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Simple Pigovian Taxes vs. Emission Fees to Control Negative Externalities: A Pedagogical Note

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Many economics texts introduce their analysis of negative externalities by examining a tax on the output of polluting firms, sometimes called a "simple Pigovian tax," often pointing out that taxing pollution directly is superior to taxing output and proceeding to discuss an emission tee as an alternative. They do not show how and why an emission fee is more efficient than an output tax. This note presents a numerical example allowing comparison of the welfare effects of the two approaches, as well as showing why simply reducing the pollution intensity of polluters' output would be inferior to an emission fee.

Keywords: Simple Pigovian tax, Emission tee, Pollution, Efficiency, Command and control

I. Introduction

Almost all principles of economics texts, public finance texts, environmental economics texts and intermediate microeconomics texts deal with the economics of externalities. (Representative Principles texts: Mankiw (2007) and Frank/Bernanke (2007). Public Finance texts: Anderson (2003), Gruber (2007), Holcombe (2006), Hyman (2008), Steineman, et al. (2005), Stiglitz (2000), and Ulbrich (2003). Environmental texts: Callan and Thomas (2000), Kahn (2005), Keohane/Olmstead (2007) and Tietenberg (2003). Intermediate Microeconomics texts: Besanko/Braeutigan (2005) and Waldman (2004).) The discussion of negative production externalities usually begins by pointing out that the "social cost" of producing goods that entail negative externalities is higher than the "private cost." The authors then point out that the resulting "excess" output can be "corrected" by imposing a tax--often called a Pigovian tax--on the output of the offending product. Many texts continue by pointing out that taxing pollution directly, instead of output, can be more efficient. However, the texts do not show or fully explain why one approach is more efficient than the other. This note offers a straightforward numerical example to illustrate the efficiency gains from taxing pollution directly rather than taxing the output of pollution-generating goods. The example also illustrates why simply ordering firms to reduce the pollution intensity of their products is less efficient than taxing pollution directly. The issue of how to deal with negative externalities is important, because the different approaches discussed in the paper can have significantly different welfare implications.

II. Current Textbook Treatment

Economics textbooks often introduce the concept of negative externalities using an example in which the production of each unit of a good results in a certain amount of external damage. (See, for example, Mankiw (2007, 206-7), Frank and Bernanke (2007, 349-51), Tietenberg (2003, 67-8), Kahn (2005, 47-8), Keohane and Olmstead (2007, 67-70), Callan and Thomas (2000, 86-95), and Besanko/Braeutigan (2005, 638-647).) The example usually shows the competitive market supply curve (Marginal Private Cost) the demand curve (Marginal Private Benefit--equal to

Marginal Social Benefit, if there is no externality in consumption) and Marginal Social Cost, equal to the vertical sum of the MPC and the Marginal External Damage (MED). The socially optimal quantity is where MSC intersects MSB, but a competitive market equilibrium quantity will be where MPB (and MSB) intersects MPC. It is a nice application of consumer surplus and producer surplus to show that the competitive market produces "too much" output, resulting in a deadweight loss. The discussion often continues by arguing that to eliminate the deadweight loss the government should impose a "Pigovian" tax equal to the level of MED. (If MED is not a horizontal line, the tax should be equal to the height of the MED line at the quantity where MSC intersects MSB.) A careful graphical analysis of the tax shows that the tax revenue collected plus the gain to pollution victims, when the tax is imposed, exceeds losses to consumers and producers by the amount of the deadweight loss that existed at the unregulated market equilibrium. (Keohane and Olmstead (2007, 134-136), Frank and Bemanke (2007, 358-9), Mankiw (2007, 206-7), and Kahn (2005, 47-8).)

Some texts point out that taxing the output of polluting firms is fully efficient only if the amount of pollution produced per unit of output is immutable (Holcombe (2006, 73-4), Kahn (2005, 47-48), and Keohane and Olmstead (2007, 13840)). If it is possible, at some cost, to reduce the amount of pollution produced per unit of output, then it is not efficient to tax the output of finns. Rather, the pollution should be taxed directly. Some authors, such as Mankiw, do not make this point at all. Mankiw in fact uses the word "Pigovian" to describe the direct taxation of pollution, rather than the taxation of the output of polluting firms. Frank and Bemanke, on the other hand, do not talk about the direct taxation of pollution at all. Authors who do talk both about taxing output and taxing pollution directly typically switch without comment from one to the other without making any effort to connect the two stories. (See, for example, Gruber (2007, 136-46), Waldman (2004, 586-590) and Hyman (2008, 107-8).) This note provides a numerical example that allows students to see the connection between the two stories and to understand why taxing output of polluting firms is almost always less efficient than taxing pollution directly.

III. The Example

Imagine a competitive industry producing good X. The industry is initially unregulated, and each unit of X produced results in the emission of 10 units of a pollutant. (Call this amount E.) Each unit of the pollutant that is emitted causes a damage of $7.50. (Call this amount f.) There is no externality associated with the consumption of the good. Then the total external damage (TED) caused by the production of the good is: f x E x x, where x is the total amount of the good produced by the industry, and the damage per unit is f x E, or $75, in this example.

The demand for the good (the Marginal Private Benefit, which in this case is also the Marginal Social Benefit) is given by:

P = 100-2 x x (1)

The function showing the cost of production (total private cost) incorporates the notion that the amount of pollutant emitted per unit of output can be reduced, at some cost. In accordance with the assumptions of our example, assume that the least costly way to produce good X is to emit 10 units of pollutant per unit of X produced. The cost function then reflects both the cost of producing more output, holding emissions per unit constant, and the cost of decreasing emissions per unit, holding output constant.

TPC = [x.sup.2] + j x [([E.sub.o] - E).sup.2] x x (2)

where j is a positive parameter, [E.sub.o] is 10 in this example, and E is the amount of emissions per unit of output that firms actually produce. Since j is assumed to be positive, firms minimize their cost of producing any given quantity of output by emitting E = [E.sub.o] units of pollutant per unit of X produced, if there is no tax on pollution and no regulation of pollution. Thus, if the firms in this example were unregulated, they would emit 10 units of pollutant per unit of X produced.

Since the supply curve in an unregulated competitive market is the Marginal Private Cost, and since firms minimize their cost by emitting E = [E.sub.o] of pollutant per unit of output, the relevant TPC = [x.sup.2] and the MPC = 2 x x.

1. Unregulated Equilibrium

Given the information provided, it is a simple matter to calculate the market equilibrium quantity and price, along with the total external damage, consumer surplus, producer surplus, net social benefit and deadweight loss at that equilibrium.

The results are as follows: P = $50, x = 25, CS = 625, PS = 625, TED = 75-25 = 1875, NSB = -625, and DWL = 703.125. DWL is arrived at by calculating the area between the MSC curve and the MSB (demand) curve over the difference in quantity between the unregulated equilibrium quantity and the socially efficient quantity. The socially efficient quantity, given that each unit of output results in 10 units of pollution, each resulting in a damage of $7.50, is the quantity at which the Marginal Social Cost (equal to MPC plus $75) intersects the demand curve. In this example, that quantity is 6.25 units, so the DWL = 0.5.(25 - 6.25) x (125 - 50) = 703.125. (See Fig. 1)

[FIGURE 1 OMITTED]

2. A Simple Pigovian Tax

Since each unit of the good produced results in an external damage of $75, a simple Pigovian tax on output of $75 per unit "corrects" the externality problem. It results in a market equilibrium price of $87.50 and a quantity of 6.25 units. At that quantity, the MSC = 75 + MPC = $87.50 = P = MSB. At that equilibrium, CS = PS = $39.0625, while Tax Revenue = Total External Damage = $468.75. Net Social Benefit = CS + PS + Tax Revenue--Total External Damage = $78.125. There is no Deadweight Loss, since the equilibrium is at the intersection of MSC and MSB, and the increase in NSB resulting from the imposition of the tax is $703.125, which was the size of the DWL in the unregulated equilibrium. It would be possible to show that the tax revenue collected, plus the reduction in total external damage exceeds the reduction in consumer and producer surpluses by $703.125. (See Fig. 1)

This is the standard story one might expect to see in a textbook treatment of a Pigovian tax that is used to "correct" an externality. (1) The story allows the student to see a number of important points: 1) in the presence of a negative production externality, an unregulated competitive market will produce "too much" of the good, because the producers of the good do not bear (and therefore the market price does not reflect) all of the costs of producing the good; 2) if the external costs are brought to bear on the market participants (by imposing a tax equal to the Marginal External Damage on either buyers or sellers), the market can be induced to produce the efficient quantity; 3) usually, the efficient quantity of output and pollution is not zero---rather, it is the quantity at which the last unit produced has a value to the marginal consumer equal to the full (private production plus external damage) marginal cost of producing it. Authors often note that this is a simplification of the "true" story, since it implicitly assumes that the amount of pollutant emitted per unit of the good produced cannot be changed. (See, for example, Steineman, et al. (2005, 214-16), and Kahn (2005, 48).) They usually say that, because the amount of pollution emissions can be changed, a better way, in principle, to deal with the problem of negative externalities is to tax the pollutant directly, rather than taxing output. However, no textbook I have found attempts to model how costs of production change when the amount of pollutant emitted per unit is reduced. Nor does any textbook present a model or example that allows the comparison of the welfare effects of taxing output versus taxing pollution directly. (2) Instead, almost all authors (for example, see Anderson, Gruber, Hyman, Ulbrich, and Waldman) simply move on to the discussion of how a firm would react to an emissions fee and other approaches to controlling emissions (such as emission standards and tradable emission permits).

3. A Tax on Pollution Emissions

We can use the model introduced above to examine how a tax on pollution emissions would work. We already know that the damage caused per unit of emissions is represented by the parameter f ($7.50, in this example). If a firm is assessed a tax of $7.50 per unit of pollutant emitted, it will reduce E (the amount of pollutant emitted per unit of output) as long as the saving in emission taxes paid exceeds the increase in production cost entailed thereby. It will stop reducing E when the reduction in taxes due to reducing E by 1 unit equals the increase in production cost due to reducing E by 1 unit. The saving in taxes equals T.x (or $7.50.x in this case), while the increase in production cost (the negative of the partial derivative of TPC with respect to E) is:

2 x j x ([E.sub.o] - E) x x. (3)

The optimal amount of E is thus where T = 2 x j. ([E.sub.o] - E). (The x's cancel.) The optimal E for firms to emit is thus [E.sup.*] = 10 - (T/(2j)). To keep the computations simple, I selected a value of j = 0.536, resulting in a value of E* of 3.0. Therefore, in my example, firms faced with an emission fee of $7.50 per unit of pollutant they emit would choose to reduce the emissions per unit of output from 10 to 3. Of course, this results in higher total and marginal production costs for firms. Given a reduction of emissions from 10 per unit to 3 per unit, the marginal cost of producing more output (the partial derivative of TPC with respect to x) becomes

[MPC.sub.x] = 2 x x + j x [([E.sub.o] - E).sup.2] = 2 x x + (0.536).([7.sup.2]) = 2 x x + 26.264 (4)

Recall, however, that the firms are paying the government $7.50 per unit of pollutant emitted. Since firms responded to the emission fee by reducing the amount of pollution emitted per unit from 10 to 3, the firms are paying $22.50 to the government, per unit of output produced, in addition to the production cost. When that "cost" is included, the height of the supply curve becomes 2 x x + 26.264 + 22.5 = 2 x x + 48.764. This is the full MC (including tax) that firms incur to produce X. It is the industry supply curve, in the presence of the emissions fee, and the intersection of this curve with the demand curve gives the market equilibrium.

Given the parameters of our example, this equilibrium is as follows: P = $74.382, output = 12.809, TSB = TPB = $1116.829, TD = Tax Revenue = $288.561, Total Private (production) Cost = $500.127, NSB = CS + PS + Tax Revenue--TD = $328.1411. (See Fig. 2)

[FIGURE 2 OMITTED]

4. Comparison of an Emission Fee with a Simple Pigovian Tax

Note that the output of the good, consumer surplus, producer surplus and net social benefit are all greater than they were when the "unregulated" amount of pollution per unit of good X was used to determine the simple Pigovian tax. With no government intervention, the least costly way to produce X was to emit 10 units of pollutant per unit of X produced. That resulted in an external damage of $75 per unit of X produced. If the government responds by imposing a $75 tax on each unit produced, firms have no incentive to reduce the amount of pollutant they emit, per unit of X produced. The equilibrium in the market is then where the price per unit of X is $75 higher than the marginal cost of production. This occurs when output is 6.25, price is $87.50, and the marginal cost of production is $12.50. By way of contrast, when pollution is taxed directly, via an emission fee of $7.50 per unit of pollution, firms are induced to reduce E from 10 per unit X to 3 per unit of X, since the marginal cost to firms of reducing pollution is less than $7.50 per unit of pollution, for emission levels higher than 3 per unit of X. When the "simple" Pigovian tax was employed, all of the correction for the pollution externality had to come in the form of reduced output of X. When the emission fee was employed, part of the correction came in the form of reducing the emissions per unit of X. The rest came in the form of reduced output. The net effect was simultaneously to reduce the amount of pollution emitted (from 62.5 units to 38.43 units) and increase the amount of X produced (from 6.25 to 12.809).

NSB is larger with the emission fee than with the simple Pigovian tax because, up to a point, reducing the E (the amount of pollution emitted per unit of X produced) is less costly to society than reducing the amount of X produced, while holding E constant. The emission fee allows market participants to make that trade-off and increase NSB.

One might argue that a well-designed output tax would give the same result as an emission fee. That is, if each producer of X were confronted with a schedule that said that the tax on its output would be $7.50 times the amount of pollutant that firm emitted, per unit of X produced, then firms would be induced to reduce the amount of pollutant emitted per unit of X, just as in the emission tee case. In fact, the output tax would in that case actually be an emission fee. (This appears to be what Stiglitz (2000, 224-5), has in mind.) Real world output taxes do not appear to be calculated that way. Instead, they look at the amount of pollution actually emitted per unit of output to determine the output tax.

5. Comparing an Emission Fee to Command and Control

Suppose the government knew firms' cost functions and decided to simply require them to reduce emissions from 10 per unit of X to 3 per unit of X (the efficient amount of emission reduction, given the cost function and the marginal damage per unit of pollution). In that case, the industry supply curve would be given by the marginal production cost curve (MC = 26.264 + 2x). The equilibrium quantity would be 18.434, and the price would be $63.132. Since the efficient quantity is 12.809, there is a deadweight loss equal to $63.281. The apparatus used in this note allows us to see how much more efficient an emission fee is than direct control, even if firms do not differ in their marginal cost functions and even if the government could, somehow, determine the proper amount of reduction in E for firms to undertake. If firms were subsidized to reduce emissions, the deadweight loss would be even greater. (3)

IV. Conclusion

Many authors introduce the analysis of negative production externalities by examining a tax on the output of polluting firms, what I have called a "simple Pigovian tax." Most then point out that taxing pollution directly is more efficient than taxing output and proceed to discuss an emission fee along with command and control regulation and tradable permits. No attempt is made in the textbooks to show how and why an emission fee is more efficient than an output tax. This note has presented a simple numerical example that allows the welfare effects of the two approaches to be easily compared. It also allows students to see easily why a government policy of ordering firms to reduce the pollution intensity of their output would be less efficient than the emission fee.

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Notes

(1.) More thorough treatments of this story are given by Callan/Thomas (2000, 79-86 and 92) and by Besanko/Braeutigan (2005, 638-47).

(2.) Holcombe explicitly asks, "What should be taxed?" He then argues verbally and graphically that taxing pollution directly results in a more efficient outcome. His Figure 4.2 (p. 74) is similar to my Figure 2. However, he does not provide the underlying model that would generate his diagram.

(3.) Nichols (1984, 27-29) reaches similar conclusions using a simplified diagrammatic approach with constant marginal costs. His treatment does not contain an explicit algebraic model showing how firms adjust the amount of pollution emitted per unit of output in response to a tax on emissions.

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