A Pedagogical Note on Modeling the Economic Benefit of Emissions Abatement vs. the Economic Harm from Emissions

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Abstract

The number of undergraduate-level textbooks on environmental economics has increased in recent years, but the textbook treatment of optimal emissions (abatement) varies markedly from textbook to textbook. In particular, there is no consensus as to whether to model the economic "bad" (i.e. emissions) or the economic "good" (abatement). This inconsistency can lead to some needless confusion for students introduced to environmental economics for the first time, particularly those students outside of the formal economics major, such as students of business administration and public policy. As a means of mitigating this confusion, I propose a simple example that instructors can use in lecture, test question, or student assignment format, that illustrates the duality between modeling emissions and abatement.

Key Words: environmental policy, optimal abatement, optimal emissions, duality, social welfare

JEL Classifications: A22, A23, Q50

Introduction

There has been a noticeable increase in the number of undergraduate-level textbooks on the subject of environmental economics in recent years. Most textbooks are structured in standard fashion starting with a review of efficient markets leading into a discussion of market failures; common property resources, externalities, and public goods, with emphasis placed on the latter two. Shortly thereafter, most textbooks then launch into a discussion of either optimal emissions or optimal abatement levels with a corresponding discussion of the various policy designs that economists have developed over the years.

The textbook treatment of optimal emissions (abatement) varies markedly from textbook to textbook, particularly for those texts aimed at the undergraduate level. In particular, there is no consensus as to whether to model the economic "bad" (i.e. emissions) or the economic "good" (abatement). Field and Field (2009) tend to model emissions while Callan and Thomas (2010) model abatement. Many textbooks, such as Tietenberg (2003), Kalstad (2011), Perman, Ma, McGilvray, and Common (2003), and Hanley, Shogren, and White (2007), will in some places model emissions and in other places model abatement (or pollution control). Perman, Ma, McGilvray, and Common (2003), for instance, will model emissions when discussing the welfare implications of an optimal emission tax and subsidy (p. 220) and model abatement when modeling tradable permit markets with firms facing different abatement cost functions (p. 226).

This inconsistency in presentation does not suggest any serious or inherent flaw in any of these textbooks. After all, minimizing the social harm caused by emissions is the economic dual

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of maximizing the net social benefits derived from abatement.[2] It is true that the relative merits of each approach, i.e. modeling the economic "good" or the economic "bad", can be debated.[3] However, this inconsistency between and within textbooks can lead to some needless confusion for those students being introduced to environmental economics. As a means of mitigating this confusion, I propose below a simple example that instructors can use, either in lecture, as a test question, or as a student assignment, that illustrates the duality. This note, then, follows in the tradition of some recent literature, such as Corrigan (2011), Main (2010), Kahane (2002), Heyes (2000), and Yates (1998) that offer instructors of environmental economics courses illustrative examples and in-class experiments to improve delivery of course topics.

The remainder of this paper is organized as follows. In the next section, I present a model illustrating the duality between the optimal abatement level and optimal emissions level. The model is kept deliberately simple and straightforward so as to be accessible to the often broad audience of students studying environmental economics: upper-level undergraduate and beginning graduate students of economics, students studying business administration, students studying law and public policy, etc. After that, I review the basic welfare implications of the two different modeling approaches and offer a short conclusion.

A Simple Example

Modeling the Economic "Good"

Consider a firm that emits as a by-product of production carbon dioxide ($C0_2$) thus degrading the air quality in a nearby neighborhood. Carbon dioxide reductions are possible but only at a cost. Let $a \in [0,1]$ be the percentage of carbon pollution created but abated at cost $A(a)$. Let the cost function be defined as $A(a) = 2a^2$. This will generate a linear marginal abatement cost function commonly published in environmental economics textbooks and familiar to most students. For context, allow costs (as well as the benefits defined below) to be measured in thousands of dollars.

Assume that the per-person benefits of abatement increase with the percent of $C0_2$ abated but at a diminishing rate. To reflect this, define the benefit function as $B(a) = a - .5a^2$. Like the abatement cost function, this will generate a linear marginal benefit schedule common in most texts. Notice also that $dB/da > 0, d^2B/da^2 < 0$, indicating that benefits increase with abatement but at a decreasing rate. Further, assume that $C0_2$ abated can be treated as a pure public good (i.e. cleaner air is non-excludable and non-rival), so that total affected population benefits are simply $NB(a)$, where N is the number of affected individuals. Let N = 12. The social welfare (SW) maximization problem is thus:

$$\max_a SW = NB(a) - A(a) . \tag{1}$$

[2] Indeed, some authors (though certainly not all) have acknowledged this duality. See, e.g. Perman, Ma, McGilvray, and Common (2003, p. 218).

[3] On the one hand, it may make more sense to model the economic "bad", given the environmental economics field's focus on pollution as an externality. However, given that optimal emissions (abatement) discussions usually occur on the heels of a review of public goods where the economic "good" is generally modeled, and that many environmental goods, such as clean air, are often held up as examples of public goods, it may make more pedagogical sense to model abatement. At the end of the day, it's probably best left to the individual instructor to decide which method is best and under what circumstances modeling, say, abatement, is preferable to, say, emissions.

Incorporating our specific functional forms, we have:

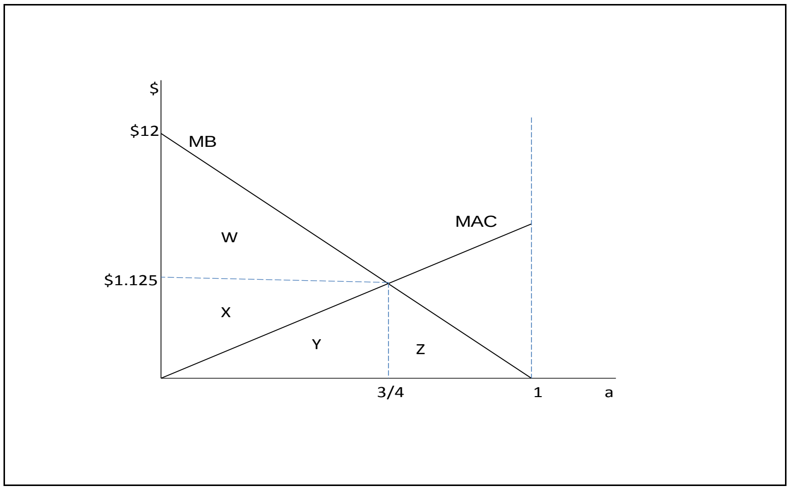
$$\max_{a} SW = 12(a - 0.5a^2) - 2a^2 \,. \qquad (2)$$

The first order condition is where the marginal benefit of abatement (*MB(a)*) equals the marginal cost of abatement (*MAC(a)*). Mathematically, from (2), this condition is:

$$12(1-a) = 4a, \qquad (3)$$

where $MB(a) = 12(1\text{-}a)$ and $MAC(a) = 4a$. Note that $dMB(a)/da < 0$, reflecting that the benefits of additional abatement diminish, and that $dMAC(a)/da > 0$, demonstrating that marginal abatement costs increase with increased abatement efforts. The resulting optimal level of abatement is $a^* = 3/4$. Thus, the optimal amount of $C0_2$ abated is seventy-five percent. This result is depicted in Figure 1 below. This figure is standard, indicating the optimal level of abatement at 3/4 with a marginal cost of abatement of $1.125 thousand.

Figure 1.



Modeling the Economic "Bad"

To set this problem up, recognize that emissions, are those pollutant releases that are not abated, or $a = 1 - e$, where $e \in [0,1]$ is the percentage of carbon emitted (i.e. the percent not abated). Secondly, environmental damages are understood as the opposite of abatement benefits. Define the damages function as $D(e) = -B(a)$. Finally, the abatement cost function with emissions as the argument is $A'(e) = -A(a)$.

Unlike the economic "good" case, the goal here is to minimize Social Costs (SC); i.e. the costs (damages plus abatement costs) associated with emissions:

$$\min_{e} SC = ND(e) + A'(e) \,. \qquad (4)$$

Again, introducing our specific functions yields:

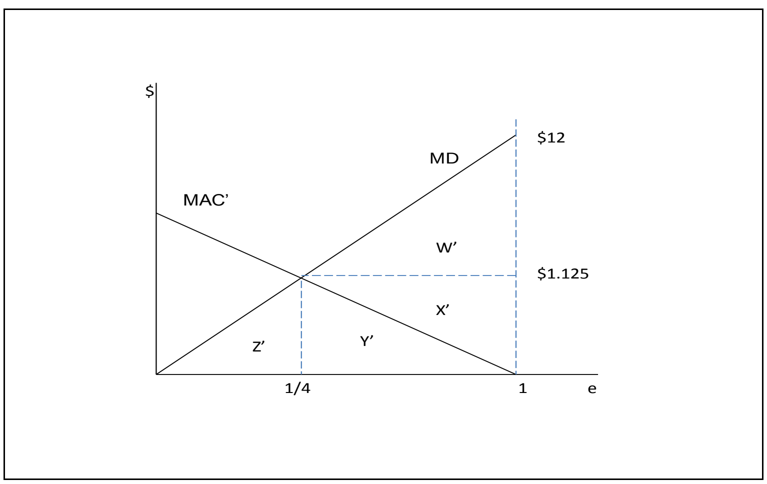
$$\min_{e} SC = -12(1-e-0.5(1-e)^2) - 2(1-e)^2. \tag{5}$$

The first order condition here is where the marginal damages from emissions (MD(e)) equals the marginal cost of abating emissions (MAC′ (e)). Mathematically, from (5), this condition is:

$$12e = 4(1-e), \tag{6}$$

where *MD(e) = 12e* and *MAC′ (e) = 4(1-e)*. The resulting optimal level of emissions is $e^* = 1/4$. Just to highlight the duality, note that *a* = 1- e* = 3/4*. Figure 2, common in most textbooks, illustrates this equilibrium and essentially represents a mirror image of Figure 1. Consistent with expectation, the model demonstrates that $dMD(e)/de > 0$, illustrating that marginal damages increase with increased pollution. Also with this model, $dMAC'(e)/de < 0$, indicating that marginal abatement costs fall as emissions increase. This reflects the notion that less effort is being directed towards abatement. While this result makes intuitive sense, it is plausible, indeed likely, that students may have some initial difficulty due to the "unusual" feature that the marginal abatement cost function is downward-sloping.[4] Once students are exposed to the duality via an example like the one presented here, the situation becomes clear.

Figure 2.



Welfare Analysis

To solidify the duality, it is valuable to include the exercise of comparing the welfare implications of both approaches. This is done below.

Welfare Analysis and the Economic "Good"

Typically, welfare analysis embodies both a calculation of the net social benefits to pollution control and/or a calculation of the total costs associated with pollution control. For optimal net social benefits of pollution control when modeling the economic "good" (SW(a*)),

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[4] Indeed, this may be a reason to favor modeling the economic "good" over the economic "bad".

we see from Figure 1 that this is quantifiably equivalent to the areas W+X. This is mathematically represented as:

$$SW(a^*) = \int_0^{3/4} 12(1-a) - 4a \;\; da\,, \tag{7}$$

which when evaluated is:

$$SW(a^*) = 12(a - 0.5a^2) - 2a^2 \Big|_0^{3/4} = 12(3/4 - 0.5(3/4)^2) - 2(3/4)^2 = \$4.5\,. \tag{8}$$

With respect to optimal social cost (SC(a*)), from Figure 1 we see that this is quantifiably equivalent to areas Y+Z, or:

$$SC(a^*) = 0.5(3/4)1.125 + 0.5(2/4)1.125 = 0.5(1.125) = \$0.5625\,. \tag{9}$$

Welfare Analysis and the Economic "Bad"

For the economic "bad" optimal net social benefits of pollution control (SW(e*)), we read Figure 2 from the right-hand-side axis. Here, the benefits are the *avoided* damages (area $W' + X' + Y'$) minus cost of abatement (Y'). This is represented mathematically as:

$$SW(e^*) = \int_{1/4}^{1} 12e - 4(1-e) \;\; de\,, \tag{10}$$

which when evaluated is:

$$SW(e^*) = 6e^2 + 2(1-e)^2 \Big|_{1/4}^{1} = 6 - \;\; 6(1/4)^2 + 2(3/4)^2 \;\; = \$4.5\,. \tag{11}$$

From Figure 2, we see that optimal social cost (SC(e*)) is quantifiably equivalent to areas $Y' + Z'$, or:

$$SC(a^*) = 0.5(1/4)1.125 + 0.5(3/4)1.125 = 0.5(1.125) = \$0.5625\,. \tag{12}$$

Again, the duality is apparent. To highlight this condition graphically, it is beneficial to point out that W+X from Figure 1 equals $W' + X'$ from Figure 2. Likewise, Y+Z from Figure 1 is equivalent to $Y' + Z'$ from Figure 2.

Conclusion

Textbook treatment of optimal emissions (abatement) varies markedly from textbook to textbook. In particular, there is no consensus as to whether to model the economic "bad" (i.e. emissions) or the economic "good" (abatement). This inconsistency can lead to needless confusion for students introduced to environmental economics for the first time, particularly those outside of the formal economics major, such as students of business administration, law and public policy. To mitigate this confusion, I propose a simple example that instructors can use to quickly illustrate the duality between modeling the emissions and modeling the abatement.

As models in environmental economics become more and more complex, and as these models filter into textbooks, consistency of presentation becomes increasingly difficult. It may be desirable from a learning perspective to model emissions when presenting, say, a cap-and-trade model and to model abatement when modeling, say, a deposit-refund system. Indeed, no textbook author should feel compelled to force consistency in model presentation at the expense of pedagogical clarity. Diversity in presentation may ultimately be a good thing, but avoiding unnecessary student confusion is desirable as well. A unifying example that encapsulates the duality associated with modeling the economic "good" and the economic "bad" can allow students to focus less on notational inconsistency and more on conceptual understanding.

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