Journal of Economic Behavior & Organization xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Journal of Economic Behavior & Organization

journal homepage: www.elsevier.com/locate/jebo

Policy tradeoffs under risk of abrupt climate change

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ARTICLE INFO

Article history:
Received 24 August 2015
Received in revised form 15 April 2016
Accepted 20 May 2016
Available online xxx

JEL classification:
C61
Q54

Keywords:
Climate policy
Catastrophic events
Mitigation
Adaptation
Steady state
Multi state

ABSTRACT

By now it is widely recognized that the more serious threats of climate change are associated with abrupt events capable of inflicting losses on a catastrophic scale. Consequently, the main role of climate policies is to balance between mitigation efforts, aimed at delaying (or even preventing) the occurrence of such events, and adaptation actions, aimed at minimizing the damage inflicted upon occurrence. The former affects the accumulation of greenhouse gases in the atmosphere; the latter determines the impact of loss once the event occurs. This work examines the tradeoffs associated with these two types of policy measures by characterizing the optimal mitigation–adaptation mix in the long run.

1. Introduction

It is widely recognized by now that the more serious threats of climate change are associated with abrupt changes capable of inflicting losses on a catastrophic scale (Alley et al., 2003; Field et al., 2012). Each link in the chain leading from anthropogenic emission of greenhouse gases (GHG) to the abrupt change in climate and the ensuing damage involves uncertain elements (Schelling, 2007; Tol, 2012). An appropriate framework to analyze such situations involves discrete events triggered by conditions that are either imperfectly understood (e.g., include unknown parameters) or involve genuine stochastic elements. Any climate change-induced event can be categorized as one or a combination of these two types.

Tsur and Zemel (1996), for example, studied the first type of climate events – those triggered when a certain threshold is crossed (i.e., tipping point events). While the threshold itself does not change (hence crossing it is a deterministic event), its location depends on parameters that are unknown or only partially known to modelers and policymakers. In contrast, the events analyzed in Tsur and Zemel (1998) or Gjerde et al. (1999) are triggered by genuinely stochastic conditions. It turns out that the method of analysis as well as the ensuing optimal policies differ between these two types of events (see discussion in Tsur and Zemel, 2007). Here we consider the latter type of climate events – those triggered by stochastic conditions.

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http://dx.doi.org/10.1016/j.jebo.2016.05.020

Policy measures for dealing with threats of abrupt climate change can be categorized into two types. The first includes measures aimed at delaying or even preventing the event occurrence by reducing emission of GHG or by capturing (sequestering) carbon and storing it at harmless locations. Such measures are commonly referred to as *mitigation* policies. Measures of the second type are aimed at reducing, or even eliminating, the damage caused by the event once it occurs, e.g., building levees to prevent flooding, developing a cure or a vaccine for diseases that are likely to spread due to the arrival of certain pathogens, or developing crop varieties that can better sustain a range of climate conditions. These measures are commonly referred to as *adaptation* policies. A comprehensive climate policy contains measures of both types and characterizing the optimal policy requires evaluating the tradeoffs between them (Tol, 2005; Bréchet et al., 2013). In this work we present a framework for accomplishing this goal, focusing on the long run.

To that end, we use the mitigation–adaptation framework offered by Zemel (2015), which combines mitigation policies affecting the random occurrence date of a detrimental event (such as in Tsur and Zemel, 1998) with adaptation policies affecting the damage inflicted upon occurrence (such as in Tsur and Withagen, 2013). By assuming that the costs and effects of adaptation investments are linear, Zemel (2015) was able to characterize the entire time profile of the optimal mitigation–adaptation policy.

In this work we relax this linearity assumption and focus on characterizing the optimal steady state, i.e., the optimal adaptation–mitigation policy in the long run. We do this by extending the method of Tsur and Zemel (2016b) for characterizing optimal steady states of multi-state dynamic systems to situations involving random events. In the present context the model contains two state variables: an atmospheric GHG stock, affecting the occurrence probability of a detrimental event and determined by the mitigation policy; and an adaptation capital stock whose role is to reduce the damage inflicted upon occurrence.

We provide necessary conditions for the location and stability of optimal steady states. These conditions give rise to a simple method for characterizing the optimal mitigation–adaptation mix in the long run. A caveat regarding the relation of these results to the realities of the climate change problem is in order here. The literature presents a long list of potential climate-related catastrophes of very diverse nature. The threats differ in the dependence of the hazard rates (or frequency of occurrence) on the GHG stock, the events may be recurrent or give rise to a single irreversible shock, the damage may destroy capital or affect consumption directly, induce loss of life or give rise to other forms of decreased welfare. Obviously, a two-state analytic model cannot pretend to describe the details of all such possibilities, nor is it the purpose of the present paper to provide such a description. This goal may be better addressed by running any of the complex numerical integrated assessment models. Here, we employ a specific (though non-trivial) formulation to illustrate how the method works in a particular setting. Indeed, many of the assumptions can be altered to fit other catastrophic models of choice. The characterization of the optimal climate policy will correspondingly change, but the method suggested here is general enough to study these variants in a simple and unified manner.

Although the formulation in the following section displays the dynamic tradeoffs over time, the analysis via the L-method provides only long-term results. Indeed, solving dynamic optimization problems with several state variables is generally intractable and the full dynamic characterization can be analytically obtained only under specific model assumptions (see Bréchet et al., 2013; Zemel, 2015, for mitigation/adaptation examples). Analyzing the long-term behavior greatly simplifies the problem and yields important information: first, the steady states provide convenient end-conditions for the full numerical solution, in case the latter is required. Second, long-term analysis can provide the correct tradeoffs and policy recommendations for a wide range of situations (as the deterministic catastrophic-event study of Finnoff et al., 2010, demonstrates). This observation is corroborated by the full dynamic solutions derived in Zemel (2015) which show a smooth monotonic state evolution from the initial state to a unique steady state. Only when one of the initial states is exceedingly large, do the solutions display some non-monotonic trends that help the system to restore the optimal balance represented by the steady state. Moreover, the numerical examples considered in the present work also suggest a unique candidate for the optimal steady state. Thus, the simple application of the L-method captures the salient features of the mitigation/adaptation policy without blurring the analysis with details that, for most cases of interest, are of secondary importance.

2. Setup

An abrupt climate-change induced event, capable of inflicting a severe damage, may occur at some uncertain future date T. The distribution of T is governed by a hazard rate function $h(Q)$ that depends on the atmospheric GHG stock Q. The event inflicts a damage $\psi(k)$ that depends on the adaptation capital k available at T. The climate policy consists of mitigation efforts to curb the accumulation of GHG and of investment in adaptation capital. The policymaker task is to set the optimal mix of these two activities over time. The model described below addresses this problem.

2.1. Climate policy

Production activities at time t generate emissions at the rate $m(t)$ that accumulate to form the GHG stock $Q(t)$ according to

$$\dot{Q}(t) = m(t) - \gamma Q(t), \tag{2.1}$$