Journal of Environmental Economics and Management 77 (2016) 75–94

Contents lists available at ScienceDirect

Journal of Environmental Economics and Management

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

A simple formula for the social cost of carbon

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ARTICLE INFO

Article history:
Received 12 September 2014
Available online 7 February 2016

JEL classification:
H23
Q54
Q48
C68

Keywords:
Climate change
Social cost of carbon
Integrated assessment models

ABSTRACT

The social cost of carbon (SCC) is the monetized damage from emitting one unit of CO_2 to the atmosphere, often obtained from computational Integrated Assessment Models (IAMs). We develop a closed-form formula that approximates the SCC for a general economy, and then explore the capacity of the analytical approach to capture the key SCC drivers and thus to replicate the results of the deterministic IAMs. The formula explains the parameter-driven SCC variation of a mainstream IAM without a systematic bias. The sensitivity analysis identifies and measures the performance limits of the closed-form formulas. We then use the analytic formula to structurally interpret a distribution of SCCs from deterministic IAMs, and develop an analytical breakdown and quantification of how different sets of parameters contribute to the SCC distribution. This allows the user of the formula to evaluate where particular parameter choices tend to place the resulting SCC outcome in the distribution of outcomes for the universe of deterministic IAMs.

Introduction

The social cost of carbon (SCC) monetizes the damage from releasing a ton of CO_2 to the atmosphere today. The monetization of damages is essential for the determination of optimal climate policies; pricing carbon according to the SCC provides the correct economic incentive for reducing current emissions. The SCC can be obtained by using computational Integrated Assessment Models (IAMs) that connect the global carbon cycle and temperature dynamics to a global economy description to assess the marginal welfare costs of emissions. There are several widely used IAMs.[1] While the IAMs overarch the contributions from various disciplines in climate-change research, they are not easily accessible to policymakers and researchers in general.[2] There are various systematic assessments of the assumptions in the IAMs and their effects on outcomes (Weyant et al., 2006; Hope, 2008; Nordhaus, 2008; Anthoff and Tol, 2013). The assessments show that higher climate sensitivity, higher estimates of damages for given temperature change, and lower discount rates generally lead to

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[1] Most notable IAMs include DICE (Nordhaus, 1992, 2008), CETA (Peck and Teisberg, 1992), PAGE (Hope et al., 1993), MERGE (Manne and Richels, 2005), FUND (Tol, 2005). MIT ISGM (Webster et al., 2003), R&DICE (Nordhaus and Boyer, 2000).

[2] The proof of the pudding is in the eating. Here we consider accessibility as revealed through use by others. Most policymakers (need to) rely on supporting researchers who can run IAMs for policy assessments. Some IAMs are considered relatively simple, but only DICE (Nordhaus, 1992) is sufficiently simple and comprehensive enough to have attracted a large group of users in the research community. R&DICE and FUND have publicly available descriptions and full source codes. R&DICE is used by a few researchers, but, to our knowledge, Ackerman and Munitz (2012) are the only researchers who used FUND, other than the developers. Learning to work with a model developed by someone else typically requires a very long learning time. Ackerman and Munitz (2012) reported on the results of their difficult process of running someone else's model; they required help by the developers.

http://dx.doi.org/10.1016/j.jeem.2016.01.005
0095-0696/

higher estimates for the SCC. They do not, however, solve a fundamental problem: to the wider audience, the IAMs remain a black box and the resulting SCC is a number accepted or rejected on the basis of trust or distrust in the models and their developers (Kelly and Kolstad, 1999a). Newbold et al. (2013) build a parsimonious and transparent IAM to help the user in understanding "how the SCC is likely to respond to alternative assumptions and input parameter values." Still, the user needs to ask the authors for the model, study it, run it, and analyze the outcomes.[3]

Golosov et al. (2014) derive an analytical formula for the SCC in an integrated assessment model, based on specific assumptions such as logarithmic utility and climate-change damages proportional to output and exponential in the atmospheric CO_2.[4] Gerlagh and Liski (2012) add a more comprehensive description of the climate system and associated temperature-change delays, and study the implications of the formula for the optimal policies in a general-equilibrium context with time-inconsistent preferences. In the current paper, we build on this emerging analytical literature to develop a closed-form SCC formula that approximates a general economy, and to provide a systematic testing of the formula. The objective is to explore the capacity of the analytical approach to capture the key SCC drivers and thus to replicate the results of the deterministic IAMs.

To evaluate the "internal validity" of the formula we test its performance against a mainstream numerical IAM (DICE, Nordhaus, 2008).[5] Using a conservative sampling of the IAM parameters, we find that, on average, the formula explains the parameter-driven variation in the IAM SCC: the eight central parameters that enter the formula predict the IAM outcome, which depends on 14 parameters, without quantitatively significant systematic bias. The largest gaps in outcomes are associated with situations where climate damages are either strongly concave or convex, and, at the same time, the discount rate takes extreme values (low or high). The reasoning behind the deviations helps in understanding and measuring the performance limits of the closed-form formula.

To consider the "external validity" of the formula, we generate a distribution for the SCC from the underlying parameter distributions derived from the literature. The resulting distribution compares well with the existing distribution of SCC estimates produced by a sample of numerical IAMs (Tol, 2009). Since the formula is a structural interpretation for the SCC distribution, we can develop an analytical breakdown and quantification of how different sets of parameters contribute to the SCC distribution. The right-skewness of the SCC distribution has little to do with the carbon cycle and temperature delay parameters; damages and the determinants of discounting have a large contribution. In addition, due to the non-depreciating climate boxes, some climate impacts are permanent, fattening the tail of the SCC distribution when discounting falls towards zero. Importantly, analytical models without a multi-box description of the climate system ignore this tail-fattening effect.

In contrast with Golosov et al. (2014) and Gerlagh and Liski (2012), we derive the SCC in closed-form for a general economy whose development is approximated by a balanced-growth path. The approximation allows extending the formula to cover elements that have been noted important in the literature: non-unitary elasticity of marginal utility (Jensen and Traeger, 2014); climate-change damages increasing more or less than proportionally with income (Hoel and Sterner, 2007; Traeger, 2014); a climate-response function based on a more comprehensive emissions-temperature model (Gerlagh and Liski, 2012). The formal derivation thus requires a balanced-growth path; then, we test how the formula performs outside the balanced growth path.[6]

The current study should be understood as an investigation into the basic mechanisms of the numerical IAMs; we do not consider climate policy making under uncertainty or learning (e.g., Kelly and Kolstad, 1999b; Keller et al., 2004; Leach 2007, Crost and Traeger, 2013). Thus, the formula, as currently expressed, cannot provide guidance on how the optimal polices should develop over time when new information about the climate–economy interactions arrive (e.g., Lemoine and Traeger, 2014; Gerlagh and Liski, 2014), or how attitudes towards uncertainty might shape the current SCC (Jensen and Traeger, 2014).[7,8] Instead, the objective is to link the predictions of the commonly used deterministic simulation models and those of the analytical representations for the current carbon price. With this focus in mind, the formula seeks to bring the knowledge that has been accumulated in the climate research to the domain of analytical economics and further democratize it: by use of our formula, any reader can perform his or her own informed assessment about the SCC.[9] Given its performance, the formula can be seen as a useful policy tool. Without the need for assistance in running an IAM, it allows the policymaker to assess the sensitivity of the SCC estimate to climate sensitivity, climate-change damages, and

[3] The current literature considers the existing simple models, such as DICE, as the furthest point to which one can get towards practical and accessible tools for assessment, away from large-scale 'black box' models, without sacrificing what is seen to be the essential structure for the climate–economy interactions.

[4] See Barrage (2014) for a sensitivity analysis of the assumptions.

[5] Because of its public availability, conciseness, transparent documentation, and middle-of-the-road assumptions, we choose DICE (Nordhaus, 2008) for testing the accuracy of the formula. We extend DICE with damages that grow more or less than proportional with output (see footnote 25).

[6] In spirit, the approach is similar as in Nordhaus (1991); he considers a steady-state approximation.

[7] Rezai and van der Ploeg (2015) propose a similar rule as van den Bijgaart et al. (2013) and allow for mean reversion in global warming damages, negative effects of global warming on trend growth, and a non-unitary elasticity of damages with respect to aggregate output. Their paper is complementary to ours; they use the formula to assess the time paths of the SCC in comparison with those produced by a benchmark model. They find minimal welfare losses if one applies the simple rule as the basis for the climate policy over time.

[8] The impact of short-term fluctuations on the choice of the optimal policy instrument has been considered, for example, in Hoel and Karp (2001, 2002) and in Karp and Zhang (2006).

[9] The reader can fill in the parameters and see the results immediately through an Excel file available through at http://dx.doi.org/10.1016/j.jeem.2016.01.005.