Beyond aggregated damage functions in an integrated assessment model

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Overview

Over the long history of modeling approach by either top-down (climate-welfare economy) or bottom-up (systems-engineering) of the integrated assessment model (IAM), huge body of modeling exercises had been focused on cost-benefit analysis to assess targets of climate change mitigation based on shadow price of carbon or social cost of carbon (SCC). Damage assessment, so-called "aggregated, simplified damage functions", is seriously attacked [Pindyck 2013] as lacking scientific basis and economic foundations, while systems-engineering models incorporate damage assessments either by the similar functions or by modeling too complex to be traceable (i.e. black-boxiness). The specific problems of the standard aggregated damage functions are fully depending on modeler's choice of (1) specific form of algebraic functions, (2) parameter settings of the calibration of the function, and (3) WTP for the damage assessment.

Our proposal to solve the problems is take alternative strategy; a lifecycle impact assessment (LCIA) model is integrated into IAM. LCIA can be described as a framework to capture a wide range of environmental impacts related to the consumption of goods and services from cradle to grave. Impacts are included at all geographical levels over the whole lifecycle. Representative LCIA models are the ReCiPi developed in EU and LIME developed in Japan [Itsubo et al., 2015], employing dose-response functions (DRFs) with environmental valuation using stated preference methods (e.g., contingent valuation method; CVM or conjoint analysis; CA).

Methods

Our IAM [Tokiamatsu et al., 2019] incorporates version 3 of LIME (LIME3) developed for global scale, based on the RICE 2010 model, combining an optimizing central planner with a series of resource balance models and a Life Cycle perspective on environmental impacts. The use of 3 resource balance models and 1 simplified climate model allows us to map resource use to an extended production function via 10 sectors representing the economy. Then, inventories reflecting this resource use by 10 sectors are used as inputs in the LIME3 model to generate environmental impacts related to 4 "policy goals" called "endpoints" concerning Human Health, Biodiversity preservation, Natural Resources and Ecosystem functioning preservation. One of merits to incorporate LIME3 is, in addition to global warming, to include other impacts categolies – local air pollutions, transboudary acidification, ozone layer depletion, land use, land-use change, resource extraction, and waste.

LCIA employs "impact-pathway" approach, identifying specific sources of damages and specific receptors (the receptors are called "midpoints" or "endpoints" in LCIA, depending on models). The relations between the sources and receptors are further investigated, by sometime employing specific science and engineering models (e.g., chemical transport models) or by literature reviews in specific topics (e.g., epidemic relations of asthma due to particulate matters). These relations are generally called dose-response functions (DRFs, or cause-effect chains). All the environmental damages by their causes (e.g., global warming, land-use, waste, etc.) are aggregated into the predetermined midpoints (in ReCiPi) or endpoints (in LIME). They are expressed as non-monetary value in their respective unit (e.g., DALY for human health, ton for natural resources). Compared to the "impact-pathway" approach, standard damage functions in climate-welfare economy IAMs are basically just relate between global temperature rise and either economic output loss or sectorial climate damages in monetary term [e.g., Howard and Sterner 2017].

Unlike to all the other LCIA models, LIME3 steps forward from the endpoints into the monetization (called "weighting" process in LCA framework, optional procedure). LIME3 applied four sets of marginal willingness to pay (MWTP) for the four endpoints having monetary conversion unit (e.g., USD/DALY, USD/ton) derived from conjoint analysis, well developed in environment and resource economics for application to natural environment. The conjoint analysis questionnaire sheets provide tables constituted from a few policy choices with five attributes – four from the endpoints and payment. Hence, the four sets of MWTP is altogether generated simultaneously and consistently, regardless of the causes of environmental damages (i.e, global warming, land-use etc), based on 7,400 samples from some 25 countries in G20 and Asia. Compared with the four sets of MWTP at the endpoints by conjoint analysis, the standard damage functions use modeler's choice or survey on very limited number of panels, some calibrated by specific sectorial damage assessments in monetary term.

In order to show differences in calculation results by applying different damage assessments, following three patterns in damage assessments are compared; the first is our original setting using fully integrating LIME3 (i.e., global warming and the others), the second is using the damage function from DICE 2016R2 for global warming instead of LIME3 while all the other impacts are retained from LIME3, and the third one is only using the damage function excluding all the other impacts. Modifications on our IAM is related to plugging damage assessment methods into our IAM. Likewise to the standard climate-welfare economy IAM, the damage function is multiplied to our production function while the environmental external cost by LIME3 is subtracted from the the damage function. Simulation run are conducted under reference (without feedback of environmental damages) and balanced growth (including the feedback without climate policy intervention).

Results

The DICE/RICE model vintage generates wide ranges in results of SCC or rises of global temperature and sea level [Nordhaus 2017]. Total leve of the damage costs in global warming estimated by our IAM (LIME3 basis) falls within the ranges by the damage functions in the vintage. One of our innovations by our IAM applying LIME3 is to show breakdown of damage estimates at the end points (i.e., human health, natural resources – crop, land by sea level rise (SLR), and energy, and biodiversity), while RICE 2010 only can show damage differences by SLR and by global mean temperature rise (GTR), and no sectorial damages due to GTR are shown by all the DICE/RICE model vintages.

The ability to show breakdown of sectorial damage estimates by our IAM (LIME3 basis), another innovation by our IAM is to indidate impacts by the other environmental impacts in addition to global warming. Under the reference scenario, the environmental external costs by local air pollution and by land-use change are comparable to that by global warming in 2100, while in the middle and the beginning of this century share of global warming is decreasing. Under the balanced growth scenario, both the costs by local air pollution and by land-use change are dramatically reduced, implying anchillery or co-benefit is induced by the internalization of the environmental external cost into the world economy.

Conclusions

Beyond the aggregated damage functions - our IAM approach - brings various benefits. The methodologies in impact assessments and its economic valuations are firmly grounded in science and enginieering in the formar and in environmental economics in the latter, respectively. Simulation results on global warming impacts and the others can be obtained simultaneously. Unlike to the DICE/RICE model vintages, our IAM enables to show energy mix structure together with those impacts in the unified forms, consistent manner and inclusive treatment of natural resources and environment, leading to the comprehensive assessment in sustainability under various climate policy targets by using Genuine Savings [Tokimatsu et al., 2019], failed in the Stiglitz report [Stiglitz et al., 2009].

References

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