Ecological Economics 87 (2013) 62–71

Contents lists available at SciVerse ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Methodological and Ideological Options

The cost of reducing CO_2 emissions: Integrating abatement technologies into economic modeling

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ARTICLE INFO

Article history:
Received 24 December 2011
Received in revised form 8 October 2012
Accepted 12 December 2012
Available online 21 January 2013

JEL classification:
C68
D24
H21
Q52

Keywords:
Cost curve
Elasticity of substitution
Computable general equilibrium model
Hybrid modeling
Carbon tax

ABSTRACT

We explore two methods of incorporating bottom-up abatement cost estimates into top-down modeling: an economy-wide method and a sector-specific method. Carbon emissions generally depend on technology and scale. Given the technology options, abatement is possible without a substantial reduction in scale. Otherwise the change must come purely through a reduction in demand. Our analysis shows that the cost of environmental policy is considerably overestimated by top-down models if a bottom-up abatement cost curve is not included. Using the data for the Swiss economy, we demonstrate two techniques of representing an abatement function explicitly in a computable general equilibrium model: a traditional and a hybrid (discrete technology modeling) approach. The results suggest that the current climate policy in Switzerland will not be able to move the economy towards the required 10% CO_2 reduction. Both approaches provide virtually the same results when the calibration process is precisely executed, which contradicts the results of previous studies.

1. Introduction

The economic costs of environmental policies are determined both by direct and indirect costs of pollution reduction. The direct economic effects are given by the expert-based marginal abatement cost (MAC) curves and can be captured by bottom-up models, while indirect effects can be captured by some top-down models, as engineering models adopt a partial equilibrium framework. The general equilibrium framework is designed specifically to represent price-dependent market interactions as well as the income sources and expenditures for different agents. On the other hand, the characteristics of the underlying abatement technologies[1] are crucial for bottom-up models, but not for top-down models. We show that it is important to represent abatement opportunities explicitly within a top-down structure.

This paper focuses on the question of integrating bottom-up assessments of pollution abatement options into a top-down analyses of economic cost. We use computable general equilibrium (CGE) models for top-down analyses. The majority of these models assume that the abatement technologies are either not available or prohibitively costly compared to fuel switching and therefore can be neglected. If abatement activities are not endogenously modeled, then the only way to reduce emissions is through an output reduction, when no substitution is possible. This is not a desirable option for economies already troubled with recessions and unemployment. Yet Nestor and Pasurka (1995) show that imposing common simplifying assumptions in modeling the impacts of environmental compliance costs may seriously hamper the ability of CGE models to accurately characterize the economic impact. We show that the economy-wide cost of environmental policy is considerably lower when abatement technologies are introduced.

In order to better assess the economic costs of environmental policy, top-down models should explicitly include the three basic pollution abatement options: (1) production factor substitution, (2) output-demand reduction, and (3) installation of abatement equipment other than fuel substitution. The efficiency with which a given policy instrument makes use of these three options, determines the intrinsic abatement cost (Bovenberg et al., 2008). The general idea is illustrated in Fig. 1. When a top-down model includes only the first two options, the MAC is overestimated because we ignore the option of reducing emissions through abatement equipment and energy-efficiency enhancing technologies are not precisely described (Wissema and Dellink, 2007). When a top-down model includes also bottom-up abatement technologies, it is important to ignore fuel substitution technologies in order to

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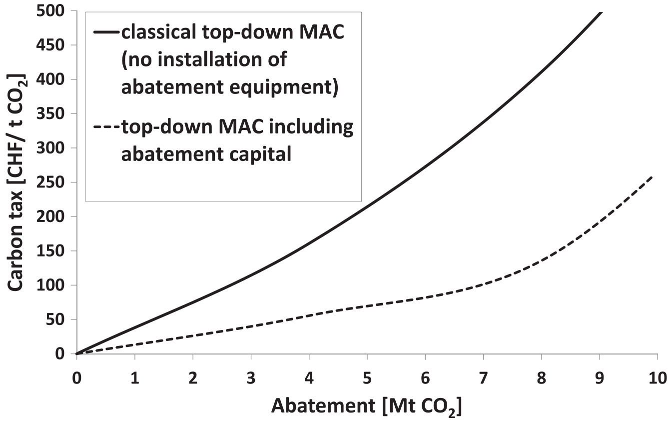
[1] Abatement technology (equipment) is any technology that reduces the pollutants emitted or that allows to emit less pollution.

0921-8009/$ – see front matter
http://dx.doi.org/10.1016/j.ecolecon.2012.12.006



Source: CGE model described in section 4 of the paper

Fig. 1. MAC curves obtained with different methodologies (classical top-down curve covers production factor substitution and output-demand reduction).

avoid a double counting. The substitution between capital and fuels is allowed within CGE models, but the substitution between materials (intermediate demand) is limited. If, for example, it is feasible to reduce emissions by using fuel-efficient vehicles, substitution between vehicle cost and fuel cost should be possible. However, top-down models do not allow for such substitution when demand for vehicles is assumed to be an intermediate demand, because it is represented then by Leontief function. Such calculations can therefore give only a weak guide to policy impact assessment.

On the other hand, bottom-up models contain the options of reducing emissions through a number of discrete technologies but ignore the interactions between markets, indirect costs, and social welfare. Such models include behavioral assumptions that allow for new technologies to penetrate the market more easy, than in top-down models. Integrating bottom-up estimations with top-down modeling allows us to generate a MAC curve that covers all three options of emission reduction. This curve lies below those that consider only some of these options (Fig. 1). It follows that the cost of environmental policy is overestimated by top-down models if they do not include a bottom-up abatement cost curve.

Typically, especially in the early CGE literature, the abatement cost was modeled only implicitly. Contributions to the field include Robinson et al. (1994), Schmutzler and Goulder (1997), Xie and Saltzman (2000), Conrad (2002), Kiuila and Sleszynski (2003), Bergman (2005). In these models, abatement cost was determined by the average pollution cleanup rate. The disadvantage of such approach was an inability to account for the effects of price changes caused by policy reforms.

Another commonly used approach is to implement the abatement expenditures through an emission tax or permits in order to generate MAC curves: Parry et al. (1999), He and Roland-Holst (2005), Pizer et al. (2006), Jacoby et al. (2008), Loisel (2009), Goulder (2010). The curves are derived by setting progressively tighter abatement levels and recording the resulting shadow price of pollutant or by introducing progressively higher emission taxes and recording the quantity of reduced emissions. Such model-based MACs do not fully represent the opportunities that may serve future mitigation, because some technological possibilities to abate are ignored. This means that emission intensities of output in such models are not fully responsive to market circumstances.

A natural question is how to properly integrate abatement possibilities and their direct and indirect costs. Welfare analysis is feasibly possible with bottom-up modeling, hence technological possibilities should serve as an input for top-down models. Such integration will make it possible to derive MAC schedules that accurately characterize the economic costs associated with all of the economy's substitutions, all of the market adjustments and technological changes that follow from the implementation of a particular mitigation strategy.

We propose an integration of bottom-up abatement costs with top-down models using either a smooth curve (traditional approach) or a step curve (hybrid approach). CGE models provide an environment for both approaches. The first approach is highly stylized, based on, for example, constant elasticity of substitution (CES) function and requires a precise evaluation of the parameters of the abatement function in order to replicate the bottom-up cost curve. We apply a non-linear optimization process with an ordinary least square (OLS) technique to calibrate the parameters of the function. This requires a formulation of a separate optimization problem, that will “translate” a step curve into a smooth curve. Next, the results are implemented into the top-down model as parameters. This procedure, though mechanically different, is done in the spirit of Dellink (2005). Alternative techniques are proposed by Hyman et al. (2003) and Jorgenson et al. (2008).

The second approach does not require a definition of any additional optimization problems, because the results from bottom-up model are directly integrated into a CGE model using an activity analysis framework. The traditional approach is based on the concept of elasticities, but the hybrid approach is not. It specifies technologies as fixed coefficient activities and therefore reduces the aggregate input substitutability of supply. All technologies which would run at an economic loss at given prices are inactive. There are a few examples of this approach for electricity generation sector: Laroui and van Leeuwen (1995), Koopmans and Velde (2001), Frei et al. (2003), Jacoby et al. (2006), Laitner and Hanson (2006), Boehringer and Rutherford (2008), but none for the technical abatement process.[2] Our paper is filling this gap.

For each approach we demonstrate two techniques (economy-wide and sector-specific) that endogenize the abatement within a static CGE model. The first method, with an economy-wide perspective, assumes a fixed abatement capacity and applies the MAC is in the whole economy rather than in a specific sector. The second method allows for a sector specific abatement process and the abatement is proportional to the size of the sector. Instead of the marginal cost, it calibrates the total cost of abatement, which requires that the original social accounting matrix (SAM) is rebalanced. Endogenizing an expert-based (bottom-up) abatement cost via either method allows for a consistent assessment of an environmental policy.

We compare both approaches and both methods through a simulation of climate policy in Switzerland. The transportation sector is one of the two largest sources for greenhouse gas (GHG) emission in the country. We illustrate our methodology for this sector only. Specifically, only the abatement technologies for light duty vehicles (LDV) are considered. Our work is based on the top-down static model developed by Imhof and Rutherford (2010) and the bottom-up cost curve was developed in the McKinsey report (2009).[3]

The authors of the engineering study claim that vehicle improvements, based on known technologies and rendering no change in vehicle characteristics, could reduce Swiss annual GHG emissions from 13.5 to 8.7 Mt. Their base scenario shows 8 possibilities to reach this goal (Table 1) with negative cost. We do aim to evaluate the credibility of the study, but to show the application of our methodology with a publicly available expert-based MAC curve. However, this “no regrets” structure (negative cost) is inconsistent with CGE modeling and reconciliation is required. We apply an additive adjustment, where the original marginal cost C_i per technology i is increased proportionally by a constant $a = max(0, min_i C_i)$. This allows us to fit a neoclassical CES function with the McKinsey technology options.

[2] It is possible to mimic a technical abatement process also via soft-linking approach, where top-down and bottom-up models are specified separately, but the outcomes of one model are entered as exogenous input into the other model. The converging outcome is then achieved via an iterative procedure. See Drouet et al. (2005) for more details.

[3] Our choice of the McKinsey curve was motivated by the public attention it has drawn.