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Modelling the costs of emission reduction: different approaches

The initial gaps between economics-oriented top-down models of the costs of emission reduction and technology-oriented bottom-up models have largely disappeared. The energy efficiency paradox – the hypothesis that it would be possible to abate greenhouse gas emissions and save money – is now partly explained and partly further investigated with the appropriate economic and behavioural research tools. New hybrid models include enough technological detail and are therefore quite realistic. Current research focuses on technological development. One strain of analysis relies on highly aggregate and stylized economic methods, while another on highly disaggregated detailed engineering methods. Both approaches need to pay more attention to distribution and welfare issues and to policy instruments, and need to be better embedded in their context and in empirical research.
Introduction

Modelling the costs of reducing greenhouse gas emissions is important to policy related to the climate. The knowledge of the expense to mitigate climate change would help politicians set targets. Unfortunately, scholars disagree, by a wide margin, on the costs of emission abatement and even on the correct approach to estimate these (Hourcade, Halsneas, Jaccard, et al. 1996, Hourcade, Richels, Robinson, et al. 1996). This paper briefly reviews some of the various approaches, their advantages and disadvantages, and outlines a shared research agenda.

The controversy between top-down and bottom-up modelling is discussed. The bridge that was originally built between the two approaches along with two novel alternative developments (both dealing with the same issue, namely technological change, but one from a top-down and one from a bottom-up perspective) are presented. The paper concludes by presenting common deficiencies in all modelling approaches.

Top-down versus bottom-up modelling

Traditionally, there were two approaches for estimating the costs of reducing greenhouse gas emissions: top-down and bottom-up modelling. The top-down modellers, dominated by applied energy economists, built smooth and highly aggregate models. The bottom-up modellers, dominated by energy engineers, built non-smooth and highly disaggregate models. The top-down models, however, lacked this feature because they assumed that the world without policy intervention was efficient. If there were opportunities to save money, they would have been taken. Top-down modellers thus initially dismissed the findings of bottom-up modellers.

Later studies explained the efficiency gap with some findings being trivial. Bottom-up models overlooked certain costs, or used the wrong discount rates, for instance. This is because these models optimize the energy systems, while households, companies, and governments do not. They maximize welfare or profit. Decision makers may simply lack the time to worry about energy expenditures which are often small (Dowlatabadi, Lave, and Russell 1995, Mabey and Nixon 1997).

However, there are inefficiencies that can be removed together with reducing carbon dioxide emissions. These inefficiencies being economic in nature, belong to top-down models rather than bottom-up models (Bovenberg and Goulder 1996, Bovenberg and Van der Ploeg 1998, Burniaux, Martin, and Oliveira-Martins 1992, Goulder 1995, Greer 1995, Parry, Williams III, and Goulder 1999, Williams 1995). It may be argued that reduction in greenhouse gas emissions is a by-product of removing such inefficiencies, rather than that the costs of such emission abatement are small or negative.

Also, even if the current situation is accepted as suboptimal, there is not much reason to assume that reducing greenhouse gas emissions will move the economy closer to its first-best solution. A review of the detailed lists of policies and measures of certain European countries reveals more, rather than less, resultant distortions.

The validity of modelling the energy system excluding detail was another point of disagreement between the top-down and the bottom-up modellers. The bottom-up modellers
won the argument resulting in the emergence of hybrid models. Detail in the energy sector was primarily needed to study the implications of technological change, which is important on the timescale of climate change. However, the process of technological change is not treated satisfactorily in top-down, bottom-up, and hybrid models. To address this deficiency, new models arose, rooted in either of the original approaches.

There are still some traditional top-down models, which are primarily used for purposes other than estimating the costs of reducing greenhouse gas emissions in any detail. The policy and scientific insights derived from top-down modelling are of a different nature. There are still some traditional bottom-up models, used for their original purpose. Although demonstrably wrong, the message that one can save money and carbon at the same time appeals to politicians.

**Hybrid models**

Hybrid models are economic models with a detailed representation of the supply side of energy, including transformation technologies and reserves of energy carriers. Prime examples are MERGE (Manne and Richels 1999, Manne, Mendelsohn, and Richels 1995), CETA (Peck and Teisberg 1991 and 1999), SGM (Edmonds, Wise, and MacCracken 1994, MacCracken, Edmonds, Kim, et al. 1999), GTEM (ABARE and Department of Foreign Affairs and Trade 1995, Tulpulse, Brown, Lim, et al. 1999), and MS-MRT (Bernstein, Montgomery, Rutherford, et al. 1999) (Weyant and Hill 1999). Unlike top-down models, which rely on aggregate production functions, hybrid models cannot burn more gas than there is, distinguish between nuclear power and biomass as alternatives to fossil fuels, and explicitly treat the changes in relative prices between alternative energy carriers. Hybrid models are thus considerably more realistic and offer substantially more insight than traditional top-down models.

Hybrid models also have better economics than bottom-up models. They typically believe that the no-policy intervention scenario is efficient, or that existing inefficiencies should be removed for reasons other than climate change. Consequently, reducing greenhouse gas emissions is always costly, because the policy forces the economy away from its maximum-welfare path.

Earlier hybrid models paid little attention to the issue of cost distribution. Recent studies report results on the international, sectoral, and temporal distribution of the costs of various policies related to the abatement of greenhouse gas emissions (Bernstein, Montgomery, Rutherford, et al. 1999, Bollen, Gielen, and Timmer 1999, Jacoby, Eckhaus, Ellerman, et al. 1997, McKibbin, Ross, Shackleton, et al. 1999). Distribution is important because, first, it is the basis of equity and, second, it often determines political feasibility.

Hybrid models are path-dependent in the capital stock. This implies that the economy is inert, and that it is always hard to leave the chosen path of capital accumulation, whether that path relies heavily on fossil fuels or renewables. Although based on microeconomic foundations, hybrid models have little behavioural detail and microeconomic richness. As a result, the treatment of policy instruments is limited to broad economic instruments—carbon taxes and tradable emission permits.

Hybrid models invariably rely on exogenous technological progress, that is, energy technologies change independent of the rest of the economy and of emission abatement. Furthermore, technological progress is free.

**New growth models**

New growth theory, a recent development in economic theory (Gomulka 1990, Solow 1987), gradually finds its way to applied fields such as energy, resource, and environmental economics (Smulders 1995, Weyant and Olavson 1999). Whereas growth theory treats technological progress as exogenous, new
growth theory places it at the centre of the analysis. Typically, new growth theory considers one or more ‘knowledge stocks’, which, like ordinary economic capital, need to be maintained and invested in. This theory describes the process of innovation and diffusion of technology, but ignores invention. Technology is assumed to behave smoothly and predictably, and investing more resources could lead to better technology.

Goulder and Schneider (1999, Schneider and Goulder 1997) and Carraro and Galeotti (1996 and 1997) are amongst the first to apply new growth theory to abatement of greenhouse gas emissions. They show that this line of modelling yields insights qualitatively different from those of other modelling approaches. Quantitative comparison is difficult, as new growth models are fundamentally different. Also, their empirical validity is limited, because obtaining and interpreting data is difficult. It is difficult to measure knowledge and research and development. Also, new growth models have, as yet, a limited amount of detail in the energy sector and may, therefore, not be fully realistic. Nevertheless, current analyses undermine many of the ‘robust’ findings of earlier studies and are, therefore, a worthwhile addition to modelling approaches (Goulder and Mathai 1998, Tol 1998 and 1999).

New growth models have path-dependencies in both the knowledge and the capital stock. The implications of this have not yet been fleshed out. The simplified representation of economic behaviour and technological progress renders a limited treatment of policy instruments.

New hybrid models

New hybrid models, perhaps a misnomer, build upon bottom-up models but with a better description of the economy. The novel aspect is that these models, like new growth models, endogenize technological progress based, unlike new growth models, on learning by doing, implying that the average costs fall if volume increases, not because of economies of scale, but because of experience gained. As a ballpark, costs fall by 20% if volume doubles. Learning by doing implies increasing returns to scale, that is, path-dependencies even stronger than those in the new growth models.

This line of modelling is championed by the IIASA (Gruebler 1996, Gruebler and Messner 1998, Messner 1996), drawing on work at the Santa Fe Institute (Arthur 1994). Technological detail, agent-based modelling, and stochasticity are the base, which make these models difficult to solve. In the last few years, substantial progress was made in the necessary numerical algorithms, which has made this modelling approach feasible.

The first results are interesting and promising although controversial. There are a number of problems, however. Data are one, as in other modelling approaches. However, deficiencies in the data are amplified because of the amount of engineering detail and the strong path-dependencies. The second problem is that the cost concepts are unclear. The model described by Gruelber and Gritsevskii (1999) appears to be a partial equilibrium model (intraregional and global) of the energy and technology markets, but issues such as market clearance and consistency are left open, particularly under uncertainty. The third problem is related. Welfare theory assumes continuity of the potential outcomes. Strong path-dependencies imply that the space of feasible outcomes becomes disjoint. That is, a future energy system based on coal is radically different from that based on solar power. People in the potential coal future cannot switch to solar, they also cannot imagine a solar-based energy system, and, therefore, cannot say whether that would be better or worse. Since both futures are continuous extensions of the present, a welfare comparison can be based on current preferences; the comparison cannot, however, be based on future preferences.
Common deficiencies

All current modelling approaches share many common deficiencies, which future research should address.

1. Distribution (sectoral, income class, international, intertemporal) is important but often ignored.
2. Path-dependencies challenge current welfare theory.
3. Costs for reducing emissions need to be linked with avoidable damages from climate change.
4. Costs for reducing emissions need to be linked with other issues, such as environmental quality, employment, inflation, and general development.
5. Better data for technological change are needed.
6. More insights into instruments for technological change are needed.

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Emission reduction techniques combining processes such as floor scraping, flushing, manure acidification, and different types of floor were modeled. The tool comprises 36 input variables, some of which have values that are based on experimental measurements. Nevertheless, reliable information concerning other relevant variables are scarce in the literature. Hence, model sensitivity analysis is imperative. We hypothesize that the ranking of input variables in terms of their effect on the model outcome will change if different uncertainty ranges are assigned to them. Model-based tool to estimate the NH3 emission reduction potential of adapted dairy housing systems. In: Annals of 66th European Federation of Animal Science (EAAP), Warsaw, Poland. Fig.