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Marginal abatement cost curves and the optimal timing of mitigation measures

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HIGHLIGHTS

- Classification of existing Marginal Abatement Cost Curves (MACC).
- MACCs do not provide separated data on the speed at which measures can be implemented.
- Optimal measures to reach a short-term target depend on longer-term targets.
- Unique carbon price or aggregated emission-reduction target may be insufficient.
- Room for short-term sectoral policies if agents are myopic or governments cannot commit.

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ABSTRACT

Decision makers facing abatement targets need to decide which abatement measures to implement, and in which order. Measure-explicit marginal abatement cost curves depict the cost and abating potential of available mitigation options. Using a simple intertemporal optimization model, we demonstrate why this information is not sufficient to design emission reduction strategies. Because the measures required to achieve ambitious emission reductions cannot be implemented overnight, the optimal strategy to reach a short-term target depends on longer-term targets. For instance, the best strategy to achieve European's −20% by 2020 target may be to implement some expensive, high-potential, and long-to-implement options required to meet the −75% by 2050 target. Using just the cheapest abatement options to reach the 2020 target can create a carbon-intensive lock-in and make the 2050 target too expensive to reach. Designing mitigation policies requires information on the speed at which various measures to curb greenhouse gas emissions can be implemented, in addition to the information on the costs and potential of such measures provided by marginal abatement cost curves.

1. Introduction

To design the best policies to cope with climate change, decision-makers need information about the options for reducing greenhouse gas (GHG) emissions. Such information has been provided in many ways, including through measure-explicit marginal abatement cost curves (MACCs). We call *measure-explicit MACCs* the curves that represent information on abatement costs and potentials for a set of mitigation measures. Measures include changing technologies, notably in the transport, housing and power sectors, and non-technological options such as waste recycling and management of land use and forest. These MACCs are usually constructed for a specific country or region, and for a specific date. They report abatement potentials as a function of the abatement cost, ranking mitigation options from the least to the most expensive (Fig. 1).

Decision makers who face an emission-reduction target need to decide which abatement options to implement, and following which schedule. They can misinterpret measure-explicit MAC curves as abatement supply curves. According to this interpretation, the optimal behavior to meet an abatement target (e.g, bringing back GHG emissions at their 1990 level by 2020) is to build a MAC curve for this date, and implement only the cheapest options that allow the target to be met (e.g. DECC, 2011, Fig. 17, p. 52).

In this paper, we explain why decision makers need to distinguish available abatement measures using their costs, abating potential, and the time it takes to implement them. Indeed, the high-abating potential options required to meet ambitious emission-reduction

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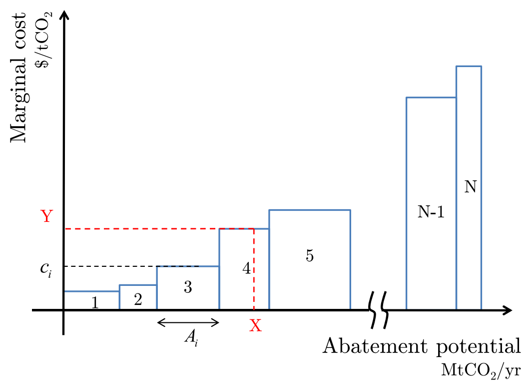

Fig. 1. A measure-explicit MACC exhibits *N* abatement options ranked from the least to the most expensive. Each option *i* is characterized by their abatement potential A_i and their marginal abatement cost c_i. This curves stand for a given date T. We explain why the optimal mitigation strategy to reach a target X at T is not necessarily to implement exclusively the measures 1–4 cheaper than Y (where Y is the marginal abatement cost corresponding to X on the curve).

targets cannot be implemented overnight. Therefore, the optimal set of measures to reach a short-term target depends on the measures required to meet longer-term targets and on the speed at which these measures can take effect.

We thus propose a new way for reporting information on emission-reduction options to the general public and decision-makers. Reports could display assessments of the cost of each option, the abating potential or carbon intensity of each option, and the speed at which each option can be implemented — taking into account the required accumulation of human and physical capital. While some MACCs factor in all this information, none provides data on these three dimensions separately.

We first contribute a classification of existing MAC curves (Section 2). Then, we build a simple model that can compute the optimal timing of GHG emission reductions (choice across time) along with the optimal dispatch of the reduction burden (choice across abatement measures) from this three dimensions (Section 3). We use it in Section 4 with an objective in terms of cumulative emissions over a long period, a so-called *carbon budget*, reportedly a good proxy for climate change. We show that it makes sense to implement the more expensive options before exhausting the whole potential of the cheapest options. We turn in Section 5 to objectives expressed in terms of aggregate abatement at one point in time, closer to the actual practices. In that case, it can be preferable to start implementing the most expensive options before cheap ones, if their potential is large and their inertia is great (Section 5.1). Finally, we explain in Section 5.2 how the optimal short-term strategy depends on the long-term emission objective. This means that MACCs should not be used as supply curves when choosing the optimal strategy to reach short-term emission targets.

2. Overview of existing marginal abatement cost curves

The term “MAC curve” refers in the literature to various curves, constructed in various ways. Here, we distinguish *continuous* MAC curves and *measure-explicit* MAC curves. We then distinguish *full-potential* measure-explicit MACCs and *achievable-potential* measure-explicit MACCs.

2.1. Continuous vs. measure-explicit MAC curves

Continuous MAC curves depict the aggregate shadow cost of an emission target against the stringency of this target. They do not depict particular mitigation measures. The existing literature builds this type of MACCs from Integrated Assessment Models (IAM). It has for instance emphasized that the cost of reducing GHG emissions inside an economy depends on external factors such as energy prices or climate policies decided abroad (Klepper and Peterson, 2006; Kuik et al., 2009; Morris et al., 2011).

In this paper we take the perspective of a decision maker who faces an exogenous abatement target and needs to decide which emission-reduction options to implement, and in which order. Continuous MACCs are out of the scope of this paper. We focus on measure-explicit MAC curves that represent information on abatement costs and potentials for a set of mitigation measures (Fig. 1).

Measure-explicit MACCs have recently reached a wide public, when McKinsey and Company published an assessment of the cost and potentials in the United States (Enkvist et al., 2007) and at the global scale (McKinsey, 2009b). These curves are increasingly used to inform policymakers: McKinsey currently lists 15 MAC curves in its website, the World Bank has assessed reduction potentials in many countries in the form of MACCs (ESMAP, 2012), and Sweeney and Weyant (2008) have proposed such a MACC for California. Other examples include the MACCs developed by the Wuppertal Institute (2006), and by Bloomberg (2010). Their usage goes beyond climate mitigation: for instance, similar depictions have been used to describe available options to reduce energy consumption (e.g. Jackson, 1991; Stoft, 1995), waste production (Beaumont and Tinch, 2004) and water consumption (McKinsey, 2009a).

Recent research has identified and proposed solutions for methodological issues when *building* measure-explicit MAC curves (Kesicki and Ekins, 2012); this has allowed to enhance the reporting of abatement costs and potentials. A first issue relates to uncertainty when assessing future costs — it can be addressed by presenting ranges of costs and potentials instead of best-guest estimates (IPCC, 2007, SPM6, p.11). A second issue is that MACCs do not depict the interaction between different measures (e.g, promoting electric vehicles and green electricity together would allow to save more GHG than the sum of the two isolated abatement measures), even if they are built taking these interactions into account (Kesicki, 2012b). Kesicki and Ekins (2012) identify other shortcomings, like the fact that MACCs frequently assess project or technological costs only, excluding institutional barriers, transaction costs and non-monetary costs. In contrast, we focus in this paper on how to *use* MAC curves, that is on how they can help to design optimal emission-reduction strategies.

2.2. Full potential vs. achievable potential measure-explicit MAC curves

While similar in appearance, two types of measure-explicit MAC curves should be distinguished, depending on their implicit definition of the abating potential of a measure.

The *full-potential* approach gives information on how much GHG could be saved if the measure was used at his technical maximum. It is calculated against a reference or baseline technology, taking into account the carbon intensity and imperfect substitutability of different technologies. For instance, this approach takes into account that an Electric Vehicle (EV) does not emit any GHG (e.g. saves 140 gCO_2/km compared to the average new vehicle sold in Europe in 2010) but that all passenger vehicles cannot be replaced by EVs due to limited driving range. This approach does not take into account any dynamic aspect.

Among others, Rubin et al. (1992) used this approach. For instance, they assess the potential of nuclear power (in the US) as the quantity of GHG that would be saved if nuclear power replaced *all* the fossil fuel capacity that was used for base load and intermediate load operation in 1989, and find 1500 $MtCO_2$/yr (Rubin et al., 1992, Table 3, footnote j). More recently, Wächter