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Consequences of irreversibilities on optimal intertemporal CO_2 emission policies under uncertainty

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Abstract

This paper investigates how irreversibilities affect the optimal intertemporal accumulation of greenhouse gases in the atmosphere under uncertainty. More precisely, the evolution of the future temperature is assumed to follow an Itô-process with the drift provided by greenhouse gas emissions. This paper considers two different kinds of irreversibilities: of emissions (i.e., CO_2 once dissolved into the air cannot be collected later) and of stopping. These issues are investigated first (in the tradition of the real option literature) as pure stopping problems and then allowing for a continuous choice of emissions. Implications for global warming are: an irreversible stopping of greenhouse gas emissions is never optimal in a continuous framework and yields in the real option framework a less conservationist stopping rule in which uncertainty increases the stopping threshold (i.e. works against conservation).

JEL Classification: Q48; D81; C61

Keywords: Itô-process; Irreversibilities; Real options; Continuous policies; Global warming; Super contact

1. Introduction

This paper investigates different kinds of irreversibilities in the context of the intertemporal management of a stock externality under uncertainty. Global warming is, at present, the by far most studied example with heated scientific discussions about the sensitivity of the global temperature to an increase in the CO_2 concentration, about the costs of a climate change, and the question when – either now or later – proper actions should be taken.

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Tsur and Zemel (1996) assume an ex ante unknown level of the CO_2 stock above which the environmental system collapses; introducing a hazard-rate allows to reduce the analysis to a 'deterministic' control model. Gjerde et al. (1999) suppose an uncertain catastrophe associated with continued CO_2 emission similar to Tsur and Zemel (1996). Brige and Rosa (1995) develop a stochastic version of the 'Global 2100' model of Manne and Richels (1991) and show that considerable uncertainty leads to significant changes in the optimal CO_2 abatement policy as well as in the optimal investment policy compared with the use of expected values. Peck and Teisberg (1993) quantify the value of information using their CETA-model, Peck and Teisberg (1992). Kolstad (1996) as well as Kelly and Kolstad (1999) focus on the learning effects in a discrete time model. Kolstad (1996) finds that the future stock externality casts little shadow over today's decisions and that rapid learning suggests 'going slowly' in controlling emissions. Kelly and Kolstad (1999) show that uncertainty about the evolution of the global mean temperature is a persistent phenomenon that cannot be resolved until several decades have elapsed due to the slow convergence of Bayesian learning rules. Nordhaus and Popp (1997) calculate the value of scientific knowledge with respect to reducing uncertainties and Fisher and Narain (2003) account for learning when the magnitude of the damage is uncertain. Dalton (1997) explicitly penalizes temperature variability in addition to temperature increases and argues that the omission of variability significantly underestimates the costs. Hoel and Karp ask Weitzman's (1974) question – taxes or quantities – for a stock pollutant (first additive uncertainty, Hoel and Karp (1998) and then multiplicative, Hoel and Karp (2001)). They find that taxes tend to dominate quotas and this effect is more pronounced for multiplicative uncertainty. This result is confirmed in the related study of Newell and Pizer (2003) and in the numerical simulations in Pizer (1999, 2002) of which the latter proposes to combine the two instruments (over time); see also Fisher et al. (2003). Although the so far quoted papers account for uncertainty, they avoid, surprisingly, stochastic calculus.

This paper investigates and differentiates between two kinds of irreversibilities.

1. Emissions are irreversible in the sense that CO_2 once dissolved into the air cannot be collected later. This plausible and realistic constraint – emissions must be non-negative at each instant of time – has the consequence that the familiar linear-quadratic set up does not imply the usual quadratic value function.
2. Stopping CO_2 emissions (i.e. a shutdown of the entire fossil fuel industry) is irreversible, compare, e.g. the special issue on irreversibility in the journal Resource and Energy Economics (2000) and in particular Pindyck (2000).

These two different kinds of irreversibility are studied in two set ups, both accounting explicitly for uncertainty. First, as real option problems (Section 3), choosing between a constant level or zero emissions, as in Conrad (1997, 2000), Saphores and Carr (2000) and Pindyck (2000, 2002) but investigating also the scenario of reversible stopping. Second, allowing for a continuous choice of carbon emissions at each instant of time (Section 4). It is surprising that such straightforward extensions (for uncertainty) of familiar deterministic dynamic optimization problems are not only surpassed in numbers by real option approaches and by two period models but lacking in the global warming and more broadly in the environmental economics (an exception and thus closer to the approach in Section 4 is the (numerical) investigation of wetlands in Fernandez and Karp (1998)) literature. While some related papers, e.g. Hartman and Hendrickson (2002) on investment, Zeitouni (2004) on groundwater extraction, allow for