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The persistence of shocks in GDP and the estimation of the potential economic costs of climate change

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ABSTRACT

Integrated assessment models (IAMs) typically ignore the impact climate change could have on economic growth. The damage functions of these models assume that climate change impacts have no persistence at all, affecting only the period when they occur. Persistence of shocks is a stylized fact of macroeconomic time series and it provides a mechanism that could justify larger losses from climate change than previously estimated. Given that the degree of persistence of climate impacts is unknown, we analyze the persistence of generic shocks in observed GDP series for different world regions and compare it to that of the leading IAMs. Under the working hypothesis of interpreting the direct impact of climate change as such shocks, the implications for growth are investigated for two RCP scenarios. The way of introducing climate shocks to GDP in most IAMs can be interpreted as assuming an autonomous, costless, large and effective reactive adaptation capacity.

1. Introduction

The causes and consequences of environmental problems tend to be highly complex and trespass disciplinary boundaries (e.g., Akhtar et al., 2013; de Vos et al., 2013; Döll et al., 2013). Integrated assessment (IA) and IAMs provide a framework to address these problems by synthesizing diverse knowledge, data, methods and perspectives with the accent differing in terms of the disciplines involved (Hamilton et al., 2015; Kelly et al., 2013). IA/IAMs have been used for the study of a wide variety of environmental issues including air pollution (Vedrenne et al., 2014), land degradation (Ibáñez et al., 2014), water management (Letcher et al., 2007), agriculture (Ewert et al., 2014), among others.

IAMs are extensively used for investigating the potential consequences of climate change on the world economy and its regions. These models typically consider a range of aspects such as agriculture, energy, human health, water and coastal resources, human settlements and ecosystems, sea level rise and in some cases catastrophic impacts (i.e., large discontinuities in the climate system). Damage functions are commonly calibrated using meta-analysis of the sectoral estimates available in the literature in order to represent the impacts of climate change for a benchmark warming (e.g., 2.5 °C; see Nordhaus and Boyer, 2003; Hope, 2006; Tol, 2009; among others). Most IAMs summarize all this information in one or two aggregated damage equations to represent the regional and/or global impacts expected for a particular increase in global annual mean surface temperature. For the purposes of this paper it is important to notice that: 1) in general, the damage functions are calibrated to *static* impact estimates corresponding to a prescribed warming scenario such as doubling of atmospheric CO_2 or a specific equilibrium global temperature change (Hitz and Smith, 2004; Parry et al., 1999). Neither transient changes in climate, nor their consequences in natural and human systems are considered. Time itself and temporal dynamics are absent from these estimates. However, the impacts and changes a system has experienced in the past can strongly influence how it can deal with present and future impacts: resilience, vulnerability and adaptation capacity are time and path dependent and can strongly modify the

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magnitude of impacts (e.g., Denton et al., 2014). 2) The impact functions interpolate these static benchmark estimates of the costs of climate change for different values of equilibrium global/regional temperatures. When applied to transient climate scenarios, a time subscript is added to match that of a particular climate projection. As such, unless explicitly modeled in the impact functions, all impact dynamics other than those imparted by the dynamics of the climate projection and in some cases by the economic growth model (Fankhauser and Tol, 2005), are excluded. 3) Most IAMs express all the diverse effects of climate change over the different sectors and systems as an aggregated percent reduction/increment of a GDP baseline scenario and impose this as a direct shock to global/regional welfare.[1] Climate changes gradually and over long period of time and therefore climate shocks to GDP occur in a sequence.

The present paper contributes to the efforts made by the integrated assessment modeling community to identify relevant shortcomings in IAMs and to propose ways to overcome them (e.g., Jakeman et al., 2006; Giupponi et al., 2013 and the *Thematic Issue on Innovative Approaches to Global Change Modelling* in Volume 44 of *Environmental Modelling and Software*). Exploring the sensitivity of IAMs to parameter values has been an important way forward for better understanding both the assumptions contained in IAMs' specification as well as for identifying key parameters determining the models' outcomes (e.g., Butler et al., 2014; Nordhaus, 1992). However, some assumptions in IAMs are not explicitly expressed in their equations and their effects can be harder to assess. In this paper we investigate the sensitivity of these models to the persistence of impacts and we propose a modification to make the impact dynamics explicit in the damage functions, contributing to improved IAM transparency (Schwanitz, 2013; Schneider, 1997).

The impacts of climate change in an IAM framework are, of course, persistent because of the persistence of the climate system, which is largely determined by the changes in the abundance of long- and short-lived radiative active substances in the atmosphere (e.g., CO2, aerosols), and by the dynamics of the long- and short-term responses of the climate system, governed to a large degree by the heat capacity of the ocean. However, the response of natural and human systems to physical impacts also imparts persistence, which is related to their intrinsic resilience and adaptive capacities. These characteristics determine the system's capacity and time to recover as well as the possibility of undergoing permanent changes (e.g., Holling, 1973; Denton et al., 2014; Gunderson, 2000; Tol, 1996; Hallegatte, 2014; Fankhauser and Tol, 2005; Dell et al., 2012). These dynamics are inherent to the system being affected and different to those of the changes in climate mentioned above. For example, a variety of economic and socioeconomic processes can amplify or damp the persistence of climate change shocks (e.g., lower expected returns of investment and/or higher risks could make impacts more persistent through reduced investment; adaptation processes such as improving production technology could make climate shocks less persistent). The dynamics of the economy can make climate change impacts even more persistent not only due to changes in productivity and capital accumulation (Fankhauser and Tol, 2005) but also to other factors such as the speed and capacity to adapt and adjust of the different economic sectors (e.g., Hallegatte, 2014).

The persistence imparted by the climate is outside of the scope of this paper, as instead we focus on analyzing the dynamics of the damage functions. Models with more complex representations of the climate system tend to be more persistent (see Alex and Marten, 2011 for a comparison of IAMs climate models). A large part of the IAMs used for estimating the costs of climate change do not explicitly model the physical impacts but only the monetized impacts (e.g., Tol and Fankhauser, 1998), and therefore all impact dynamics can in practice only occur in two parts of IAMs: 1) in their damage functions or 2) through the dynamics of the economic growth model, if included in the IAM. In any case, impact functions in IAMs should be able to represent the most salient features of the dynamics of impacts.

Most economic IAMs represent climate change impacts as aggregated direct shocks to GDP. This makes GDP the variable of interest to study impact dynamics in these models. The level of persistence of climate shocks to GDP is unknown. However, some studies have suggested that these shocks tend to persist in time and only gradually dissipate. Fankhauser and Tol (2005) studied this problem from a theoretical perspective analyzing the dynamic effects of climate change impacts in future welfare by means of economic growth models. They showed that in addition to the direct impacts of climate change, this phenomenon can have important indirect impacts over capital accumulation, the propensity to save and capital-labor ratio due to climate change's potential health effects. Hallegatte (2005, 2007) stresses the importance of considering the climate and economic dynamics (and feedback processes between these two systems) as well as the short-term socioeconomic constraints in determining the long-term costs of climate change. He argues that the impacts associated to these dynamic processes can be larger than those shown in the traditional assessments of the costs of climate change that have been published. The existence of poverty traps has been also pointed out as a potential mechanism that can create persistent effects over economic growth through its impact on demographic and economic dynamics (Tol, 2011; Hallegatte, 2007).

The long-term impact of extreme events on economic growth has been addressed in the literature leading to opposite results. These differences may be explained by the modeling approaches taken and the treatment of temporal dynamics of impacts in particular (Noy, 2009; Raddatz, 2007). Skidmore and Toya (2002), by means of a (static) cross-sectional analysis for the period 1960–1990, conclude that higher frequencies of climatic disasters are positively correlated with higher rates of human capital accumulation, increases in total factor productivity and economic growth. On the contrary, studies based on macroeconomic models have shown that disasters do not increase economic growth and that economic dynamics and constraints can make the overall production loss considerably larger than the direct costs of the disaster (Hallegatte et al., 2007; Hallegatte and Dumas, 2008). Although the study of the effects of disasters in growth offers the large advantage of data availability on the consequences of past events, the effects of climate change over economic growth are far more general and sustained than those of extreme events alone and the dynamics need not be similar (e.g., Tol, 2011; Fankhauser and Tol, 2005; Dell et al., 2014).

A useful way for analyzing the temporal dynamics of a process or system is to study how single shocks (or one-time "pulses") propagate through time using, for example, impulse response functions. A single perturbation is introduced in the equation describing the process of interest (e.g., an impact function) at time t and its effects over the following periods are analyzed. A shock is persistent if its effects take longer to dissipate than the length of the time step. This is how the temporal dynamics of the impact functions in IAMs are investigated in this paper. Different approaches are available for studying persistence in economic variables, notably the classical econometrics approach based on time-series models and the Real Business Cycle (RBC; see King and Rebello,

[1] The baseline GDP scenarios used in climate change studies represent what is expected to occur conditional on a set of assumptions about some determinant factors. Any external perturbation that is imposed to these projections can be interpreted as a shock (for a definition of shock in economics see Black et al., 2009).