggregate figures. Under a myopic structure: $WB[e_1] = [1 - F(e_1)]e_1 - F(e_1)X$, and $WB[e_2] = [1 - F(e_1, e_2)]e_2 - F(e_1, e_2)X$. It is the easily shown that $WB[e_1^M] + (1 + \delta)^{-1}WB[e_2^M] > WB[e_1^{NM}] + (1 + \delta)^{-1}WB[e_2^{NM}]$. On the other hand, under a forward-looking structure, we obtain the opposite result: $WB[e_1^{NM}, e_2^{NM}] > WB[e_1^M, e_2^M]$, where $WB[e_1, e_2] = [1 - F(e_1)]e_1 + [1 - F(e_1)][1 - F(e_1, e_2)]e_2 - F(e_1)[X[1 + (1 + \delta)^{-1}] - [1 - F(e_1)]F(e_1, e_2)X(1 + \delta)^{-1}]$. Full welfare comparisons are reported in [Table 2.3](#).

Table 2.3. Welfare Analysis

$WB[e_1^M]$	$WB[e_2^M]$	$WB[e_1^M] + (1 + \delta)^{-1}WB[e_2^M]$	$WB[e_1^M, e_2^M]$
3.333	2.012	5.249	1.572
$WB[e_1^{NM}]$	$WB[e_2^{NM}]$	$WB[e_1^{NM}] + (1 + \delta)^{-1}WB[e_2^{NM}]$	$WB[e_1^{NM}, e_2^{NM}]$
1.075	3.003	3.805	3.641

2.6 Comparative Statics

The aim of this section is to use the numerical simulation to investigate the impact of changes in the main parameters values on the optimal emissions level, on the probability to trigger a natural disaster and on the welfare level under both preferences structure.

We first focus on the social Cost X of the possible natural disaster (first column of [Table 2.4](#)).

Under a myopic preference structure, emissions decrease with X in the first time period, as: $\frac{\partial}{\partial X} e_1^M = -\frac{1}{2} < 0$. In the second time period (yet with myopic behaviour), we get a weaker relation with respect to the first time period: $\frac{\partial}{\partial X} e_2^M = -\frac{(1+\beta)}{4}$. Notice also that the larger is β , the larger is the reactivity of e_2^M to X ; indeed, a larger decay rate implies that more “risk free” emissions are available in the second period (if no disaster took place in the first period) as a larger decay rate implies larger second period emissions *ceteris paribus* and, making therefore increases in X more dangerous.

The evidence in the forward-looking case is similar. In fact, there is a negative relation between X and emissions with a non-myopic planner in both time periods: $\frac{\partial}{\partial X} e_1^{NM} : -\frac{2+(1+\delta)^{-1}(1-\beta)}{4-(1+\delta)^{-1}(1-\beta)} < 0$, and $\frac{\partial}{\partial X} e_2^{NM} : \frac{-(1+\beta)+(1+\delta)^{-1}(1-\beta)}{4-(1+\delta)^{-1}(1-\beta)} < 0$.

We can therefore conclude that the social loss related to a possible disaster affects negatively emission levels in both scenarios. Comparing the reactivity of emissions to X in the myopic and non-myopic case, we do not find huge differences. It is however easily shown that $|\frac{\partial}{\partial X} e_1^M| < |\frac{\partial}{\partial X} e_1^{NM}|$; for example, for $X = 20$ and in the forward-looking case, the social planner decides to stop emissions during the first time period, whereas, the myopic planner chooses positive emissions in both periods (Figure 2.3).

Turning to the impact of changes in the decay rate and, as a result, in the learning opportunities, as measured by β , under myopic preferences, a change in β does not affect first time period emissions (second column of the first panel of the Table 2.5), as $\frac{\partial}{\partial \beta} e_1^M = 0$; indeed, during the first time period the only reason that pushes the myopic social planner not to increase emissions as much as possible is the fear of triggering the natural disaster. The “dangerous” updating is then exploited by the social planner in the second period. Clearly, the larger is β the larger will be the “risk free” emissions to be exploited in the second period, and, therefore, the larger will be second period emissions themselves: $\frac{\partial}{\partial \beta} e_2^M : \frac{\bar{e}-X}{4} > 0$. In other words, myopic preferences and the related “recklessness” are more “fruitful” if β is larger.

Under forward-looking preferences (third and fourth panels of Table 2.5), the regulator plans to exploit the new information that becomes available between the first and the the second time period, distributing the risk of a natural disaster along the two time periods. Thus, the forward-looking social planner anticipates the policy, postponing the risk to the period when more information will be available.

Table 2.4. Comparative Statics: Social Cost X of possible Natural Disaster

X	e_1^M	e_2^M	$e_2^M + (1 - \beta)e_1^M$	$F(e_1^M)$	$F(e_1^M, e_2^M)$	$1 - F_1^M$	F_2^M
1	14.5	7.975	21.677	0.483	0.421		0.217
5	12.5	6.875	18.687	0.417	0.321		0.187
10	10	5.5	14.5	0.333	0.225		0.15
20	5	2.75	7.475	0.167	0.09		0.075
30	-	-	-	-	-		-
X	$W[e_1^M]$	$W[e_2^M]$	$W[e_1^M] + (1 + \delta)^{-1}W[e_2^M]$	$W[e_1^M, e_2^M]$			
1	7.008	3.777	10.442	8.542			
5	5.208	2.634	7.602	4.945			
10	3.333	2.012	5.249	1.572			
20	0.833	0.475	1.265	-1.65			
30	-	-	-	-			
X	e_1^{NM}	e_2^{NM}	$e_2^{NM} + (1 - \beta)e_1^{NM}$	$F(e_1^{NM})$	$F(e_1^{NM}, e_2^{NM})$	$1 - F_1^{NM}$	F_2^{NM}
1	9.734	10.119	18.88	0.324	0.451		0.305
5	6.195	9.712	14.936	0.206	0.382		0.303
10	1.77	9.203	10.796	0.059	0.32		0.301
20	-	5	5	-	0.167		0.167
30	-	-	-	-	-		-
X	$W[e_1^{NM}]$	$W[e_2^{NM}]$	$W[e_1^{NM}] + (1 + \delta)^{-1}W[e_2^{NM}]$	$W[e_1^{NM}, e_2^{NM}]$			
1	6.251	4.834	10.645	9.251			
5	3.883	3.901	7.43	6.183			
10	1.075	3.003	3.805	3.641			
20	-	0.833	0.793	1.136			
30	-	-	-	-			

2.7 Stochastic decay rate β

In this section, we add another source of uncertainty, introducing a stochastic decay rate. More specifically, we assume that in the first period the social planner does not know whether the decay rate is β_H or β_L , with $\beta_H > \beta_L$, but just at the beginning of the second time period such information is revealed. On the other hand, in the first period the social planner has an *a priori* distribution concerning the parameter β , namely $\beta = \beta_H$ with probability p_H and $\beta = \beta_L$ with probability $(1 - p_H)$. As a result, the expected value of β is $\hat{\beta} = p_H\beta_H + (1 - p_H)\beta_L$.

Clearly, the myopic social planner is not affected by this new kind of uncertainty, as the value of β affects myopic decision making only in the second period (second column of first panel of

Table 2.6). On the other hand, during the second time period there is a positive relationship between the (ex post) decay rate and emissions $\frac{\partial}{\partial \beta} e_2^M = \frac{\bar{e}-X}{4} > 0$ (third column of first panel of **Table 2.5**), as in the case of a deterministic decay rate.

In the non-myopic case results are significantly different. First of all, as shown in the comparative statics under a deterministic decay rate, any change in it affects the emissions decision in both periods (second and third column of third panel of **Table 2.5**). From section 4.2, and substituting $\beta = \hat{\beta}$, emissions under a non-myopic social planner are in this case:

$$\begin{cases} e_1^{NM} = \frac{[2-(1+\delta)^{-1}(1-\hat{\beta})]\bar{e}-[2+(1+\delta)^{-1}(1-\hat{\beta})]X}{4-(1+\delta)^{-1}(1-\hat{\beta})^2} \\ e_2^{NM} = \frac{(1+\hat{\beta})[\bar{e}-X]+X(1+\delta)^{-1}(1-\hat{\beta})}{4-(1+\delta)^{-1}(1-\hat{\beta})^2} \end{cases}$$

As a result, any change in the a priori distribution or in the ex post values of β that lead to a change in $\hat{\beta}$, affects emissions level during both periods. More specifically, we can derive comparative statics results regarding probability p_H that the social planner links to having a high decay rate, β_H . In order to cover all possible scenarios, we chose “extreme” values of the high and low ex post decay rates: $\beta_H = 0,9$ and $\beta_L = 0,1$. Thus, if $\beta = \beta_H$ the environment is able to absorb most emissions produced in the first time period.

Comparing the myopic and non-myopic cases, according to the numerical example provided, we notice that emissions carried out during the second time period under myopic case, when $\beta = \beta_L$ ex post, are lower than the ones carried out in the forward-looking case; indeed, for any value of p_H : $e_2^M(\beta_L) < e_2^{NM}$. On the other hand (**Table 2.6**), when $\beta = \beta_H$ ex post, the reverse holds true: $e_2^M(\beta_H) > e_2^{NM} \quad \forall \quad p_H$. Hence: $e_2^M(\beta_H) > e_2^{NM}(p_H) > e_2^M(\beta_L) \quad \forall \quad p_H$. Thus, we can argue that the forward-looking social planner spreads the risk along the two time periods, but she does not exploit the new information on the realization of β that is revealed between the first and the second period. On the other hand, the myopic social planner takes most of the risk during the first time period but then she exploits the new information during the second one.

As a result, the same conclusions apply when comparing overall emissions: $(1-\beta_H)e_1^M + e_2^M(\beta_H) > (1-\hat{\beta})e_1^{NM} + e_2^{NM}(\hat{\beta}) > (1-\beta_L)e_1^M + e_2^M(\beta_L) \quad \forall \quad p_H$. Myopic behaviour allows the planner to exploit all the information that is revealed across the two time periods, but also implies a larger risk run in the first time period. Clearly, in case of “bad news” (β_L), the welfare for the myopic social planner dramatically decreases; in this case, the risk taken in the first period does not pay off

in the second, as the ex post decay rate is very low. We can note, more generally, that, under a myopic social planner, welfare is decreasing (increasing) over time when $\beta = \beta_L$ ($\beta = \beta_H$) ex post. On the other hand, a forward looking social planner always implies an increasing welfare over time. On the other hand, even in the best possible scenario, the welfare increase obtained in the forward looking case would not mimic that obtained in the myopic case.

2.8 Conclusions and Remarks

We have investigated, in a setting *a la* Barrett (2013), augmented to account for two time periods, as in Tarui and Polasky (2005), the impact on environmental policy and welfare of uncertainty regarding the possibility of a natural disaster. We have addressed two possible institutional settings, one featuring a myopic social planner and one featuring a forward-looking planner, and obtained that no straightforward welfare ordering is possible, albeit emissions comparisons turned out to lead to expected outcomes. An important role in our results is played by what we called “dangerous learning”, i.e. the incentive of the myopic planner to push emissions further than the forward looking one, learning in such a way more information on where the actual threshold is, of course at the expenses of a larger risk of disaster in the first period. Clearly, it is more important for the myopic social planner to have a large decay rate. These considerations imply that, the comparison between myopic and forward looking settings turn out not to be straightforward: the countervailing forces of risk spreading over time vs. information updating benefits may lead to non-myopic paradox, where welfare in the second period is larger in a myopic setting if the myopic planner pushes emissions far enough in the first period. Also, by introducing a stochastic decay rate, we show that the environment can punish or reward myopic behaviour, depending on its ex post value.

Additional steps will imply more realistic objective function for the social planner, as well as a more general distribution function for the random emissions threshold.

Table 2.5. Comparative Statics: Decay Rate β of toxic emissions

β	e_1^M	e_2^M	$e_2^M + (1 - \beta)e_1^M$	$F(e_1^M)$	$F(e_1^M, e_2^M)$	$1 - F_1^M$	F_2^M
0	10	5	15	0.333	0.25	0.167	
0.1	10	5.5	14.5	0.333	0.225	0.15	
0.2	10	6	14	0.333	0.2	0.133	
0.3	10	6.5	13.5	0.333	0.175	0.117	
0.4	10	7	13	0.333	0.15	0.1	
0.5	10	7.5	12.5	0.333	0.125	0.083	
0.6	10	8	12	0.333	0.1	0.067	
0.7	10	8.5	11.5	0.333	0.075	0.05	
0.8	10	9	11	0.333	0.05	0.033	
0.9	10	9.5	10.5	0.333	0.025	0.017	
β	$W[e_1^M]$	$W[e_2^M]$	$W[e_1^M] + (1 + \delta)^{-1}W[e_2^M]$	$W[e_1^M, e_2^M]$			
0	3.333	1.25	4.524	1.071			
0.1	3.333	2.012	5.249	1.572			
0.2	3.333	2.8	6	2.089			
0.3	3.333	3.612	6.773	2.623			
0.4	3.333	4.45	7.571	3.173			
0.5	3.333	5.312	8.392	3.74			
0.6	3.333	6.2	9.238	4.324			
0.7	3.333	7.112	10.107	4.924			
0.8	3.333	8.05	11	5.541			
0.9	3.333	9.012	11.916	6.175			
β	e_1^{NM}	e_2^{NM}	$e_2^{NM} + (1 - \beta)e_1^{NM}$	$F(e_1^{NM})$	$F(e_1^{NM}, e_2^{NM})$	$1 - F_1^{NM}$	F_2^{NM}
0	0.625	9.687	10.312	0.21	0.33	0.323	
0.1	1.77	9.203	10.796	0.052	0.32	0.301	
0.2	2.809	8.876	11.123	0.094	0.301	0.277	
0.3	3.774	8.679	11.321	0.126	0.288	0.252	
0.4	4.687	8.594	11.406	0.156	0.265	0.224	
0.5	5.57	8.607	11.392	0.186	0.238	0.194	
0.6	6.436	8.713	11.287	0.214	0.206	0.162	
0.7	7.299	8.905	11.095	0.243	0.167	0.126	
0.8	8.173	9.183	10.818	0.272	0.121	0.088	
0.9	9.069	9.546	10.453	0.302	0.066	0.046	
β	$W[e_1^{NM}]$	$W[e_2^{NM}]$	$W[e_1^{NM}] + (1 + \delta)^{-1}W[e_2^{NM}]$	$W[e_1^{NM}, e_2^{NM}]$			
0	0.404	3.195	3.447	3.487			
0.1	1.075	3.003	3.805	3.641			
0.2	1.61	3.104	4.566	3.663			
0.3	2.041	3.304	5.188	3.851			
0.4	2.392	3.658	5.876	4.098			
0.5	2.679	4.173	6.653	4.401			
0.6	2.91	4.86	7.538	4.761			
0.7	3.09	5.744	8.56	5.18			
0.8	3.222	6.859	9.754	5.66			
0.9	3.304	8.254	11.165	6.206			

Table 2.6. Comparative Statics: Decay Rate $\hat{\beta}$ of toxic emissions

$\hat{\beta}$	e_1^M	e_2^M	$e_2^M + (1 - \hat{\beta})e_1^M$	$F(e_1^M)$	$F(e_1^M, e_2^M)$	$1 - F_1^M$	F_2^M
β_L	10	5.5	14.5	0.333	0.225	0.15	
β_H	10	9.5	10.5	0.333	0.025	0.017	
$\hat{\beta}$	$W[e_1^M]$	$W[e_2^M]$	$W[e_1^M] + (1 + \delta)^{-1}W[e_2^M]$	$W[e_1^M, e_2^M]$			
β_L	3.333	2.012	4.524	1.071			
β_H	3.333	9.012	11.916	6.175			
p_H	e_1^{NL}	e_2^{NL}	$e_2^{NL} + (1 - \hat{\beta})e_1^{NL}$	$F(e_1^{NL})$	$F(e_1^{NL}, e_2^{NL})$	$1 - F_1^{NL}$	F_2^{NL}
0.1	2.608	8.931	11.07	0.087	0.311	0.284	
0.2	3.395	8.744	11.256	0.113	0.295	0.262	
0.3	4.144	8.632	11.367	0.138	0.279	0.241	
0.4	4.866	8.589	11.411	0.162	0.26	0.218	
0.5	5.57	8.607	11.392	0.186	0.238	0.164	
0.6	6.263	8.685	12.333	0.21	0.213	0.168	
0.7	6.953	8.818	11.182	0.232	0.183	0.141	
0.8	7.647	9.006	10.994	0.255	0.15	0.112	
0.9	8.35	9.248	10.751	0.278	0.111	0.08	
p_H	$W[e_1^{NM}]$	$W[e_2^{NM}]$	$W[e_1^{NM}] + (1 + \delta)^{-1}W[e_2^{NM}]$	$W[e_1^{NM}, e_2^M]$			
0.1	1.512	3.083	4.448	3.633			
0.2	1.879	3.205	4.931	3.769			
0.3	2.19	3.427	5.454	3.943			
0.4	2.455	3.748	6.024	4.154			
0.5	2.679	4.173	6.653	4.401			
0.6	2.868	4.708	7.352	4.685			
0.7	3.024	5.365	8.133	5.005			
0.8	3.149	6.16	9.016	5.364			
0.9	3.242	7.113	10.016	5.763			

References

- [1] BARRETT, SCOTT (2013): “Climate Treaties and Approaching Catastrophes”, *Journal of Environmental Economics and Management*, Vol. 66, pp. 235–250. Available at: <http://www.sciencedirect.com/science/article/pii/S0095069612001222>.
- [2] COSTELLO, CHRISTOPHER AND LARRY KARP (2004): “Dynamic Taxes and Quotas with Learning”, *Journal of Economic Dynamic & Control*, Vol. 28, pp. 1661–1680. Available at: <http://www.sciencedirect.com/science/article/pii/S0165188903000824>.
- [3] KURZ, MORDECAI (1987): “*Myopic Decision Rule*” in *A Dictionary of Economics*: Palgrave Macmillan.
- [4] NEWELL, R.G. AND W.A. PIZER (2003): “Regulating Stock Externalities under Uncertainty”, *Journal of Environmental Economics and Management*, Vol. 45, pp. 416–432. Available at: <http://www.sciencedirect.com/science/article/pii/S0095069602000165>.
- [5] ROBERT, M. AND A. SPENCE (1976): “Effluent Charges and Licenses under Uncertainty”, *Journal of Public Economics*, Vol. 5, No. 3-4, pp. 193–208. Available at: <http://www.sciencedirect.com/science/article/pii/0047272776900141>.
- [6] STAVINS, ROBERT N. (1996): “Uncertainty and Instrument Choice”, *Journal of Environmental Economics and Management*, Vol. 30, pp. 218–232. Available at: <http://www.sciencedirect.com/science/article/pii/S0095069696900157>.
- [7] TARUI, NORI AND STEPHEN POLASKY (2005): “Environmental regulation with technology adoption, learning and strategic behavior”, *Journal of Environmental Economics and Management*, Vol. 50, No. 3, pp. 447–467. Available at: <http://www.sciencedirect.com/science/article/pii/S0095069605000392>.
- [8] WEITZMAN, M.L. (1974): “Prices vs. Quantities”, *Rev. Econom. Studies*, Vol. 41, pp. 477–491. Available at: http://scholar.harvard.edu/files/weitzman/files/prices_vs_quantities.pdf.

Chapter 3

Environmental Disasters and Electoral Cycle: An Empirical Analysis on Floods and Landslides in Italy

Abstract

The aim of this paper is to provide an empirical analysis concerning the potential drivers of regulators' behaviour in the presence of a potential natural disaster. More specifically, we focus our attention on floods and landslides, and we select building permits as our measure of regulatory stringency.

We first build up a simplified theoretical framework based on [List and Sturm \(2006\)](#), and derive theoretical results to be tested empirically. This is done by relying on a unique dataset covering Italy in the period 1995-2013 and containing information on soil sealing, building permits and natural disasters (floods and landslides), together with data on elections, at provincial level.

Our main conclusions suggest that a bad history in terms of disasters decreases building permits, suggesting that such a bad history strengthens the relevance of "green" voters. On the other hand, the relevance of the construction sector increases the number of issued building permits. Finally, the closeness to elections appears to increase the number of building permits, indirectly suggesting a stronger reactivity of "brown" voters, linked to the construction sector or not affected by environmental disasters.

Keywords: Catastrophic events, Land use, Uncertainty, Environmental Policy, Risk, Natural Disaster.

JEL Classification: Q54

3.1 Introduction

In the last sixty years, soil sealing and soil exploitation have terribly increased in Italy. Along with the increase in soil sealing, also the number of natural events like floods and landslides has dramatically increased. While there is a vast part of the literature exploring the socio-economic consequences of natural catastrophes from a theoretical point of view, empirical evidence on the link between natural disasters and policy-related issues is scant. This is mainly due to shortage of

data. Among the very few contributions, [Miao and Popp \(2014\)](#) find a positive relation between extreme events (e.g. floods, earthquake and droughts) and innovation.

Our work is intended to investigate the potential role of the electoral cycle, lobbies and socio-demographic features on the willingness of local policy authorities in granting building permits. In so doing, we will also assess how those permits react to past extreme events, in order to get to a better understanding of whether past experiences matter and on how strong is the “memory” of policy makers with respect to past events.

The rationale behind our work is that a flood or a landslide can only partially be deemed as a “natural” event, but rather it is the combination of a natural hazard with a human system that is exposed to it and suffers from damages and perturbations ([Hallegatte, 2014](#)). In fact, the disaster occurs if the hazard (so the event) happens in conjunction to a human system, leading to negative consequences; thus, our work is closely related with this definition of natural disaster that is, above all, a social and human event ([World Bank, 2010](#)).

We aim to contribute to the existing literature providing both a theoretical and empirically supported analysis about the link existing between soil exploitation and environmental preservation (cities’ expansion done without a proper control and without a proper urban planning) with electoral cycle and proper politics.

There is an extensive literature in geology about the causal link between soil sealing, land instability and extreme events like floods and landslides (e.g. [Guzzetti et al., 2005](#), [Haase and Nuissl, 2007](#)). We assume that both politicians and citizens are aware of this link, at least in general terms.

To our knowledge, only very few papers deal with the linkages between economics, policy and environmental realms focusing on extreme events. Our paper rests on different strands of literature. The first set of papers we refer to deals with the political agency literature starting with the contributions by, among others, [Barro \(1973\)](#) and [Besley and Case \(1995\)](#). More specifically, we refer to the works by [Besley and Burgess \(2002\)](#) and [List and Sturm \(2006\)](#), where multiple policy instruments are accounted for and environmental policy is seen as a secondary policy, so that preferences of “single issue voters” may matter for electoral reasons. In our setting, examples of single issue voters may be citizens living close to a heavily built and resilience-damaged land, on one hand, and the local construction firms, on the other.

Following this branch of literature we construct a simple political agency model where the incumbent politician decides whether to exploit the soil, giving more building permits or not. We

account for specific interest groups like the housing sector, past extreme events, the myopia of policy makers and role of elections for land allocation decisions.

We also refer to the literature on environmental disasters and the role of policies. [Barrett \(2013\)](#), among the very few, analyses uncertainty in relation to environmental disasters, by focusing on the impact of uncertain climate threshold on the likelihood of success for international climate agreements. More recently, [D’Amato and Rampa \(2015\)](#) analyse how environmental policy may change under the same kind of uncertainty regarding the possibility of a natural disaster in the presence of a social planner that can be myopic or forward looking, and that can learn information concerning the uncertain threshold triggering the disaster by increasing current environmental impacts (so called “*dangerous learning*”). The reactivity of policies in our paper is expected to depend (also) on such information related incentives.

In the second part of the paper, we test the predictions of the theoretical model by means of an empirical analysis of the drivers of building permits granted in Italian provinces. We analyse the Italian territories in the period 1995-2013 using a unique dataset containing information on soil sealing, building permits and natural disasters (floods and landslides), together with data on elections, at provincial level.

The outline of the paper is as follows. Section 2 presents the basic structure of the theoretical model and the testable implications. Section 3 presents the empirical framework, the strategy and data description. Section 4 outlines and comments on the main empirical results. Finally, the last section provides some concluding remarks.

3.2 Theoretical Framework

3.2.1 Background

As argued above, [Miao and Popp \(2014\)](#) inspire this study. Their paper finds a relation between natural extreme events (e.g. floods, droughts, or earthquakes) and innovation. We aim to provide a closely related analysis bridging events occurrence, environmental sensibility of voters, industry lobbies and the policy maker’s land planning strategy.

The political agency model provided entails a theoretical framework close to [Besley and Burgess \(2002\)](#), where an incumbent politician chooses an effort dimension (in our setting, the amount of newly issued building permits) in order to maximize the chance to be re-elected. Every agent knows

that soil sealing increases the exposure to risk, but some fraction of population considers the benefit of new construction enough to justify the increase in such risk. Thus, the politician’s chances to be elected depend on whether the fraction of people that care about the risk of floods or landslides is larger or smaller than the fraction of population that considers the benefit of new construction, as well as on the resulting strategy in terms of building permits. Thus, like in [List and Sturm \(2006\)](#), there are two kinds of citizens: “*green voters*” (against soil sealing), and “*brown voters*” (not against soil sealing).

Straightforward, the amount of past disasters affects the different share of citizens. Indeed, it is licit to think that a big number of past natural disasters is positively correlated with the share of green voters, whereas a great share of employment in the construction sector is positively correlated with the share of brown voters. As a result, we expect the politician to update her beliefs concerning the shares of voters on the basis of such information, and to affect the resulting probability of being elected by choosing the amount of issued building permits accordingly.

The first set of determinants we wish to investigate deals with electoral cycles and public goods provision. In this respect, we mostly refer to the theoretical analysis by [List and Sturm \(2006\)](#), where environmental policy is considered as a secondary policy potentially affected by voting behaviour of single issue voters. In such a setting, the authors suggest that the politicians may distort their policy choices with respect to these “secondary” areas to gain in terms of probability to be re-elected. The theoretical model by [List and Sturm \(2006\)](#) shows that this kind of distortion does not take place when the (incumbent) politician has no possibility of being re-elected, while the incentive to manipulate secondary policies is stronger in settings where electoral competition is stronger. As in our setting secondary policies consist in granting building permits, we can expect single issue voters to be environmentalists or citizens that have experienced or are at risk of floods or landslides, on one side, and construction firms (and construction sector workers) on the other. Clearly, the relative lobbying strength of single issue voters will determine the direction of the change in policy.

3.2.2 The Model

We deal with a two time-periods model; there are two kinds of voters: against and not against soil sealing. β is the fraction of population against soil sealing (“green voters”), so that $1 - \beta$ is the fraction of citizens that favour soil sealing (“brown voters”). β is high if the population has suffered

a disaster in the past.

The incumbent politician is an opportunistic one *à la* Besley and Burgess (2002); so, she only wants to be re-elected, in order to gain an “ego rent” λ . To do so, she chooses an effort given by $e = \overline{BP} - bp$, where \overline{BP} is the quantity of building permits requested from the citizens and bp are the amount actually issued. The assumption behind the assumption is that not issuing a requested building permit has a political cost. So, for example, if all requested permits were indeed granted, effort e would be zero. Straightforward, the politician chooses her effort e aiming to maximize the prior probability $\pi(\cdot)$ to be re-elected.

The voters’ reaction to an increase in bp is not directly observable. Indeed, this response is different if the voters are “green” or “brown”: the green voters respond to bp through the function $q(bp, s)$, while brown voters react to bp and s according to the function $p(bp, s)$. We assume that green (brown) voters reduce (increase) their voting propensity in reaction to an increase in bp , as it is reasonable. In other words, $q_{bp} < 0$, while $p_{bp} > 0$. We also assume that the green voters are indifferent with respect to the relevance of the construction sector, while the brown ones increase their votes in reaction to an increase in s ; namely: $q_s = 0$, while: $p_s > 0$. Finally and again intuitively we assume $p_{bp,s} > 0$, that is, the marginal propensity of brown voters increases with the relevance of the construction sector¹. Our model is completed by assuming that a fraction $(1 - \gamma)v$ of the population votes for the incumbent politician for ideological reasons, where v is a uniform random variable, $v \sim [a, 2b - a]$ with $1 > b > a > 2b - 1$; we can assume (like in Besley and Burgess (2002)) that the parameter b represents the expected level of support and a the noise in voting. On the other hand, the fraction $\gamma\sigma$ votes for the incumbent politicians according to the observed effort level, where σ is the turnout rate of non-ideological voters.

Putting together all the above assumptions, we can conclude that the share of population voting for the incumbent politician will be given by: $\alpha(\cdot) = [q(bp, s)\beta + p(bp, s)(1 - \beta)]\gamma\sigma + (1 - \gamma)v$.

Straightforward, the incumbent wins the election if $\alpha(\cdot) > \frac{1}{2}$, that is, with probability $\pi(\cdot) = Prob\left[\alpha(\cdot) > \frac{1}{2}\right]$. Given the assumed distribution of v , and focusing on cases where $\pi(\cdot) \in (0, 1)$, we can then conclude that the probability of being re-elected is:

$$\pi(\cdot) = \frac{2(1 - \gamma)(b - a) + \gamma\sigma[q(\cdot)\beta + p(\cdot)(1 - \beta)] + (1 - \gamma)v - \frac{1}{2}}{2(1 - \gamma)(b - a)}$$

¹More generally, we assume that all second order conditions for an interior solution hold. This amounts to assume that $\Theta[q_{bp,bp}(\cdot)\beta + p_{bp,bp}(\cdot)(1 - \beta)] < 0$.

In order to get the effort choices of the politician, we assume that she bears a political cost of denying building permits that varies linearly with $e = \overline{BP} - bp$. As a result, the number of issued building permits is chosen in order to solve the following maximization problem:

$$\max_{bp} \{ \pi(bp, s, a, b, \gamma, \sigma, \beta, p, q)\lambda - e \} \quad (3.1)$$

Straightforward, first order condition is:

$$\Theta[q_{bp}(bp^*, s)\beta + p_{bp}(bp^*, s)(1 - \beta)] = -1 \quad (3.2)$$

where $\Theta = \lambda \frac{\sigma}{2(b-a)} \frac{\gamma}{(1-\gamma)}$. Focusing on comparative statics, we obtain the following Proposition.

Proposition 1. *The number of building permits issued by the incumbent politician is larger if:*

- a. *s is larger; i.e. the construction lobby is stronger or more employment comes from construction sector.*
- b. *If the territory has not suffered disasters in the past (or is not at risk), making the share of green voters β smaller.*

Finally, the number of building permits increases as elections get closer if the marginal propensity to vote of brown voters is sufficiently larger than the marginal propensity to reduce voting of green voters in reaction to an increase in bp.

Proof. See the Appendix

3.2.3 Empirical Implications

The political equilibrium obtained and the comparative statics directly lead to our testable implications which are clearly coherent with [List and Sturm \(2006\)](#). Starting from the proposition provided above, we get to the following four testable implications, that will be the main focus of our empirical model.

We investigate how the anthropic pressure and the lobbies affected the voters' preferences and then the land policy implemented by the incumbent politician.

Testable implication 1. *The number of building permits is expected to increase with the share of employment in the construction sector.*

We study if past natural disasters push voters and politicians to a proper land preservation policy.

Testable implication 2. *The number of building permits issued decreases if the territory has suffered floods and landslides during the past years.*

We do not explicitly include an explicit testable implication concerning the electoral cycle. Indeed, the reactivity of building permits to the closeness of elections is shown to be ambiguous in Proposition 1.

3.3 Empirical Framework

3.3.1 The Model

We provide empirical tests about our theoretical predictions using data on 96 provinces in order to analyse the politicians' responses to voters lobbies. More specifically, we use data on city council elections taking place in the province main city, because the building permits are granted at municipality level (according to Italian legislation).

Using building permits like dependent variable, the regressors are selected to indirectly describe the expectations of the incumbent politician regarding the distribution of voters between green and brown voters. Our empirical model is the following:

$$\begin{aligned} bp_{it} = & \alpha_i + \beta_1 E_constr_{i,(t-1)} + \beta_2 D_{i,t-2} + \beta_3 Crime_{r,(t-1)} + \\ & + \beta_4 E_{i,(t-1)} + \beta_5 GDPpc_{r,t-1} + \beta_6 Elect_year_{i,t} + X'_i \delta_t + \tau_t + \varepsilon_{it} \end{aligned} \quad (3.3)$$

where bp_{it} is the logarithm of building permits granted in year t and in province i , α_i captures unobservable time-invariant province features, $E_constr_{i,(t-1)}$ is the share of employment in the construction sector (in $t - 1$); $D_{i,t-2}$ is a dummy of floods and landslides with fatalities between year $t - 2$ and year t ; $Crime_{r,(t-1)}$ is the logarithm of the number of incriminations for crime against public administration per capita at regional (NUTS2) level; $E_{i,(t-1)}$ is the logarithm of total employment in the province (in $t - 1$); $GDPpc_{r,t-1}$ is per capita GDP at the regional (NUTS2) level; $Elect_year_{i,t+1}$ is a share variable that measures the fraction of population interested by election in province i in t ; X'_i is a set of time-invariant province-specific variables whose effect is allowed

to differ in time $(\delta_t)^2$ and τ_t are year dummies. We also provide evidence for slightly different specifications in terms of lag structure of our variables of interest.

3.3.2 Data and Variables

Data about the number of floods and landslides experienced in Italy are provided by IRPI-CNR based in Perugia, Italy. In particular, the data we use are the total number of floods and landslides with fatalities occurred in Italy. Data about building permits, regional GDP and population are provided by the national statistical institute (ISTAT). Information on average rainfall is taken from Ente CRA, Italian Institute for Agricultural Research. Data on province-level employment (total and by sector) is retrieved from the ASIA (Archivio Statistico delle Imprese Attive) database (ISTAT). Information about election years for the city council of each province's capital city, as well as other informations on elections, come from the repository of the Ministero dell'Interno.

Table 3.1 shows the variables used and their sources:

[Table 3.1 about here]

3.4 Results

As a first step we want to evaluate whether current or recent catastrophic events, used as a proxy for the share of green voters, are related to building permits granted by municipalities. The summary statistics are available on tables 3.2, 3.3, 3.4, 3.5 and 3.6.

[Tables 3.2, 3.3, 3.4, 3.5 and 3.6, refer to summary statistics about here]

Moreover, we perform the same analysis regarding the lobbying power of the construction sector using the share of employment in the building industry. Results are reported in Table 3.7.

[Table 3.7 about here]

Before commenting on the results, we have to account for a possible problem of endogeneity. Indeed, the value of employment in the construction sector may suffer of a reverse causality issue linked to the relation between building permits and the dimension of the construction sector. We

²These include macro-region dummies (NUTS1) and average rainfall in the province. These variables account for region-specific shocks and for the occurrence of region-specific extreme events or extreme events that hit areas that are systematically more exposed to risk due to their average rainfall.

account for this potential issue by adopting an instrumental variables approach and using the share of bad debts. This is an indicator of demand shock in real estate, because a credit shock is expected to affect the liquidity in the housing industry (and so the hiring and the employment in the same sector) without affecting the number of building permits directly; indirectly, however, the construction sector would in turn reduce the amount of required building permits. We expect, therefore, the exclusion restriction to be satisfied: the instrumental variable affects the dependent variable, but only through its impact on the potentially endogenous variable and without having a direct effect on building permits.

From Table 3.7, we can conclude that testable implications 1 and 2 are not rejected: a larger share of employment in the construction sector, by increasing the number of brown voters, leads to an increase in the number of building permits granted. Results suggest, also that a larger number of catastrophic events in the recent past (i.e. a potentially larger share of green voters) negatively affects the number of building permits granted. Another interesting result has to do with the possible relevance of illegal behaviour and potential corruption in explaining the number of building permits. This is linked to the possibility for constructions to take place also in the absence of a regular permit, which we expect to happen more often where illegal behaviour is larger, as measured by crimes against public administration. Indeed, Table 3.7 shows that a larger number of permits is issued when illegal behaviour is more significant. The intuition for this result may be that corruption may tend to reduce the voting reactivity (or the willingness to vote) of green voters, due to the lack of credibility of institutions.

[Table 3.8 about here]

As a second step, and coherently with theoretical analysis, we also consider the role played by elections in explaining the number of building permits. We do this by investigating the role played by the share of population subject to elections in a given year. What results outlined in Table 3.8 show is that building permits increase with the share of population subject to elections. Coupled with theoretical analysis, this result seems to indirectly support the idea that the reactivity of brown voters is larger than the one of green voters, so that when elections get closer, incumbent politicians react by increasing building permits. However, also the variable “share of population in municipalities subject to election” is potentially endogenous: for instance, corruption (not directly observable) tends to “blow up” the number of building permits granted; at the same time, the probability that a city council is subject to anticipated election is correlated with the presence of

corruption or mismanagement. Thus, in order to avoid an omitted variable bias we use the share of population undergoing “regular” elections (i.e. at the end of the term of office) as an IV. Results are confirmed (right column in Table 3.8).

3.5 Concluding remarks

Our paper provides theoretical and empirical evidence about the behaviour of policy makers in presence of natural disasters. Our simple theoretical model highlights potential trade-offs between a prudent policy (i.e. limiting building permits) that attracts “green voters” and a more risky policy (i.e. granting more building permits) that increases the risk of experiencing a natural disaster but also favours “brown voters”. Moreover, the incumbent politician will be more likely to exploit the policy lever represented by building permits (in a way or in the other) closer to election year(s).

Our empirical analysis, based on a panel of Italian provinces, confirms the testable implications of our theoretical model. First, natural disasters that are likely to increase the share of “green” voters also result in a reduction in building permits to accommodate this change in the electoral preferences. Second, in the proximity of election years and when the construction sector is sufficiently important in local employment, politicians have the incentive of using the lever of granting more building permits (and incurring the risk of causing a natural disaster) to attract votes from “brown” voters.

Table 3.1. Variables used and sources

Dependent Variable	Source:
Building permits	ISTAT, National Statistical Institute
Independent Variable	
Number of Floods and Landslides with Fatalities	IRPI, Research Institute for Geo-Hydrological Protection
Population Density	ISTAT, National Statistical Institute
Total employment	ISTAT, National Statistical Institute: Banca dati ASIA
Employment in Construction Sector	ISTAT, National Statistical Institute: Banca dati ASIA
Employment in Industry Sector	ISTAT, National Statistical Institute: Banca dati ASIA
Number of incriminations for corruption	ISTAT, National Statistical Institute
Average annual rainfall	Ente CRA
Regional (NUTS2) GDP	ISTAT, National Statistical Institute
Share of pop interested by municipal elections in the prov	Ministero dell'Interno
Instrumental Variable	
Share of unpaid debts	Bank of Italy
Other details	
<i>Number of Provinces</i>	96
<i>Sample time series</i>	1995-2013

Appendix

Comparative Statics:

From first-order conditions (3.2) and from the definition of $\pi(\cdot)$, we can derive the following comparative statics results:

- $\frac{dbp^*}{ds} = -\frac{[p_{bp,s}(1-\beta)]}{[q_{bp,bp}(\cdot)\beta + p_{bp,bp}(\cdot)(1-\beta)]} > 0$, since $p_{bp,s} > 0$ by assumption, while $q_{bp,bp}(\cdot)\beta + p_{bp,bp}(\cdot)(1-\beta) < 0$ for concavity.
- $\frac{dbp^*}{d\beta} = \frac{[p_{bp}(\cdot) - q_{bp}(\cdot)]}{[q_{bp,bp}(\cdot)\beta + p_{bp,bp}(\cdot)(1-\beta)]} < 0$, as $[q_{bp,bp}(\cdot)\beta + p_{bp,bp}(\cdot)(1-\beta)] < 0$ for concavity and $[p_{bp}(\cdot) - q_{bp}(\cdot)] > 0$,
- $\frac{dbp^*}{d\sigma} = \frac{[q_{bp}(\cdot)\beta + p_{bp}(\cdot)(1-\beta)]}{[q_{bp,bp}(\cdot)\beta + p_{bp,bp}(\cdot)(1-\beta)]} \frac{\partial \Theta}{\partial \sigma} \geq 0$ if $\frac{p_{bp}(\cdot)}{q_{bp}(\cdot)} \leq \frac{\beta}{1-\beta}$, due to concavity conditions and as $\frac{\partial \Theta}{\partial \sigma} > 0$.

Table 3.2. Descriptive Statistics. Pre-Sample Mean

Year (1)	Building permits per capita (in 1000s) (2)	Disaster index (weighted by population) (3)	Election index (4)
1997	0.8734308	0.3595581	0.2992598
1998	0.890964	0.4467587	0.2154039
1999	0.9722355	0.514625	0.4244145
2000	1.023175	0.3450322	0.1036177
2001	1.066636	0.3856012	0.1931589
2002	1.240692	0.3908979	0.2164361
2003	1.12254	0.3116969	0.0828848
2004	1.201383	0.4029309	0.4209038
2005	1.135453	0.303082	0.1175115
2006	1.071573	0.1776201	0.1739375
2007	1.042844	0.1038292	0.2272153
2008	0.8828101	0.0693928	0.1114047
2009	0.6795468	0.1438244	0.4123358
2010	0.5769498	0.1900902	0.114171
2011	0.5377904	0.3397631	0.1735471
2012	0.4342602	0.3450068	0.2086216

Column 2 shows the buildings permits released; Column 3 shows the number of disasters suffered in the province weighted by population of the same province. Column 4 shows an election index computed through the ratio of population interested by municipal election in the year investigated.

Table 3.3. Descriptive Statistics. Building Permits

Year (1)	No disasters pre-2000 (2)	Disasters pre-2000 (3)	Total (4)
2000	1.106035	0.9720004	1.023175
2001	1.163596	1.006784	1.066636
2002	1.349504	1.173549	1.240692
2003	1.199587	1.07502	1.12254
2004	1.274757	1.156042	1.201383
2005	1.233046	1.07529	1.135453
2006	1.133444	1.033426	1.071573
2007	1.097965	1.008994	1.042844
2008	0.9547009	0.8386563	0.8828101
2009	0.6848529	0.6762877	0.6795468
2010	0.6015375	0.5618852	0.5769498
2011	0.520941	0.5481039	0.5377904
2012	0.4261391	0.4392484	0.4342602

Column 2 and 3 show descriptive statistics of the dependent variable, Building permits, in the case when no disasters occurred (2) and when disasters occurred (3). Column 4 shows the total number of building permits by year. This table is a proxy of “green” voters. Population weights are considered.

Table 3.4. Descriptive Statistics.
Share of employment in construction sector

Year (1)	No disasters pre-2000 (2)	Disasters pre-2000 (3)	Total (4)
2000	0.2036527	0.2006321	0.2017854
2001	0.2073964	0.2039383	0.2052582
2002	0.210181	0.2084647	0.2091196
2003	0.2226733	0.2198204	0.2209087
2004	0.2315394	0.2266603	0.2285238
2005	0.2358084	0.2358605	0.2358406
2006	0.240473	0.2400143	0.2401893
2007	0.2500158	0.2522991	0.2514304
2008	0.2509322	0.2555079	0.2537669
2009	0.2501406	0.2533387	0.2521218
2010	0.247413	0.2491569	0.2484944
2011	0.2313086	0.2362266	0.2343593

Column 2 and 3 show descriptive statistics of the dependent variable, Share of employment in construction sector, in the case when no disasters occurred (2) and when disasters occurred (3). Column 4 shows the total number of building permits by year. This table is a proxy of “brown” voters. Population weights are considered.

Table 3.5. Descriptive Statistics.
Building Permits (events post-2000)

Year (1)	No disasters post-2000 (2)	Disasters post-2000 (3)	Total (4)
2000	0.9686448	1.034221	1.023175
2001	0.9674446	1.086665	1.066636
2002	1.154794	1.257987	1.240692
2003	1.11802	1.123447	1.12254
2004	1.146923	1.212308	1.201383
2005	1.098101	1.142923	1.135453
2006	1.055442	1.074793	1.071573
2007	1.023706	1.046643	1.042844
2008	0.8618859	0.8869467	0.8828101
2009	0.6799431	0.6794688	0.6795468
2010	0.5787911	0.5765869	0.5769498
2011	0.5093985	0.5433762	0.5377904
2012	0.4420103	0.43273	0.4342602

Column 2 and 3 show descriptive statistics of the dependent variable, Building permits, in the case when no disasters occurred (2) and when disasters occurred (3). Column 4 shows the total number of building permits by year. This table is a proxy of “green” voters. Population weights are considered.

Table 3.6. Descriptive Statistics. Share of employment in construction sector (events post-2000)

Year (1)	No disasters post-2000 (2)	Disasters post-2000 (3)	Total (4)
2000	0.2443835	0.1931561	0.2017854
2001	0.2479155	0.1966447	0.2052582
2002	0.2498449	0.2009198	0.2091196
2003	0.2612102	0.2128171	0.2209087
2004	0.2736778	0.2194654	0.2285238
2005	0.2798036	0.227049	0.2358406
2006	0.2852999	0.2311838	0.2401893
2007	0.2993496	0.2419201	0.2514304
2008	0.3034268	0.2439492	0.2537669
2009	0.3019858	0.2422944	0.2521218
2010	0.2948277	0.2393609	0.2484944
2011	0.2750497	0.2263539	0.2343593

Column 2 and 3 show descriptive statistics of the dependent variable, Share of employment in construction sector, in the case when no disasters occurred (2) and when disasters occurred (3). Column 4 shows the total number of building permits by year. This table is a proxy of “brown” voters. Population weights are considered.

Table 3.7. Drivers of construction permits (IV)

Dep var: log(permits granted)	(1)	(2)	(3)
Share of empl in construction (t-1)	7.602** (3.461)	6.930** (3.022)	7.540** (2.959)
Disasters in the last 3 years	-0.0506** (0.0235)	-0.0529** (0.0233)	-0.0192 (0.0187)
log(crime corrupt per capita in NUTS2, t-1)	0.0349* (0.0198)	0.0320* (0.0187)	0.0619*** (0.0198)
log(tot employment, t-1)		0.120 (0.229)	0.530** (0.222)
log(GDP per capita in NUTS2, t-1)		0.756 (0.835)	0.599 (0.428)
Year dummies	Yes	Yes	Yes
Year-NUTS1 dummies	No	No	Yes
Year dummies x average rainfalls	No	No	Yes
Year dummies x average soil sealing	No	No	Yes
F test excluded IV	27.09	27.54	17.87
R sq	0.732	0.742	0.778
N	1149	1149	1149

IV-FE model weighted by average population in NUTS3. Standard errors clustered by NUTS2 region in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. IV for Share of employment in the construction sector in t-1: share of unpaid debts in NUTS3 in t-1 and t-2.

Table 3.8. Effect of elections on building permits granted

Dep var: log(permits granted)	Elections exogenous	Elections endogenous
Share of empl in construction (t-1)	6.945** (2.991)	6.943** (2.997)
log(tot employment, t-1)	0.124 (0.226)	0.123 (0.227)
log(GDP per capita in NUTS2, t-1)	0.762 (0.833)	0.761 (0.833)
Disasters in the last 3 years	-0.0527** (0.0229)	-0.0528** (0.0229)
Share of pop in municipalities in elect year	0.0714** (0.0288)	0.0594** (0.0257)
log(crime corrupt per capita in NUTS2, t-1)	0.0324* (0.0187)	0.0323* (0.0187)
Year dummies	Yes	Yes
F test excluded IV	27.59	18.38
R sq	0.743	0.743
N	1149	1149

IV-FE model weighted by average population in NUTS3. Standard errors clustered by NUTS2 region in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. IV for Share of pop interested by municipal elections in the prov: share of pop that should have had elections due to the natural expiring time.

References

- [1] BARRETT, SCOTT (2013): “Climate Treaties and Approaching Catastrophes”, *Journal of Environmental Economics and Management*, Vol. 66, pp. 235–250. Available at: <http://www.sciencedirect.com/science/article/pii/S0095069612001222>.
- [2] BARRO, ROBERT (1973): “The control of politicians: An economic model”, *Public Choice*, Vol. 14, No. 1, pp. 19–42. Available at: http://econpapers.repec.org/article/kappubcho/v_3a14_3ay_3a1973_3ai_3a1_3ap_3a19-42.htm.
- [3] BESLEY, TIMOTHY AND ROBIN BURGESS (2002): “The Political Economy of Government Responsiveness: Theory and Evidence from India”, *The Quarterly Journal of Economics*, Vol. 117, No. 4, pp. 1415–1451. Available at: <http://qje.oxfordjournals.org/content/117/4/1415.full.pdf+html>.
- [4] BESLEY, TIMOTHY AND ANNE CASE (1995): “Incumbent Behavior: Vote-Seeking, Tax-Setting, and Yardstick Competition”, *American Economic Review*, Vol. 85, No. 1, pp. 25–45. Available at: https://www.princeton.edu/~accase/downloads/Incumbent_Behavior.pdf.
- [5] CARRERA, L., G. STANDARDI, E. E. KOKS, L. FEYEN, L. MYSIAK, J. C. J. H. AERTS, AND F. BOSELLO (2015): “Economics of flood risk in Italy under current and future climate”, *Annual Conference of the European Association of Environmental and Resource Economists*. Available at: http://www.webmeets.com/files/papers/eaere/2015/1029/Carrera%20et%20a1_EAERE.pdf.
- [6] D’AMATO, ALESSIO AND ANDREA RAMPA (2015): “Living on the Edge of the Catastrophe”, *Seeds-Sustainability WP Series*, No. 3. Available at: www.sustainability-seeds.org/papers/RePec/srt/wpaper/0315.pdf.
- [7] FEYEN, L., D. RUTGER, K. BODIS, P. SALAMON, AND J. I. BARREDO (2012): “Fluvial flood risk in Europe in present and future climates”, *Climatic Change*, No. 112, pp. 47–62. Available at: <http://link.springer.com/article/10.1007%2Fs10584-011-0339-7>.
- [8] GUZZETTI, F., P. REICHENBACH, M. CARDINALI, M. GALLI, AND F. ARDIZZONE (2005): “Probabilistic landslide hazard assessment at the basin scale”, *Geomorphology*, No.

- 72, pp. 272–299. Available at: <http://www.sciencedirect.com/science/article/pii/S0169555X05001911>.
- [9] HAASE, D. AND H. NUISSL (2007): “Does urban sprawl drive change in the water balance and policy? The case of Leipzig (Germany) 1870-2003”, *Landscape and Urban Planning*, No. 80, pp. 1–13. Available at: <http://link.springer.com/article/10.1007%2Fs10584-011-0339-7>.
- [10] HALLEGATTE, S. (2014): “An Exploration of link between Development, Economic Growth, and Natural Risk”, *World Development Report*. Available at: <http://elibrary.worldbank.org/doi/abs/10.1596/1813-9450-6216>.
- [11] KELLENBERG, D. K. AND A. M. MOBARAK (2011): “The Economics of Natural Disasters”, *Annual Rev. Resour. Econ.*, Vol. 3, pp. 297–312. Available at: <http://www.annualreviews.org/doi/pdf/10.1146/annurev-resource-073009-104211>.
- [12] KOKS, E. E., B. JONGMAN, T. G. HUSBY, AND W. J. W. BOTZEN (2015): “Combining hazard, exposure and social vulnerability to provide lessons for flood risk management”, *environmental science & policy*, No. 47, pp. 42–52. Available at: <http://www.sciencedirect.com/science/article/pii/S1462901114002056>.
- [13] LIST, JOHN A. AND DANIEL M. STURM (2006): “How Elections Matter: Theory and Evidence from Environmental Policy”, *Quarterly Journal of Economics*. Available at: <http://qje.oxfordjournals.org/content/121/4/1249.full.pdf+html>.
- [14] MIAO, Q. AND D. POPP (2014): “Necessity as the mother of invention: Innovative responses to natural disasters”, *Journal of Environmental Economics and Management*, No. 68, pp. 280–295. Available at: <http://www.sciencedirect.com/science/article/pii/S0095069614000357>.
- [15] PISTOCCHI, A., C. CALZOLARI, F. MALUCELLI, AND F. UNGARO (2015): “Soil sealing and flood risks in the plains of Emilia-Romagna, Italy”, *Journal of Hydrology: Regional Studies*, Vol. 4, pp. 398–409. Available at: <http://www.sciencedirect.com/science/article/pii/S2214581815000841>.
- [16] SCALENGHE, R. AND F. AJMONE MARSAN (2009): “The anthropogenic sealing of soil in urban areas”, *Landscape and Urban Planning*, No. 90, pp. 1–10. Available at: <http://www.sciencedirect.com/science/article/pii/S0169204608001710>.

- [17] WORLD BANK (2010): “Natural hazards unnatural disasters. The economics of effective prevention.”, Technical report.