Induced Technological Change in the Stabilisation of Carbon Dioxide Concentrations in the Atmosphere : Scenarios using a a large-scale econometric model

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Abstract

This paper addresses the question of the costs of stabilisation of the concentration of carbon dioxide in the atmosphere. A reduction in the modelled costs of achieving stabilisation is demonstrated when induced technological change (ITC) is taken into account. The approach is based on new concepts in the modelling of ITC and thus introduces new dimensions into the debate surrounding the stabilisation costs. In particular, a sectoral and regionally specific analysis is presented using the model E3MG (energy-environment-economy model of the globe), coupled to the simple climate model MAGICC, which are both components of the Community Integrated Assessment System (CIAS) of the UK Tyndall Centre. A baseline scenario is compared with three others in which carbon taxes with revenue recycling are applied to achieve stabilisation of carbon dioxide concentrations at three different levels by 2100.

1. Introduction

This study examines the role of induced technological change in determining the costs of stabilisation of carbon dioxide in the atmosphere. Existing studies have already highlighted the key role of technological change in estimates of stabilisation costs. However, these studies have tended to rely upon the use of general equilibrium economic models, and usually treat the global economy in aggregate. This study is the first which uses an econometric model with a dynamic structure, which is both sectorally and regionally specific. A new, specific treatment of substitution between fossil and non-fossil fuel technologies is employed, accounting for non-linearities resulting from investment in new technology, learning-by-doing, and innovation.

In this study the model is used to derive the costs of moving from a baseline to each of three stabilisation levels. To achieve stabilisation we simulate carbon taxes with and without incorporation of induced technical change in the model. A range of different stabilisation levels are considered, which are intended to satisfy article 2 of the UNFCCC which requires that we achieve “a stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system”. Mastrandea and Schneider [1] discuss methods to assess danger levels.

At this stage only preliminary example estimates of the stabilisation costs for particular concentration targets are provided, since we have yet to carry out our uncertainty analysis of both the economic and climate models which is required to provide estimates of the potential ranges of costs for each level of stabilisation. For example, the use of different parameters in the representation of the carbon cycle in the MAGICC climate model would strongly affect whether or not the actual scenario runs used here would deliver stabilisation of carbon dioxide concentrations in 2100. Furthermore, a wider range of policies than carbon taxes and permit trading might be considered useful. The purpose of the paper is thus not to provide specific estimates of stabilisation costs, but to use our novel treatment of the economy and innovation processes to illustrate the influence of the treatment of induced technical change upon estimates of stabilisation costs.

2. A short history of the modelling of technological change in relation to the costs of stabilisation

Grubb, Köhler and Anderson [2] review how many energy economic environment (E3) models do not incorporate induced technical change, but instead used the older concept of technology as exogenous 'manna from heaven'. Following the work in particular of IIASA [3], models investigating induced technical change emerged during the mid- and late 1990s. These models show that induced technical change (ITC) can alter results in many ways. Nakicenovich and Riaci [4] also note the great significance of the choice of baseline scenario in driving stabilisation costs. However, this influence is itself largely due to the different assumptions made about technological change in the baseline scenarios. Hourcade and Shukla (in [5]) reviewed modelling studies of costs of stabilisation in post SRES mitigation scenarios. In particular the Stanford Energy Modelling Forum identified widely differing costs of stabilisation at 550 ppmv of between 0.2 and 17 trillions of 1990 US $ whilst GDP reductions for stabilisation at 550 ranged from 0.2 to 1.75% GDP. Hourcade and Shukla explain that a main reason for the range of estimates of the costs (and also the optimal timing of) emission reductions is the treatment of technological change in the models. The studies incorporating ITC suggest that it could reduce stabilization costs substantially. ITC greatly broadens the scope of technology-related policies and usually increases the benefits of early action, which accelerates development of cheaper technologies. This is the opposite of the result from models with autonomous technical change, which can imply waiting for better technologies to arrive.

More recent work seems to confirm these findings. For example, Manne and Richels [6] and Goulder [7] also found that ITC lowers mitigation costs and that more extensive reductions in GHGs in are justified than with exogenous technical change. Nakicenovich and Riahi [4] noted how assumptions about the availability of future technologies was a strong driver of stabilisation costs.

Edmonds *et al* [8] studied stabilisation at 550 ppmv CO2 in the SRES B2 world using the MiniCAM model and showed a reduction in costs of a factor of 2.5 in 2100 using a baseline incorporating technical change. Edmonds considers that advanced technology development is far more important a driver of emission reductions than are carbon taxes. Van Vuuren et al [9] also concluded that technology development is key in achieving emission reductions as a result of carbon taxes: omitting technology development reduced the efficacy of C tax by 50% in their model. Weyant [10] concluded that stabilisation will require development on a large scale of new energy technologies and that costs would be reduced if many technologies are developed in parallel and there is early adoption of policies to encourage technology development.

3. The approach to modelling the economy and technological change

The contribution that this paper makes is to introduce a completely new approach to the modelling of technological change to the literature concerning the costs of stabilisation of greenhouse gases in the atmosphere. It throws new light on one of the most critical and challenging aspects of the modelling of stabilisation costs of greenhouse gases in the atmosphere.

The approach used here to economic and technology modelling involves a linkage between the top-down macroeconomic model, E3MG and the bottom-up technology ETM model. Thus, like the WGBU study [4] which is also based on the linkage of top-down and bottom-up models, our modelling approach avoids the typical optimistic bias often attributed to a bottom-up engineering approach, and unduly pessimistic bias of typical macroeconomic approaches. The advantages of using this combined approach have recently been reviewed [11].

The top-down model, E3MG, is unique in that it is a detailed, annual, dynamic econometric simulation model incorporating a database covering the period from 1970-2001, projecting forward to 2100. The database contains information about the historic changes in emissions, energy use, energy prices and taxes, input-output coefficients, macro-time series and sectoral series, as well as bi-lateral trade data. In the model, these data are projected into the future, and thus an important aspect of technological change can be represented through changes in input-output coefficients, e.g. the inputs of fossil fuels into the power generation industry, with associated emissions of greenhouse gases.

E3MG requires as inputs dynamic profiles of population and energy use, and it derives outputs of carbon dioxide and other greenhouse gas emissions, SO2 emissions, GDP, and modelled energy use. E3MG covers 20 world regions, and considers 42 sectors aggregating to 8 generic industries, 12 energy carriers, 19 energy users, and 26 energy technologies.

The bottom-up model is an annual, dynamic technology model, referred to here as the ETM model [12]. It is based on the concept of a price effect on the elasticity of substitution between competing technologies. Existing economic models usually assume constant elasticities of substitution between competing technologies. Although the ETM is not specifically regional and is not estimated by formal econometric techniques, it does model, in a simplified way, the switch from carbon energy sources to non-carbon energy sources over time. It is designed to account for the fact that a large array of non-carbon options is emerging, though their costs are generally high relative to those of fossil fuels. However, costs are declining relatively with innovation, investment and learning-by-doing. The process of substitution is also argued to be highly non-linear, involving threshold effects. The ETM models the process of substitution, allowing for non-carbon energy sources to meet a larger part of global energy demand as the price of these sources decrease with investment, learning-by-doing, and innovation.

One component of the ETM is the learning curve [13]. The importance of including a learning curve in the model cannot be underestimated, as the technology costs do not simply decline as a function of time, but decrease as experience is gained by using a particular technology. As investment is made in ‘new’ technologies, learning takes place and the cost of the new technology lowers so that it becomes competitive with the ‘old’ technologies. For each type of energy demanded there is usually a technology or fuel ‘of choice’—what might be termed a ‘marker’ technology—against which the alternatives will have to compete. In the ETM, the total capital and operating costs of using this fuel per unit output are used as a basis or numeraire for expressing the relative costs of the alternatives. Even though the numeraire technology may comprise the majority of the market, there are always so-called niche markets and opportunities where the non-carbon technology is cheaper than then numeraire. ETM provides a simple model of the process of switching from a numeraire technology to the possible substitutes. This substitution process may be accelerated if a carbon tax is implemented.

The econometric approach used here also does not suffer from the drawbacks of those macroeconomic models which handle inter-temporal optimisation. In order to do so such models have to assume that the social planner has perfect foresight with no uncertainty, and that perfectly functioning markets exist.

4. Derivation of Pathways and Scenarios to 2100

4.1 Baseline scenario

The Common POLES-IMAGE baseline is used, which is based partly on the IMAGE IPCC SRES A1B and B2 baselines. CPI assumes continued globalisation, medium technology, continued development, and strong dependence on fossil fuels. Economic growth is near the historic average at 2.1% in the near term, declining to 1.4% in 2100. Population follows the UN medium projections for 2030, and the UN long-term medium projection between 2030 and 2100. Further details may be found in [15]. This baseline is used in un-calibrated form in E3MG, and used to produce a baseline set of carbon dioxide emissions, one in which E3MG and ETM allow technological change, and another in which they do not. In the case of the baseline, no carbon taxes are applied but technological change still occurs and is modelled as a projection of the econometric data and through learning by doing.

4.2 Design of high and low carbon pathways to stabilisation

Three arbitrarily selected stabilisation scenarios are used in this study, in which carbon dioxide concentrations stabilise at 450, 500 and 550 ppmv by 2100. Emission pathways for the three stabilisation scenarios are taken from the MAGIC-C model as used by the IPCC [5]. Costs of stabilisation are then calculated relative to the baseline. Many other studies of stabilisation costs [4,9] also use the MAGIC-C climate model to represent the relationship between emissions and concentrations. It is a set of linked reduced form models emulating the behaviour of a GCM. It consists of coupled gas-cycle, radiative forcing, climate and ice-melt models integrated into a single package. It calculates the annual-mean global surface air temperature and sea-level implications of emission scenarios for greenhouse gases and sulphur dioxide. In this study, MAGIC-C is used to determine which emission pathways for CO_2 result in stabilisation of CO_2 concentrations at particular levels by particular dates. Although MAGIC-C does model the effects of emissions scenarios detailing non-CO_2 greenhouse gases, we do not consider these in this first analysis.

The three CO_2 emission profiles from MAGICC are not unique and have been arbitrarily selected. The outputs from MAGICC-C which are used in the economic modelling are the global CO_2 fossil fuel emissions which satisfy the stabilisation constraints. These emission scenarios are also subject to exogenously defined dates at which Annex-1 and non-Annex 1 countries join in carbon taxation schemes. By default carbon tax starts in Annex I 2013-2029, then diffuses to non-Annex I slowly, with full participation by 2040.

5. Results for Alternative Mitigation Policies

Results will be tabulated detailing the baseline and three stabilisation scenarios. For each of the three stabilisation scenarios, results will be presented comparing with the CPI baseline, using carbon tax to achieve stabilisation and highlighting the effect of inclusion of ITC in the modelling of both baseline and stabilisation scenarios.

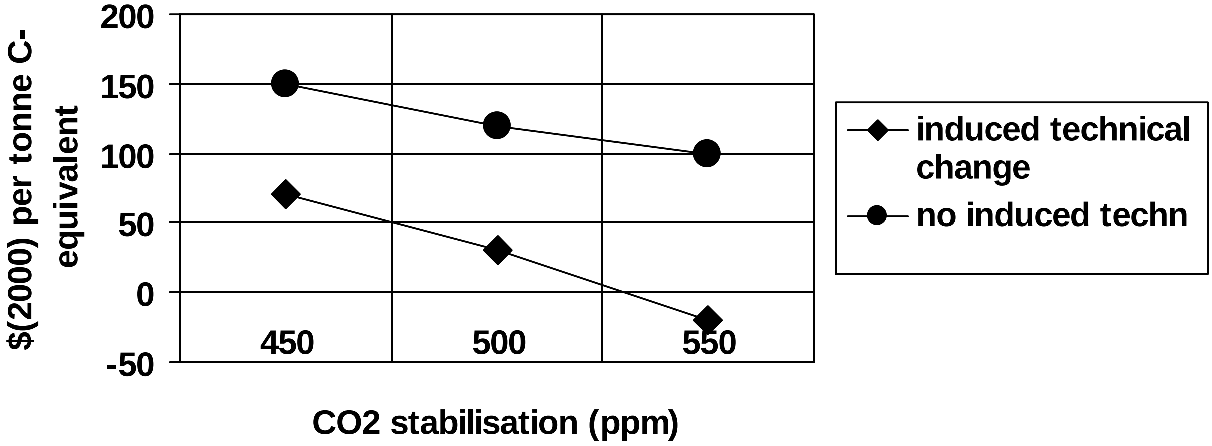

Figure 1. Illustrative results only for the cost of carbon mitigation: effects of stabilisation levels and induced technological change in the case where carbon taxes only are applied.

Emissions 2100						
	with ITC			**no ITC**		
CO2	**450**	**500**	**550**	**450**	**500**	**550**
% Changes in GDP from baseline						
	with ITC			**no ITC**		
	450	**500**	**550**	**450**	**500**	**550**
Annex 1						
Non-annex 1						
World						
Carbon tax applied ($/tC)						
	with ITC		**no ITC**			
	450	**500**	**550**	**450**	**500**	**550**
Annex 1						
Non-annex 1						
World						

Table 1. The modelled effect of ITC upon CO2 emissions and GDP in the case where carbon taxes only are applied (to be completed in full paper).

6. Discussion and conclusions

Results will be discussed in the light of recent literature in the field [9,10,14-19] . Comment will be provided on how the novel econometric and technology modelling adds to the understanding of the role played by technical change in estimates of the costs of stabilisation of carbon dioxide in the atmosphere. The discussion will also cover future work plans to examine a wider range of policies, differing spatial and temporal burden sharing arrangements, and a full uncertainty analysis.

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