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Abrupt positive feedback and the social cost of carbon

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ABSTRACT

Optimal climate policy should act in a precautionary fashion to deal with tipping points that occur at some future random moment. The optimal carbon tax should include an additional component on top of the conventional present discounted value of marginal global warming damages. This component increases with the sensitivity of the hazard to temperature or the stock of atmospheric carbon. If the hazard of a catastrophe is constant, no correction is needed of the usual Pigouvian tax. The results are applied to a tipping point resulting from an abrupt and irreversible release of greenhouse gases from the ocean floors and surface of the earth, which set in motion a positive feedback loop. Convex enough hazard functions cause overshooting of the carbon tax, but a linear hazard function gives rise to undershooting. A more convex hazard function and a high discount rate speed up adjustment.

1. Introduction

The idea that the prime role of climate policy is to deal with the small risk of abrupt and often irreversible climate disasters and tipping points at high temperatures rather than to internalize smooth global warming damages at low and moderate temperatures is gaining traction (e.g., Lenton and Ciscar, 2013; Kopits et al., 2013; Pindyck, 2013). Climate policy must deal with catastrophic events such as destroying a large chunk of productive capacity or unleashing positive feedback loops at higher temperatures. A well-known example is the ice-albedo effect. Global warming may be accelerated with sudden melting of ice sheets (e.g., Greenland), since water and earth reflect less solar radiation than ice and absorb more heat. The warming up causes more ice to melt and sets in motion even more global warming. The positive feedback acts more quickly over the oceans than over land, because sea ice can melt faster than continental ice sheets. Positive feedbacks can also occur with the death of rain forests as plants have a lower reflectivity than bare soil and there will be less transpiration. A final example is the Clathrate gun hypothesis, which states that a rise in sea temperatures and/or a rise in sea levels can trigger the sudden release of methane from methane clathrate compounds buried in sea-beds and permafrost (e.g., from the tundra in the Arctic, mostly Eastern Siberia). Since methane is itself a powerful (albeit shorter lived) greenhouse gas, this methane release will increase global warming and set in motion further methane clathrate

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destabilization. This type of positive feedback might trigger a runaway process, which in the long run is stabilized via the natural decay of the stock of atmospheric carbon. There is a lot of debate about whether these positive feedback effects will occur at higher temperatures and also about the magnitude of such effects. We have nothing to contribute to this debate. Our objective is to study a regime switch caused by a temperature-dependent risk of an irreversible, sudden release of greenhouse gases and show how such a risk of a regime switch resulting in a disastrous change in the climate dynamics affects the social cost of carbon and the optimal carbon tax. We analyze what to do when burning more fossil fuel leads to a higher stock of carbon in the atmosphere and higher global temperature and thus to a higher risk of a climate calamity.

Our contribution is to show that with temperature-dependent risks of a climate calamity the optimal carbon tax and the social cost of carbon have to be higher than indicated by the normal Pigouvian formula for the social cost of carbon (i.e., the present discounted value of marginal global warming damages resulting from burning an additional unit of fossil fuel). Our contribution is also to do this in a tractable partial equilibrium model of climate policy with tipping points generating regime switches and changes in the carbon cycle and the system dynamics at some random future moment of time. We thus investigate how the carbon tax should respond to a sudden unleashing of positive feedback loops at higher global mean temperatures and change in system dynamics (cf., Naevdal, 2006).[2] The expected time it takes to unleash such positive feedback loops decreases with temperature and the accumulated carbon stock, which results from a hazard function which increases in the carbon stock.

We show how the optimal social cost of carbon associated with burning fossil fuel can be decomposed into three components. The first component arises from the usual need to correct for marginal global warming damages which internalizes the adverse effects on all future global warming damages arising from burning an additional unit of fossil fuel. This requires that this component of the social cost of carbon is set to the present value of all future marginal global warming damages where the relevant discount rate is the social rate of discount augmented by the hazard of a tipping point as well as the rate of atmospheric decay. The hazard makes society more impatient, so that the marginal global warming damages are discounted more heavily which depresses this conventional expression for the Pigouvian social cost of carbon. The second component of the social cost of carbon arises because burning an additional unit of fossil fuel increases the stock of atmospheric carbon and thus curbs the welfare after the tipping point. This raises the cost of a tipping point and thus requires a boost to the social cost of carbon before the disaster strikes. This is called the 'raising the stakes' effect. The third component of the social cost of carbon arises because burning an additional unit of fossil fuel increases global mean temperature and thus increases the risk of a tipping point and a discrete catastrophic loss in value. This component is also positive. The resulting boost to the social cost of carbon curbs fossil fuel use and the risk of a tipping point. This is referred to as the 'averting risk' effect. We illustrate our results with some calibrated simulations. This permits us to also investigate how the optimal carbon tax and social cost of carbon depend on the shape and especially the convexity of the hazard function, since it is plausible that the risk of a tipping point increases relatively more at higher temperatures.

Our analysis of the effects of the catastrophic unleashing of positive feedback loops and what to do about it differs from earlier literature in five respects. First, we differ from Nordhaus (2008) and Golosov et al. (forthcoming) who deal with a moderate cost of global warming at low temperatures and a catastrophic cost of global warming at higher temperatures but combine the two in an expected damage parameter without dealing with the analysis of regime switches and tipping points. Second, our analysis deals with the risk of extreme global warming increasing the risk of climate calamity and pushing up the carbon tax but differs from Weitzman (1998) who argues the case for an ambitious climate policy using fat-tailed risk of global warming. Our analysis also differs from Gollier (2008, section 3.2) and Gollier (2012, Chapter 5) who uses a Markov 2-regime switching model to show that an exogenous small risk of a very large drop in the growth rate of GDP depresses the efficient discount rate for long maturities. Since this boosts the social cost of carbon, this also makes a case for a more aggressive climate policy. Third, we differ from work on discrete thresholds for the stock of carbon in the atmosphere or global mean temperature which once passed result in a regime of much less assimilative capacity of carbon (Amigues and Moreaux, 2012; Prieur et al., 2013).[3] Although this work deals with positive feedback and changes in capacity to assimilate carbon, it takes the threshold for the catastrophe as given. In contrast, we have an uncertain threshold as we have the risk of tipping increasing with the carbon stock or global mean temperature. Fourth, our catastrophe directly affects the intrinsic dynamics of the carbon cycle whilst most earlier work deals with a catastrophic shock to global warming damages.[4] We also differ from Lemoine and Traeger (2014) who consider a catastrophic shock to the equilibrium climate sensitivity.[5] Finally, as van der Ploeg and de Zeeuw (2013), we offer a decomposition of the optimal carbon tax in the face of impending

[2] This is related to recent work on discrete thresholds which result in a regime of much less assimilative capacity of carbon once the stock of carbon in the atmosphere crosses a given threshold (Amigues and Moreaux, 2012) and on a an economy with exhaustible resources and a regime switch entailing a total destruction of assimilative capacity with zero decay of atmospheric carbon (Prieur et al., 2013).

[3] Prieur et al. (2013) deal with an economy with exhaustible resources and a regime switch entailing a total destruction of assimilative capacity with zero decay of atmospheric carbon.

[4] For example, the loss of the Greenland Ice Sheet or the Antarctic Ice Sheet might lead to sea levels rising by 7 and 3 m, respectively, and the resulting damages can take millennia and may already be occurring. A more imminent example is the collapse of the Atlantic thermohaline circulation and is likely to already occur at relatively moderate degrees of global warming. This will have different effects on damages from global warming (viz. the stopping or reversal of the Gulf Stream will mainly hurt northern Europe).

[5] They model the release of methane from melting permafrost as an instantaneous doubling of the equilibrium climate sensitivity, but it is not clear that this makes sense from a climate science point of view. We prefer to model this as a sudden unleashing of a positive feedback loop in the carbon cycle.