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On the problem of optimizing through least cost per unit, when costs are negative: Implications for cost curves and the definition of economic efficiency

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ABSTRACT

For society and industry alike, efficient allocation of resources is crucial. Numerous tools are available that in different ways rank available options and actions under the aim to minimize costs or maximize profit. One common definition of economic efficiency is least cost per unit supplied. A definition that becomes problematic if cost take negative values. One model, where negative costs are not uncommon, is expert based/bottom up [marginal abatement] cost curves. This model is used in many contexts for understanding the impact of economic policy as well as optimizing amongst potential actions. Within this context attention has been turned towards the ranking problem when costs are negative.

This article contributes by widening the discussion on the ranking problem from the MACC context to the general definition of least cost per unit supplied. Further it discuss why a proposed solution to the ranking problem, Pareto optimization, is not a good solution when available options are interdependent. This has particular consequences for the context of energy systems, where strong interdependencies between available options and actions are common. The third contribution is a proposed solution to solve the ranking problem and thus how to define economic efficient when costs are negative.

1. Introduction

Organizing and allocating resources is essential for developing, and potentially sustaining, our modern society. However, it is a complex and often problematic task, a task that society, industry and individuals must manage in the best possible manner. If not there is a risk that welfare, dividends and wealth fall short of their potential [38].

During the 1970s, the combination of the oil crises and improved computational capabilities created a demand for new models to quantify the effect of changes on energy systems and the economic performance of energy markets [54]. Originating from a dissertation by Meier[29]; an iterative bottom-up optimization model called conservation supply curves (CSC) was developed during this era. The aim was an analytical methodology to provide a solution to the questions of was it more economical to invest in energy efficiency or build new electric power production capacity, and how to prioritize between different available options. The model is used today for many different applications (besides energy conservation) by firms, governments and NGOs such as the International Energy Agency (IEA), Intergovernmental Panel on Climate Change (IPCC) and World Bank.

The CSC model is based on the partial equilibrium (PE) model. The supply and demand curves of PE are one of the most basic models used in economics. CSC differs from PE in how the supply curve is generated. Instead of the traditional smooth curves generated through economic models, the performance of discrete actions is estimated, such as adopting certain technologies, to estimate the supply curve. With price as marginal cost per additional kWh on y-axis and the quantity of kWh on the x-axis, CSC allows the calculation of supply and demand through a set of such discrete available options. As a result, instead of the smooth supply curves generated through economic models, CSC's "supply" curve instead consists of a sequence of boxes corresponding to calculations or estimations of each considered action (see Fig. 1). This has been referred to as expert-based or bottom-up estimations in the literature [22,44].

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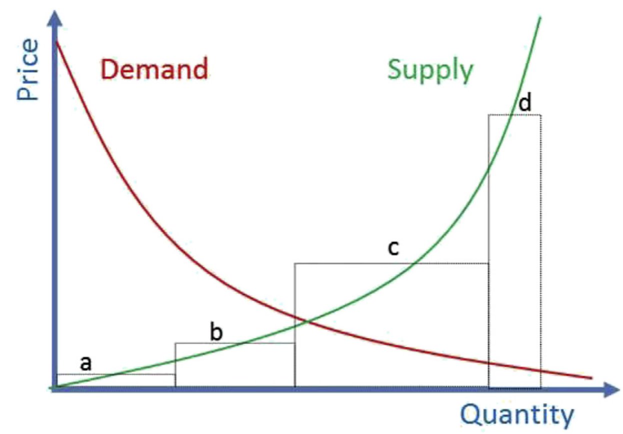

Fig. 1. In CSC, the "supply curve" is estimated through analyzing the effect of adopting discrete options, corresponding to the boxes **a-d**. In this example, adopting option **a** and **b** would almost meet the demand.

In essence this is a bottom-up least cost integrated planning approach [46] with the aim of understanding the effect of discrete actions. Such an approach establishes a merit between a set of available options in the CSC model through least cost per unit(s) supplied.

During 1990s, the CSC model was transformed to fit a climate change context in the form of marginal abatement cost curve (MACC) by Jackson[16]. As noted by Taylor [44], Ward [48] and Wallis [49,50]; the application of this bottom-up or expert-based optimization approach is problematic when considering actions with a negative marginal cost.

The metric problem of the CSC/MACC model, when options with a negative marginal cost are considered, is simply illustrated with the following example from the climate change context. Consider that a firm has three different investment options that would reduce CO_2 emissions and reduce costs (Table 1). In practice, many options that both increase productivity and reduce CO_2 emissions are similar to this logic. Option A has a marginal cost (MC) of −10 and "supply" the quantity of 5 units of CO_2 abatement (marginal abatement, MA = 5); option B has a MC of −15 and MA of 10; and option C has an MC of −10 and a MA of 1.

Common sense dictates that we should prioritize the allocation of resources to the option with the highest financial return (lowest MC), which also supplies most CO_2 emissions reductions (highest MA). In this case option B reduces cost and emissions the most. Option A and C reduce the cost equally, but A reduces CO_2 emissions more than C, which is why it is the better option of the two. The result is an optimal prioritization sequence of B-A-C.

If we use the metric of the partial equilibrium model (as well as in present CSC/MACC), that is least cost per unit supplied, we get another result though. Defined as marginal abatement cost (MAC), in other words cost per unit in the form of MC divided with MA, option C would seem to be the better option with a MAC of −10. Second in merit we would find option A at an MAC of −2, while least in merit we would find option B with an MAC of −1.5.

Table 1
Option A, B and C used to exemplify the optimization problem of expert-based least cost integrated planning through the partial equilibrium-based CSC/MACC model.

Option	MC	MA	MAC (MC/MA)
A	−10	5	−2
B	−15	10	−1.5
C	−10	1	−10

Although, as I previously discussed, option B is the best option financially and in terms of climate change abatement. This is a potential problem for all optimizations where least cost per unit supplied is used as a metric, when costs could take negative values. The problem is thus not limited to the context of CSC/MACC.

This is an easily spotted problem in both corporate and scientific derived CSC/MACCs, once awareness is raised. The area of the boxes corresponds to the MC, the width along the x-axis to MA. Wider boxes with a larger area thus correspond to better options than narrower bars with a smaller area, although such merit is not used in the present CSCs/MACCs.

One example of a biased conclusion made through the faulty ranking is found in the research by Fleiter et al.[6]; who concluded that it would be more economically efficient to reduce CO_2 emissions in low carbon economies such as Sweden than in high carbon economies such as Poland. Using common sense similar to the example in Table 1, looking at least cost and largest effect on reducing emissions, and thus managing the ranking problem, their result would prove the opposite. Some other examples of this error are the curves by the consultancy firm McKinsey & Company, in reports such as their "Global abatement cost curve 2.1" [28]. Here, one example is the emphasis on substituting present illumination with the LED technology, which gives a considerably small desired supply through small cost reductions. Other options such as plug-in hybrid vehicles and improving efficiency in industrial processes has much larger cost reductions and supply, but are ranked as less economically efficient than LED.

Many research articles apply CSC/MACC. Some examples showing the spread in application of the model and biased ranking include the following: Nakicenovic and John [55], who used CSC and MACC to analyze worldwide CO_2 abatement strategies. Morthorst [34] used MACC to conclude that it was possible for Denmark to reduce CO_2 emissions without inflicting a significant economic burden. Halsnaes et al. [10] and Halsnaes [9] used MACC to analyze the difference in abatement costs between different nations and abatement actions. Mirasgedis et al. [31] and Georgopoulou et al. [8] used MACC to evaluate different policies to reduce CO_2 emissions in Greece. Flachsland et al. [5] used MACC to analyze the effect of including road transport in the EU Emissions Trading Scheme (ETS). Nordrum et al. [37] used MACC to assess the potential of different options and corresponding costs for the petroleum industry in California, while Murphy and Jaccard[35] analyzed the results generated by McKinsey & Company for the US.

The problem of ranking options with negative marginal cost was already identified in research in 1992 by Wallis[48,49]; but not as a methodological argument. The notion of the problem by Wallis was part of a larger discussion and the scientific community does not seem to have taken notice of its methodological implications.

In 2012 Taylor[44], raised the problem again. Taylor proposed avoiding the optimization problem by utilizing Pareto optimization instead. The thought of Pareto optimization is to establish what options are Pareto optimal. In this case it is the set of options, where a shift between options cannot improve either MC or MA without reducing the other. Pareto optimization is problematic though in relation to energy systems and does not solve the metric problem, as will be argued for later.

Still, MACCs/CSCs with the problematic optimization continue to be published in articles in high ranked journals, as well as an increasing number of corporate reports that utilize the model. Amongst the recent research articles we find Dedinec et al.[3] with abatement in the Macedonian transport sector; Wächter [51]with abatement strategies for Austria; Yang et al. [52] with abatement from the cement industry in China; and Garg et al.[7] with abatement related to electric power production emissions in India. Other recent examples include analyses of efficiency improvement