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Internalization of the external costs of global environmental damage in an integrated assessment model

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ABSTRACT

This study simulates the internalization of the external costs of major global environmental issues using an optimal economic growth model. We merged two existing models: an integrated assessment model (IAM) and a life-cycle impact assessment (LCIA) model. We sought to achieve simultaneously the following three objectives: (i) to incorporate environmental issues including global warming in the IAM; (ii) to assess environmental impacts with a bottom-up approach from the LCIA; and (iii) to internalize external costs obtained from the environmental impact study. The study also provides initial simulation results obtained from the merged model.

Simulation results indicate that global warming will account for somewhere from 10% to 40% of all external costs in the 21st century. The remaining cost will come from land use and its changes. The internalization of the external cost will cause a decline in economic growth by approximately 5%, whereas forest preservation will increase by 40% and fossil-fuel consumption will be reduced by 15%. The estimated sustainability indicators imply that a necessary condition of sustainable development is satisfied for the entire world and for the developed countries during the 21st century, but is not satisfied until the latter half of this century for the developing counties.

1. Introduction

Cost-benefit analyses are a common and powerful tool to evaluate the pros and cons of policy measures for global and local environmental issues. Lots of simulation studies of cost-benefit analyses for climate policy has been performed worldwide during the past two decades using so-called integrated assessment models that incorporate the interrelationship between global warming and economic growth. The pioneer of this kind of research is the Dynamic Integrated Model of Climate and the Economy (DICE) developed by Nordhaus (1994).

The DICE model and its multi-region extension RICE98 model (Nordhaus and Boyer, 2000) indicate the economic impact due to global warming as a percentage of gross domestic product (GDP) and assume the percentage to be an exponential function of the global mean temperature rise. The models can internalize external costs due to global warming for a global total by multiplying this percentage by the production function, which consists of the capital and labor inputs in the models.

It is, however, hard to verify and judge the validity of the external cost calculation in the DICE model, since it is based on rough estimates of the economic impact on several economic sectors (Nordhaus, 1994; Tol, 2002; Fankhauser, 1995). Another existing approach assesses economic impacts minutely in a bottom-up manner for each economic sector, but it cannot incorporate impacts on economic growth (Kainuma et al., 2003). This implies that external costs by global warming cannot be internalized. Moreover, neither approach treats economic impacts other than global warming due to greenhouse gas (GHG) emissions from energy consumption.

Recently, some global and regional-scale energy modeling studies such as Klaassen and Riahi (2007), Rafaj and Kypreos (2007), Holmgren and Amiri (2007) and Nguyen (2008) have attempted to internalize external costs concerning not only global warming but also other environmental issues. These studies apply the results of European Commission's ExternE Project (Friedrich and Bickel, 2001) based on a life-cycle impact assessment (LCIA) to introduce externalities so that the external costs covered in the models are limited to the impacts of the emissions of carbon dioxide (CO_2), sulfur oxides (SO_X), nitrogen oxides, and particulate matters from energy supply systems. None of these studies except for Klaassen and Riahi (2007) internalize the external costs into macro-economy.

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Clearly, when we intend to comprehensively consider environmental issues and their impacts to economy, environmental damages caused by the sectors other than the energy supply sector should also be incorporated. For example, land use and land cover are expected to potentially affect considerable impacts to the global carbon balance as well as ecological quality.

In this study, using an integrated assessment model, we apply a life-cycle impact assessment model to internalize major environmental external costs caused by energy systems, land use and land-use change (LU&LUC) in the global economy. That is, the primary purpose of this paper is to achieving simultaneously the following three objectives: (i) to incorporate environmental issues in addition to global warming in an integrated assessment model; (ii) to use environmental impacts in a bottom-up manner, unlike the top-down manner of the DICE model; and (iii) to internalize external costs due to detailed environmental impacts with the bottom-up manner of a life-cycle impact assessment model.

Some environmental indicators for the future will be calculated. The indicators include: (1) the total external costs and their percentages relative to GDP calculated endogenously in the framework of the model that merges an integrated assessment model (IAM) with a life-cycle impact assessment model, and (2) genuine saving and the change in wealth per capita, which are known as "weak sustainability" indicators proposed by Hamilton (2003) and Pearce,[1] estimated by using the results of the model.

The remainder of the paper is structured as follows. Section 2 briefly describes and summarizes fundamental information on the original life-cycle impact assessment model (life-cycle impact assessment model based on endpoint modeling, LIME) and the integrated assessment model (Global Relationship Assessment to Protect Environment, GRAPE) applied in the present study and previously reported elsewhere in greater detail. Section 3 then introduces the advances made by the present study, specifically, the methodology used to merge the two models. Section 4 presents major simulation results including the external costs calculated with the integrated model, and Section 5 shows the genuine savings and changes in wealth per capita estimated in an application of the model. Section 6 presents an extensive discussion of the methodological development in this study. Section 7 provides conclusions.

2. The life-cycle impact assessment model and the integrated assessment model used in this study

2.1. Life-cycle impact assessment model

We use the Japanese version of life-cycle impact assessment modeling based on damage calculation named LIME developed by Itsubo and Inaba (2005) as a part of a national project of life-cycle assessment. This method assesses environmental impacts in present-day Japan in a bottom-up way from substances[2] (causes of global environmental problems) to safeguard subjects harmed by these substances.

LIME can assess 11 categories of environmental impact, as shown in Fig. 1. They consist of the following: (1) global warming, (2) ozone depletion, (3) acidification, (4) photochemical oxidants, (5) urban air pollution, (6) toxic chemicals, (7) ecotoxicity, (8) eutrophication, (9) land use, (10) resource consumption, and (11) waste. These 11 kinds of environmental impact arise through the concentration in the environment of substances including CO_2 and SO_X (shown as 'Inventory' in Fig. 1). The environmental categories are subsequently divided into four safeguard subjects – human health, social welfare, biodiversity, and primary productivity – through category endpoints including heat/cold stress and infectious disease (indicated in the 'Category Endpoint' column in Fig. 1). By summing up the impact on each safeguard subject with its weighting factor, we derive the total external cost expressed as a single index.

In LIME, damage functions for the four safeguard subjects based on the emissions of environmental burden substances are developed by applying the relationship between the exposure of receptors such as humans and the amount of potential damage that the receptor suffers. Then weighting factors of the safeguard subjects are obtained by applying conjoint analysis so that the monetary value of environmental impact of one unit of each substance can be calculated from them (Itsubo and Inaba, 2005).

2.1.1. Development of damage functions

A damage function expresses the quantitative relationship between inventory and endpoint damage. The damage indicators for the four safeguard subjects are, respectively, (1) disability-adjusted life years (DALY) that is used internationally in insurance statistics, for human health, (2) an economic indicator (expressed in Japanese yen) for social welfare, (3) the expected increase in the number of extinct species defined based on the extinction risk evaluation used in conservation ecology for biodiversity, and (4) net primary production (NPP) that is widely used in ecology and landscape architecture as an indicator representing the variety of ecosystems, for primary productivity.

The endpoints for each impact category such as global warming are selected, followed by the development of damage functions that estimate the physical damages of each category endpoint caused by the emission of a pollutant. Table 1 shows the category endpoints considered in this method in relation to impact categories and safeguard subjects. The endpoints included in the blank cells are ignored in the first version of LIME because their impacts appear negligible or are unquantifiable (Itsubo and Inaba, 2005). Table 1 also indicates the references that describe the details of the derivation of each damage function. Some notes on the derivation of the damage functions for the impact categories of global warming and land use, which will strongly influence the present study, are shown in the Appendix A.

2.1.2. Development of weighting factors

A choice-based type of questionnaire survey, regarding marginal willingness to pay (MWTP) to prevent environmental damage, was submitted to 400 respondents selected by random sampling. Using the survey data, the amount of MWTP for avoiding a unit of damage of every safeguard subject was estimated by a conditional logit model based on the random utility theory reflecting the responses to the questionnaire. The estimation was revealed to be statistically significant at the 1% level. For more detailed information regarding the development of weighting factors, see Itsubo et al. (2004).

The obtained weighting factor corresponds to the monetary value of the environment obtained by measuring the marginal welfare change necessary to prevent environment damage.[3]

[1] Pearce, D.W., 2005. Environment and Economic Development, Unpublished manuscript.

[2] Substances indicated include CO_2, SO_X, heavy metals, chemical products, etc. We use the word to indicate not only substances normally used but also actions that cause environmental damages such as land-use changes.

[3] Concrete monetary values of environmental impacts according to LIME will be shown in Section 3.1.