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Fat-tailed risk about climate change and climate policy

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HIGHLIGHTS

- A fat tail is classified and the tail effect on climate policy is discussed.
- The optimal carbon tax is not necessarily unbounded.
- The basic principle of cost-benefit analysis maintains its applicability.
- This is a numerical confirmation of the recent theoretical research.

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ABSTRACT

This paper investigates the role of emissions control in welfare maximization under fat-tailed risk about climate change. We provide a classification of fat tails and discuss the effect of fat-tailed risk on climate policy. One of the main findings is that emissions control may prevent the "strong" tail-effect from arising, at least under some conditions such as bounded temperature increases, low risk aversion, low damage costs, and bounded utility function. More specifically, the fat-tailed risk with respect to a climate parameter does not necessarily lead to an unbounded carbon tax. In this case, the basic principle of cost-benefit analysis maintains its applicability.

1. Introduction

It is well known that uncertainty has an impact on climate policy. In general uncertainty leads to precautionary actions (i.e. enhancing emissions control). Especially when uncertainty is deep its impact greatly increases. Weitzman (2009) proves this using a two-period climate-impact model and terms it the Dismal Theorem: There is a good reason to believe that the uncertainty about climate change is fat-tailed, leading to an arbitrarily large willingness to pay for the reduction of greenhouse gas (GHG) emissions. The theorem has brought about a big controversy over the applicability of cost-benefit analysis based on the expected utility theorem (Tol, 2003; Karp, 2009; Nordhaus, 2011; Pindyck, 2011; Weitzman, 2011; Millner, 2013; Hwang et al., 2013; Horowitz and Lange, 2014).

In order to investigate the effect of deep uncertainty about climate change on policy, the existing literature generally sets a bound on the variables of interest such as consumption, utility, or temperature increases. For instance, Weitzman (2009) sets an upper bound on the willingness to pay for emissions reduction. Newbold and Daigneault (2009) and Dietz (2011) set a lower bound on consumption. Costello et al. (2010) impose an upper bound on temperature increases. Pindyck (2011) sets an upper limit to marginal utility and Ikefuji et al. (2010) apply a bounded utility function.[1] They take advantage of the fact that bounded utility (wherever it comes from) can be applied to a problem of

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[1] One the other hand, some studies propose an alternative decision-making criterion or an alternative way out of economic catastrophes induced by climate change. For example, Anthoff and Tol (2014) use various alternative criteria such as the mini–max regret, the tail risk, and the Monte Carlo stationarity. Tol and Yohe (2007) investigate the effect of an international aid to a devastated country.

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maximizing expected utility under deep uncertainty (Arrow, 1974). The outcomes of these models are generally consistent with the Dismal Theorem: The willingness to pay to avoid climate impacts or the social cost of carbon becomes arbitrarily large under fat-tailed uncertainty.

Whereas climate policy is generally *absent* in existing papers, this paper considers the effect of deep uncertainty on optimal carbon tax in the *presence* of abatement policy. The absence of abatement policy is one of the main reasons why previous papers generally find a case for Weitzman's Dismal Theorem. This paper finds that although fat-tailed uncertainty implies more stringent abatement, an arbitrarily large carbon-tax or the instant phase-out of fossil fuels is not necessarily justified in the presence of abatement policy. This result favors the argument that the importance of balancing the costs of climate change against its benefits also holds under deep uncertainty. The numerical results of this paper are consistent with a recent paper by Millner (2013). Millner extends the Dismal Theorem by introducing climate policy and argues that when climate policy is explicitly introduced into the Weitzman's model, whether or not arbitrarily large impacts of fat tails on welfare show up depends on model specifications such as the elasticity of marginal utility. The numerical analysis in this paper can be seen as a numerical confirmation of Millner (2013)'s theoretical work.

The paper proceeds as follows. The definition of “fat tail” and “tail-effect” are given in Section 2. Section 3 presents a simple model of climate and the economy with emissions control. Numerical applications are given in Section 4. Section 5 concludes.

2. Fat tail and the tail-effect

There is no consensus on the exact definition of the term “fat tail” (Nordhaus, 2011). However, most climate change economists use the term as the following: “a Probability Density Function (PDF) has a fat tail when its moment generating function is infinite-that is, the tail probability approaches 0 more slowly than exponentially” (Weitzman, 2009: 2). We follow this definition of fat tail. Some examples that have a fat tail are a Student-t distribution, a Pareto distribution, a Cauchy distribution, and the climate sensitivity distribution of Roe and Baker (2007).

As far as climate change is concerned, fat tails can be broadly classified into three types:[2] Type 1) A fat tail of the distribution of a parameter of interest such as the climate sensitivity; Type 2) A fat tail of the distribution of a future temperature change; Type 3) A fat tail of the distribution of an economic impact of climate change such as marginal damage cost. Of course each type can be classified into subtypes.[3]

This paper is mainly concerned with the effect of Type 1 fat tail on a variable of interest such as optimal carbon tax or social welfare.[4] Put differently, the main question of this paper is whether or not Type 1 fat tail leads to unbounded carbon tax or social welfare. If this is the case, we say that the effect of Type 1 fat tail on the variable of interest is “strong” (or “strong tail-effect”). Otherwise we say that the effect of Type 1 fat tail is “weak” (or “weak tail-effect”). Notice that even when there is no strong tail-effect, Type 1 fat tail may have an impact on the variable of interest such as to increase or decrease the level of the variable of interest.

3. Greenhouse gas emissions control

Eq. (1) is a simple two-period model including climate policy. The gross output of the economy today is normalized to be 1 and the damage cost today is assumed to be zero without loss of generality. The uncertain variable is assumed to have a fat-tailed distribution and thus the first moment does not exist.

$$\begin{aligned} &\max_{\mu\in[0,1]} U(1-\Lambda(\mu)) + \beta\mathbb{E}U\big(C(T_{AT})\big) \\ &= U(1-\Lambda(\mu)) + \beta\int_{\{\lambda\}} U\big(C(T_{AT})\big)g_\lambda(\lambda)d\lambda \end{aligned} \tag{1}$$

where μ is the rate of emissions control, U is the utility function, Λ is abatement cost function, β is the discount factor, $\mathbb{E}$ is the expectation operator, C is consumption, T_{AT} is atmospheric temperature changes from the first period, λ is the equilibrium climate sensitivity which measures the magnitude of temperature increases as a result of a doubling of atmospheric carbon dioxide concentration, g_λ is the probability density function of λ, and $\{\}$ denotes the set of any variable of interest.

The problem of the decision maker is to choose the rate of emissions control so as to maximize social welfare, defined as the discounted sum of expected utility of consumption. A unit increase in carbon emissions today induces future climate change, resulting in the reduction of social welfare. This is due to the loss of future consumption as a consequence of higher temperature increases. Thus the decision maker controls, at a cost, the level of carbon emissions today. Consumption is gross output minus the abatement cost and the damage cost.

This paper applies a HARA utility function $U(C)=\zeta\{\eta + C/\alpha\}^{1-\alpha}$ and polynomial climate impacts function $C=\frac{Y}{(1+\pi T_{AT}^{\gamma})}$, where Y is the gross output, $\alpha(>0)$, $\eta(\geq 0)$, $\pi(>0)$, $\zeta(<0)$, $\gamma(>1)$ are parameters, and $\zeta\frac{(1-\alpha)}{\alpha}>0$. The conditions on the parameters assure the concavity of the utility function and the convexity of the damage cost function.

The global mean temperature changes have a relationship with radiative forcing as in Eq. (2).[5]

$$T_{AT}=\lambda RF/RF_0 \tag{2}$$

where RF is radiative forcing which is a decreasing function of the emissions control rate ($\frac{\partial RF}{\partial\mu}<0$), RF_0 is radiative forcing from a doubling of carbon dioxide.

Eq. (2) says that a doubling of carbon dioxide concentration leads to temperature increases of λ, which is consistent with the definition of the equilibrium climate sensitivity. For more on this, see Wigley and Schlesinger (1985), Gregory and Forster (2008), and Baker and Roe (2009).

The climate sensitivity is assumed to have the following distribution with parameters $\bar{f}$ and σ_f (Roe and Baker, 2007).

$$g_\lambda(\lambda) = \frac{1}{\sigma_f\sqrt{2\pi}}\frac{\lambda_0}{\lambda^2}\exp\left\{-\frac{1}{2}\left[\frac{\left(1-\bar{f}-\frac{\lambda_0}{\lambda}\right)}{\sigma_f}\right]^2\right\} \tag{3}$$

where λ_0 is the reference climate sensitivity in a blackbody planet, which is an idealized planet representing a reference climate

[2] The authors are grateful to Reyer Gerlagh for sharing an idea on this classification.

[3] For instance, Type 2 can be divided into two subtypes according to a specific variable of interest such as the transient temperature change in a specific year, say in 2100 (Type 2A) or the equilibrium temperature change (Type 2B).

[4] We can also investigate the effect of Type 2 or Type 3 fat tail on optimal carbon tax or social welfare. In this paper, Type 1 fat tail leads to Type 2 or Type 3 fat tail. The case where Type 1 does not lead to Type 2 or Type 3 is discussed in Hwang et al. (2013). For the other cases we refer to future research.

[5] Radiative forcing is defined as follows. “Natural and anthropogenic substances and processes that alter the Earth's energy budget are drivers of climate change. Radiative forcing (RF) quantifies the change in energy fluxes caused by changes in these drivers. Positive RF leads to surface warming, negative RF leads to surface cooling.” (Stocker et al., 2013: 11).