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The optimal time path for carbon abatement and carbon sequestration under uncertainty: The case of stochastic targeted stock

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ABSTRACT

We explore the optimal time path of carbon sequestration and carbon abatement in stabilizing CO_2 levels under uncertainty of climate impacts. Using a two-period sequential decision making model, we analytically derive optimal rates for the two control variables, abatement and sequestration rates. Uncertainty is assumed to affect the desired future stabilization level of the CO_2 stock but is resolved prior to the decision on how much to control the stock in the second period. Contrary to recent numerical studies, we find that uncertainty can make it optimal to use carbon sequestration either earlier or later depending on the relative rates of change in both marginal cost curves and on the amount of land that can be converted to forest. Comparative statics suggest that an increase in the discount factor could either increase or decrease the optimal rate of sequestration in the first period depending on the expected rate of change of the marginal cost of sequestration in the second period and on future benefits of current sequestration.

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1. Introduction

The Kyoto protocol initiated a broad scientific discussion concerning the role of carbon sequestration as a strategy to limit greenhouse gases (GHG) emissions. Although there is a consensus in the scientific world that carbon sequestration should be included in a portfolio of GHG mitigation strategies (Nabuurs et al., 2007; Richards and Stokes, 2004) the optimal timing of its implementation is still debated. Some argue that carbon sequestration should be viewed as a short term reduction strategy either to buy time for other technologies to emerge (Metz et al., 2001; Feng et al., 2002) or because the attractiveness of carbon sequestration in term of its cost will decrease in the long run (Stavins, 1999). On the contrary, some argue that carbon sequestration should be delayed toward the end of the century given that carbon prices are increasing over time (Van't Veld and Plantinga, 2005; Sohngen and Mendelsohn, 2003). Other findings suggest that the rate of growth in carbon prices can influence the optimal timing of carbon sequestration (Sohngen and Sedjo, 2006).

An important feature of carbon sequestration that distinguishes it from abatement technologies is its ability to actually reduce atmospheric concentrations of CO_2, by planting trees for example. Carbon abatement, in contrast, cannot be larger than emissions at any given period. At the extreme, one could abate all emissions and hold the stock constant whereas carbon sequestration has the potential to reduce the atmospheric stock of CO_2 in absolute terms or relative to a baseline. This asymmetry may play a crucial role in determining the optimal timing of a sequestration policy. Consider the following example. Assume we would like to stabilize the atmospheric stock at B ppm at a given time in the future. But, currently, we are uncertain about the severity of impacts at that level of stabilization. For instance, choosing today a specific concentration X ppm could produce a likely global warming as low as 1.5 °C, but warming could be as high as 4.5 °C, increasing the severity of impacts. If sequestration is currently cheaper than abatement, should we use most sequestration capacity in the near future or should we save it as insurance in case the severity of impacts is large and we need to do more in terms of reducing the atmospheric stock?

Applying a dynamic optimization approach, this paper explores the optimal time path of carbon sequestration and carbon abatement in stabilizing the level of carbon dioxide in the atmosphere under uncertainty in climate impacts. Current international efforts to mitigate climate change are focused on stabilizing atmospheric concentrations of greenhouse gases by specific times (Den Elzen et al., 2010; National Research Council, 2010). A two-period sequential decision making model is analyzed. Expected present value costs of abatement and sequestration are minimized subject to two state variables: the level of CO_2 stock in the atmosphere and the stock of suitable land that can be converted to forest and, thereby, sequester carbon. Both controls are treated as investments where current reduction efforts yield future reduction benefits. Uncertainty regarding the desired stabilization level of the atmospheric stock is resolved prior to the decision on how much to control the stock in the second period. Our results show that uncertainty in climate impacts may lead to three different outcomes depending on the structure of both marginal cost curves and on the amount of sequestration capacity: the *Aggressive Path* in which uncertainty results in more deployment of abatement and sequestration in the first period, the *Conservative Path* in which uncertainty results in less deployment of abatement and sequestration in the first period and the *Indeterminate Path* in which uncertainty can lead to either more or less deployment of abatement and sequestration in the first period.

There are a handful of studies in the economics literature on the optimal time path of carbon sequestration and/or carbon abatement in controlling GHG but only a few incorporate uncertainty in the analysis. Webster (2002) shows, by using a two-period sequential decision-making model, that uncertainty in climate impacts which is resolved through time can lead to either more restrictive or less restrictive abatement reduction policies today. This author does not, however, consider tradeoffs between carbon abatement and carbon sequestration along the optimal time path. The rest of the studies explore uncertainty with respect to climate damages in a numerical analysis. Main results are consistent with the *conservative path* suggesting that substantial amounts of carbon could be optimally sequestered in forests especially toward the end of the century (Sohngen and Mendelsohn, 2003) and as a safety measure for future use in case of catastrophic climate events (Gitz et al., 2006). We show that these previous studies are special cases of the broader theory.