Special Edition: Endogenous Technological Change and the Economics of Atmospheric Stabilisation

April, 2006

Pages 1-16

Technological Change for Atmospheric Stabilization: Introductory Overview to the Innovation Modeling Comparison Project

by Michael Grubb (Faculty of Economics, Cambridge University), Carlo Carraro (Department of Economics, University of Venice) and John Schellnhuber (Potsdam Institute for Climate Impact Research)

Pages 17-56

The Transition to Endogenous Technical Change in Climate-Economy Models: A Technical Overview to the Innovation Modeling Comparison Project

by Jonathan Köhler (Tyndall Centre and Faculty of Economics, University of Cambridge), Michael Grubb (Imperial College and Faculty of Economics, University of Cambridge), David Popp (Department of Public Administration, Center for Policy Research, The Maxwell School, Syracuse University) and Ottmar Edenhofer (Potsdam Institute for Climate Impact Research)

Abstract

This paper assesses endogenous technical change (ETC) in climate-economy models, using the models in the Innovation Modeling Comparison Project (IMCP) as a representative cross-section. ETC is now a feature of most leading models. Following the new endogenous growth literature and the application of learning curves to the energy sector, there are two main concepts employed: knowledge capital and learning curves. The common insight is that technical change is driven by the development of knowledge capital and its characteristics of being partly non-rival and partly non-excludable. There are various different implementations of ETC. Recursive CGE models face particular difficulties in incorporating ETC and increasing returns. The main limitations of current models are: the

lack of uncertainty analysis; the limited representation of the diffusion of technology; and the homogeneous nature of agents in the models including the lack of representation of institutional structures in the innovation process.

Pages 57-108

Induced Technological Change: Exploring its Implications for the Economics of Atmospheric Stabilization: Synthesis Report from the Innovation Modeling Comparison Project

by Ottmar Edenhofer (Potsdam Institute for Climate Impact Research), Kai Lessmann (Potsdam Institute for Climate Impact Research), Claudia Kemfert (DIW (German Institute for Economic Research) and Humboldt University), Michael Grubb (Imperial College and Faculty of Economics, Cambridge University) and Jonathan Köhler (Tyndall Centre and Faculty of Economics, University of Cambridge)

Abstract

This paper summarizes results from ten global economy-energy-environment models implementing mechanisms of endogenous technological change (ETC). Climate policy goals represented as different CO2 stabilization levels are imposed, and the contribution of induced technological change (ITC) to meeting the goals is assessed. Findings indicate that climate policy induces additional technological change, in some models substantially. Its effect is a reduction of abatement costs in all participating models. The majority of models calculate abatement costs below 1 percent of present value aggregate gross world product for the period 2000-2100. The models predict different dynamics for rising carbon costs, with some showing a decline in carbon costs towards the end of the century. There are a number of reasons for differences in results between models; however four major drivers of differences are identified. First, the extent of the necessary CO2 reduction which depends mainly on predicted baseline emissions, determines how much a model is challenged to comply with climate policy. Second, when climate policy can offset market distortions, some models show that not costs but benefits accrue from climate policy. Third, assumptions about long-term investment behavior, e.g. foresight of actors and number of available investment options, exert a major influence. Finally, whether and how options for carbon-free energy are implemented (backstop and end-of-the-pipe technologies) strongly affects both the mitigation strategy and the abatement costs.

Pages 109-122

Induced Technological Change in a Limited Foresight Optimization Model

by Fredrik Hedenus, Christian Azar and Kristian Lindgren (Department of Physical Resource Theory, Chalmers University of Technology)

Abstract

The threat of global warming calls for a major transformation of the energy system in the coming century. The treatment of technological change in energy system models is a critical challenge. Technological change may be treated as induced by climate policy or as exogenous. We investigate the importance of induced technological change (ITC) in GET-LFL, an iterative optimization model with Limited Foresight that incorporates Learning-by-doing. Scenarios for stabilization of atmospheric CO2 concentrations at 400, 450, 500 and 550 ppm are studied. We find that the introduction of ITC reduces the total net present value of the abatement cost over this century by 3-9% compared to a case where technological learning is exogenous. Technology specific policies which force the introduction of fuel cell cars and solar PV in combination with ITC reduce the costs further by 4-7% and lead to significantly different technological solutions, primarily in the transport sector.

Pages 13-140

Importance of Technological Change and Spillovers in Long-Term Climate Policy

by Shilpa Rao, Ilkka Keppo and Keywan Riahi (International Institute for Applied Systems Analysis)

Abstract

This paper examines the role of technological change and spillovers within the context of a climate policy in a long-term scenario of the global energy system. We use the energy-systems optimization model MESSAGE considering endogenous learning for various technologies, such that they experience cost reductions as a function of accumulated capacity installations. We find that the existence of technological learning while reducing overall energy system costs becomes particularly important in the context of a long-term climate policy. Diversity in technological portfolios is emphasized and results indicate deployment of a range of energy technologies in reducing emissions. An important finding is that technological learning by itself is not sufficient for climate stabilization and that climate policies are an absolute necessary complimentary element. Under a climate constraint, spillovers across technologies and regions due to learning results in increased upfront investments and hence lower costs of carbon free technologies, thus resulting in technology deployment and emissions reductions, especially in developing countries. We conclude that learning and spillover effects can lead to technologically advanced cost-effective global energy transition pathways. We suggest that coordinated climate stabilization policies can serve as important institutional mechanisms that facilitate the

required technological investments, especially in developing countries and thus ensure long-term cost reductions.

Pages 141-162

Analysis of Technological Portfolios for CO2 Stabilizations and Effects of Technological Changes

by Fuminori Sano, Keigo Akimoto, Takashi Homma and Toshimasa Tomoda (Research Institute of Innovative Technology for the Earth)

Abstract

In this study, cost-effective technological options to stabilize CO2 concentrations at 550, 500, and 450 ppmv are evaluated using a world energy systems model of linear programming with a high regional resolution. This model treats technological change endogenously for wind power, photovoltaics, and fuel-cell vehicles, which are technologies of mass production and are considered to follow the “learning by doing” process. Technological changes induced by climate policies are evaluated by maintaining the technological changes at the levels of the base case wherein there is no climate policy. The results achieved through model analyses ixnclude 1) cost-effective technological portfolios, including carbon capture and storage, marginal CO2 reduction costs, and increases in energy system cost for three levels of stabilization and 2) the effect of the induced technological change on the above mentioned factors. A sensitivity analysis is conducted with respect to the learning rate.

Pages 163-174

Comparison of Climate Policies in the ENTICE-BR Model

by David Popp (Department of Public Administration, Center for Environmental Policy Administration, Center for Technology and Information Policy, The Maxwell School, Syracuse University)

Abstract

This paper uses the ENTICE-BR model to study the effects of various climate stabilization policies. Because the ENTICE-BR model includes benefits from reduced climate damages, it is possible to calculate the net economic impact of each policy. In general, only the least restrictive concentration limit is welfare enhancing. While the policies are welfare enhancing in simulations using optimistic assumptions about the potential of the backstop

energy technology, such assumptions mean that the backstop is also used in the no-policy base case, so that climate change itself is less of a problem. Finally, assumptions about the nature of R&D markets are important. Removing the assumption of partial crowding out from energy R&D nearly doubles the gains from policy-induced energy R&D.

Pages 175-190

Assessment of CO2 Reductions and Economic Impacts Considering Energy-Saving Investments

by Toshihiko Masui (National Institute for Environmental Studies, Integrated Assessment Modeling Section, Social and Environmental Systems Division), Tatsuya Hanaoka (National Institute for Environmental Studies, Integrated Assessment Modeling Section, Social and Environmental Systems Division), Saeko Hikita (Tokyo Institute of Technology), and Mikiko Kainuma (National Institute for Environmental Studies, Integrated Assessment Modeling Section, Social and Environmental Systems Division)

Abstract

Using a global dynamic optimization model that includes a notion of endogenous energy-saving investments, economic impacts and energy-system changes are assessed under several policy cases where CO2 concentration is stabilized at the 450, 500, and 550 ppm levels by the year 2100. The effect of increased investments in energy-saving technologies on energy efficiency is derived exogenously from results of the AIM/Enduse model applied to Japan, then endogenized in the global dynamic optimization model.
We find that with diffusion of energy-saving technologies, GDP loss during the 21st century falls from 2.5% to 2.1% in the 450 ppm case. The impact is small for the 550 ppm case, however, because a shift to low-carbon-intensive energies such as gas and renewable energies does not occur to a significant extent under this target.

Pages 191-206

The Dynamics of Carbon and Energy Intensity in a Model of Endogenous Technical Change

by Valentina Bosetti (Fondazione Eni Enrico Mattei), Carlo Carraro (Fondazione Eni Enrico Mattei, Palazzo Querini Stampalia) and Marzio Galeotti (Fondazione Eni Enrico Mattei)

Abstract

In recent years, a large number of papers have explored different attempts to endogenise technical change in climate models. This recent literature has emphasized that four factors – two inputs and two outputs – should play a major role when modeling technical change in climate models. The two inputs are R&D investments and Learning by Doing, the two outputs are energy-saving and fuel switching. Indeed, R&D investments and Learning by Doing are the main drivers of a climate-friendly technical change that eventually affect both energy intensity and fuel-mix. In this paper, we present and discuss an extension of the FEEM-RICE model in which these four factors are explicitly accounted for. In our new specification of endogenous technical change, an index of energy technical change depends on both Learning by Researching and Learning by Doing. This index enters the equations defining energy intensity (i.e. the amount of carbon energy required to produce one unit of output) and carbon intensity (i.e. the level of carbonization of primarily used fuels). This new specification is embodied in the RICE 99 integrated assessment climate model and then used to generate a baseline scenario and to analyze the relationship between climate policy and technical change. Sensitivity analysis is performed on different key parameters of the energy module in order to obtain crucial insights into the relative importance of the main channels through which technological changes affects the impact of human activities on climate.

Pages 207-222

Mitigation Strategies and Costs of Climate Protection: The Effects of ETC in the Hybrid Model MIND

by Ottmar Edenhofer (Potsdam Institute for Climate Impact Research), Kai Lessmann (Potsdam Institute for Climate Impact Research), Nico Bauer (Paul Scherrer Institute)

Abstract

MIND is a hybrid model incorporating several energy related sectors in an endogenous growth model of the world economy. This model structure allows a better understanding of the linkages between the energy sectors and the macro-economic environment. We perform a sensitivity analysis and parameter studies to improve the understanding of the economic mechanisms underlying opportunity costs and the optimal mix of mitigation options. Parameters representing technological change that permeates the entire economy have a strong impact on both the opportunity costs of climate protection and on the optimal mitigation strategies e.g. parameters in the macro-economic environment and in the extraction sector. Sector-specific energy technology parameters change the portfolio of mitigation options but have only modest effects on opportunity costs e.g. learning rate of the renewable energy technologies. We conclude that feedback loops between the macro-economy and the energy sectors are crucial for the determination of opportunity costs and mitigation strategies.

Pages 223-240

ITC in a Global Growth-Climate Model with CCS: The Value of Induced Technical Change for Climate Stabilization

by Reyer Gerlagh (Institute for Environmental Studies, Vrije Universiteit)

Abstract

We assess the effect of ITC in a global growth model, – DEMETER-1CCS – with learning-by-doing, where energy savings, energy transition and carbon capturing and sequestration (CCS) are the three main options for emissions reductions. The model accounts for technological change based on learning by doing, embodied in capital installed in previous periods. We run five scenarios: one baseline scenario with no climate change policy and four stabilization scenarios in which atmospheric CO2 concentrations are stabilized at 550, 500, 450, and 400 ppmv. We find that the timing of emissions reductions and the investment strategy is relatively independent of the endogeneity of technological change. More important is the vintages' structure of production. ITC does reduce costs by approximately a factor of 2, however, these benefits only materialize after some decades.

Pages 241-258

Decarbonizing the Global Economy with Induced Technological Change: Scenarios to 2100 using E3MG

by Terry Barker (Faculty of Economics, University of Cambridge), Haoran Pan (Faculty of Economics, University of Cambridge), Jonathan Köhler (Zuckerman Institute for Connective Environmental Research, School of Environmental Sciences, University of East Anglia), Rachel Warren (Zuckerman Institute for Connective Environmental Research, School of Environmental Sciences, University of East Anglia), and Sarah Winne (Zuckerman Institute for Connective Environmental Research, School of Environmental Sciences, University of East Anglia)

Abstract

This paper reports how endogenous economic growth and technological change have been introduced into a global econometric model. It explains how further technological change might be induced by mitigation policies so as to reduce greenhouse gas emissions and stabilize atmospheric concentrations. These are the first results of a structural econometric approach to modeling the global economy using the model E3MG (energy-environment-economy model of the globe), which in turn constitutes one component in the

Community Integrated Assessment System (CIAS) of the UK Tyndall Centre. The model is simplified to provide a post-Keynesian view of the long-run, with an indicator of technological progress affecting each region's exports and energy use. When technological progress is endogenous in this way, long-run growth in global GDP is partly explained by the model. Average permit prices and tax rates about $430/tC (1995) prices after 2050 are sufficient to stabilize atmospheric concentrations at 450ppm CO2 after 2100. They also lead to higher economic growth.

Pages 259-276

Endogenous Structural Change and Climate Targets Modeling Experiments with Imaclim-R

by Renaud Crassous, Jean-Charles Hourcade, Olivier Sassi (CIRED—Centre International de Recherche sur l'Environnement et le Développement)

Abstract

This paper envisages endogenous technical change that results from the interplay between the economic growth engine, consumption, technology and localization patterns. We perform numerical simulations with the recursive dynamic general equilibrium model Imaclim-R to study how modeling induced technical change affects costs of CO2 stabilization. Imaclim-R incorporates innovative specifications about final consumption of transportation and energy to represent critical stylized facts such as rebound effects and demand induction by infrastructures and equipments. Doing so brings to light how induced technical change may not only lower stabilization costs thanks to pure technological progress, but also trigger induction of final demand—effects critical to both the level of the carbon tax and the costs of policy given a specific stabilization target. Finally, we study the sensitivity of total stabilization costs to various parameters including both technical assumptions as accelerated turnover of equipments and non-energy choices as alternative infrastructure policies.