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Subsidizing Non-Polluting Goods vs. Taxing Polluting Goods for Pollution Reduction

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Subsidies for Non-Polluting Goods vs. Taxes on Polluting Goods to Promote Pollution Reduction

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Proper policy to deal with pollution resulting from the production of goods has occupied economists for many years. The Pigovian approach of taxing the output of polluting goods (or, more properly, the pollution from those goods) has been established as the First Best solution to the problem. However, pollution taxes face substantial political opposition. Often, as in the case of energy production, a less-polluting or non-polluting alternative exists, and subsidies for these sources are politically very attractive. A number of recent studies have examined, in various contexts, the notion that taxes on polluting goods and subsidies for non-polluting substitutes could be employed simultaneously[1]. This paper uses a simple linear partial equilibrium model of a competitive industry in which some sources emit a certain amount of pollution per unit of the good produced, while others emit no pollution. (The goods produced by polluting firms are perfect substitutes for those produced by non-polluting firms.) This specification allows straightforward calculation of the net social benefit (NSB) resulting from various policy approaches. As expected, a tax on the polluting sources equal to the Marginal External Cost resulting from producing a unit of the good (and no subsidy to non-polluting sources) maximizes NSB. Other combinations of taxes on polluting sources and subsidies for non-polluting sources are also evaluated. It is possible to find the best level of subsidy, corresponding to any chosen level of tax and to compare the NSB for all alternatives. It is also possible to calculate the best level of tax, given any level of subsidy.

The recent interest in combining taxes on heavy emitters with subsidies for those who emit less is exemplified by Galinato and Yoder (Galitano and Yoder 2010), who developed a general equilibrium model to estimate the welfare effects of taxing heavy emitters of greenhouse gases and subsidizing low emitters while limiting the dollar amount of subsidies to be no greater than the amount of tax revenue collected from heavy emitters. They find that the system they examine generates social benefits that fall short of those obtainable by employing a Pigovian tax system. Gilbert Metcalf (Metcalf 2009) discusses the many problems that subsidizing low-carbon technologies (rather than taxing high-carbon technologies) encounters and points out that a Pigovian tax on pollution (instead of subsidies for non-pollution) would resolve most, if not all, of those problems. My model (and illustrative numerical example) limits itself to a single industry (such as energy production) and uses a simple partial equilibrium linear demand and supply apparatus to evaluate outcomes. Instead of limiting subsidies for “clean” sources to be no greater than tax revenue collected from “dirty” sources, as Galinato and Yoder do, the model calculates the constrained optimal (NSB-maximizing) subsidy to provide to the clean sources, given any level of tax assessed on the dirty sources.

In addition to showing that a Pigovian tax on dirty sources (and no subsidy for clean sources) maximizes NSB, the model calculates how much lower NSB would be if any combination of taxes and corresponding subsidies would be, compared to the fully optimal solution. A surprising result is that, given any level of tax on the dirty source, the optimal corresponding subsidy results in the same amount of the *clean* good as would result if the fully optimal tax were imposed (with no subsidy for the clean sources). Similarly, if the subsidy is set at any arbitrary level, the model calculates the level of tax that would maximize NSB, given the level of the subsidy. The level of tax on dirty sources that maximizes NSB, given any arbitrary level of subsidy for clean sources, results in the same amount of the *dirty* output as would result if only a tax on dirty sources (and no subsidy for clean sources) were imposed. The results of the two approaches (choose optimal subsidy, given a level of tax vs. choose optimal tax, given a level of subsidy) do not give the same answer. For example, given the parameters in my example (in which the Marginal External Cost of output from dirty sources equals $25), if a tax of $15 per unit is imposed on dirty sources, the optimal subsidy for clean sources would be $5.71, but if a subsidy of $5.71 is provided to clean sources, the optimal tax on dirty sources would be $20.43.

The sum of the tax on dirty sources plus the subsidy for clean sources tells us the difference between the effective price received by clean and dirty sources. In order for the total output to be produced cost-effectively (at lowest aggregate cost), those prices should differ by an amount equal to the Marginal External Cost (MEC). For any outcome *other than* the case where the dirty sources are assessed a tax equal to MEC (with no subsidy to the clean sources), the output is not produced cost-effectively. When a tax (less than MEC) is specified first, then the optimal subsidy is calculated, the sum of the tax and subsidy will be less than the MEC, meaning that, given the total output produced, its aggregate cost would be lower if less of it were produced by dirty sources and more by clean sources. On the other hand, when the subsidy for clean energy is specified first, then the tax on dirty sources is chosen so as to maximize NSB, the sum of the subsidy and the tax exceeds the MEC. This means that the total cost of the output that is produced would be lower if less were produced from clean sources and more from dirty sources.

Although it does not seem realistic to suppose that one branch of government is in charge of establishing taxes on dirty sources, while another branch is in charge of setting the subsidy for clean sources, it may be useful imagine this arrangement. The tax-setting branch is assumed to set the tax so as to maximize Net Social Benefit, given the subsidy that has been established. Similarly, the subsidy-setting branch is assumed to set the subsidy so as to maximize Net Social Benefit, given the tax that has been established. Viewing the situation this way makes it a game, and the Nash equilibrium would be the outcome at which each branch is making its decision to maximize NSB, given what the other branch is doing. The Nash equilibrium outcome turns out to be characterized by a tax on dirty sources equal to MEC and no subsidy.

The Model and Numerical Example

The linear model employed in this paper can be expressed by the demand curve for the good exhibited by consumers, the supply curves of the two types of sources for the good (regular—or "dirty"—and alternative—or "clean"), and the Total External Cost (TEC) function. For some purposes, it is helpful to specify values for the parameters, so that illustrative numerical answers can be obtained. The equations are as follows:

$P_c = h - j \cdot Q_T$, where Q_T is the sum of output from dirty and clean sources, and h and j are positive constants. In the example, h = 100 and j = 2.

The inverse supply curve for the "regular" or dirty is source is

$P_r = a + b \cdot Q_r$ (a and b are positive constants). In the example, a = 10 and b = 1.5.

The inverse supply curve for the "alternative" or clean source is

$P_a = e + f \cdot Q_a$ (e and f are positive constants). In the example, e = 35 and f = 0.5.

The Total External Cost (TEC) = $Q_r \cdot MEC$, where MEC is a positive constant. In the example, MEC = \$25.[2]

The objective is to maximize Net Social Benefit (NSB), subject to various constraints.

$NSB = PS_r + PS_a + CS - TEC + \text{Tax Revenue} - \text{Total Subsidies Paid}$[3]

Prior to investigating alternative tax and/or subsidy interventions, we can calculate the outcome of an unregulated market (no tax on regulated sources and no subsidy for alternative sources). The results are as follows:

$$P_c = P_r = P_a = \frac{\frac{a}{b}+\frac{e}{f}+\frac{h}{j}}{\frac{1}{b}+\frac{1}{f}+\frac{1}{j}} = \$40$$

(The subscripts refer to prices paid by consumers, received by regular suppliers, and received by alternative suppliers, respectively.)

Given the price,

$$Q_r = \frac{P-a}{b} = 20$$

$$Q_a = \frac{P-e}{f} = 10$$

$$Q_d = Q_r + Q_a = 30$$

$$CS = h \cdot Q_d - 0.5 \cdot j \cdot Q_d^2 - P \cdot Q_d = 900$$

$$PS_r = P \cdot Q_r - (a \cdot Q_r + 0.5 \cdot b \cdot Q_r^2) = 300$$

$$PS_a = P \cdot Q_a - (e \cdot Q_a + 0.5 \cdot f \cdot Q_a^2) = 25$$

$$TEC = MEC \cdot Q_r = \$500$$

$$NSB = CS + PS_r + PS_a - TEC = \$725.$$

If subsidies for alternative sources of S, per unit, are provided and taxes of T, per unit are imposed on regular sources, NSB becomes

$$NSB = CS + PS_r + PS_a - TEC + \text{Tax Revenue} - \text{Total Subsidies Paid}$$

Given any level of subsidy provided for alternative sources, what tax on regular (dirty) sources would be optimal?[4] One way to arrive at that answer is to set the partial derivative of NSB with respect to T equal to zero and solve for T. The solution to that equation is

$$T = MEC - \frac{S \cdot j}{j+r}$$

If S = 0, then the optimal tax on regular (dirty) sources equals MEC.

This is the familiar Pigovian result. Given the illustrative parameter values, the outcome when a tax equal to MEC is imposed on regular suppliers (and no subsidy is provided to alternative producers), the results are as follows:

T = MEC = $25

$P_c = P_a = \frac{\frac{a+T}{b}+\frac{e}{f}+\frac{h}{j}}{\frac{1}{b}+\frac{1}{f}+\frac{1}{j}}$ = $45.263

$P_r = P_a - T$ = $20.263

$Q_r = \frac{Pr-a}{b} = 6.842$

$Q_a = \frac{Pa-e}{f}$ = 20.526

$Q_T = Q_r + Q_a = Q_d$ = 27.368

TEC = $MEC \cdot Q_r$ = $171.053

CS = $h \cdot Q_d - 0.5 \cdot j \cdot Q_d^2 - P_c \cdot Q_d$ = $749.031

$PS_r = P_r \cdot Q_r - (a \cdot Q_r + 0.5 \cdot b \cdot Q_r^2)$ = $35.111

$PS_a = P_a \cdot Q_a - (e \cdot Q_a + 0.5 \cdot f \cdot Q_a^2)$ = $105.332

Tax Revenue = $T \cdot Q_r$ =$171.053

NSB = $889.474

No other tax would achieve a higher level of NSB. This is shown by the fact that $\frac{dNSB}{dT} = \frac{dCS}{dT} + \frac{dPSr}{dT} + \frac{dPSa}{dT} - \frac{dTEC}{dT} + \frac{dTaxRev}{dT} = -\frac{dPc}{dT} \cdot Qt + \frac{dPr}{dT} \cdot Qr + \frac{dPa}{dT} \cdot Qa + \left(Qr + T \cdot \frac{dQr}{dT}\right) - MEC \cdot \frac{dQr}{dT} = 0$ when T = MEC = $25.

If taxation of regular (dirty) sources is politically impossible, but subsidies for alternative (clean) sources can be imposed, then NSB would be given by CS + PS_r + PS_a – TEC – Total Subsidy Paid. The highest NSB would be achieved where $\frac{dNSB}{dS} = \frac{dCS}{dS} + \frac{dPSr}{dS} + \frac{dPSa}{dS} - \frac{dTEC}{dS} - \frac{dTotal\ Subsidy}{dS} = -\frac{dPc}{dS} \cdot Qt + \frac{dPr}{dS} \cdot Qr + \frac{dPa}{dS} \cdot Qa - \left(Qa + S \cdot \frac{dQa}{dS}\right) - MEC \cdot \frac{dQr}{dS} = 0$.

The general solution to this equation, when T is positive, is $S = \frac{j \cdot (MEC-T)}{j+b}$. If T = 0, then the optimal S is given by $S = \frac{j \cdot (MEC)}{j+b}$. Given the parameter values in our example, the results are as follows:

S = $14.286

$P_c = P_r = \frac{\frac{a}{b}+\frac{e-S}{f}+\frac{h}{j}}{\frac{1}{b}+\frac{1}{f}+\frac{1}{j}}$ =\$30.977

$P_a = P_c + S$ = \$45.263

$Q_r = \frac{Pr-a}{b} = 13.985$

$Q_a = \frac{Pa-e}{f}$ = 20.526

$Q_T = Q_r + Q_a = Q_d$ = 34.511

TEC = MEC·Q_r = \$349.624

CS = $h \cdot Q_d - 0.5 \cdot j \cdot Q_d^2 - P_c \cdot Q_d$ = \$1191.028

$PS_r = P_r \cdot Q_r - (a \cdot Q_r + 0.5 \cdot b \cdot Q_r^2)$ = \$146.684

$PS_a = P_a \cdot Q_a - (e \cdot Q_a + 0.5 \cdot f \cdot Q_a^2)$ = \$105.332

Total Subsidy = $S \cdot Q_a$ =\$293.233

NSB = \$800.188

Note that NSB is smaller with the "optimal" subsidy for alternative sources (and no tax on regular sources) than it would be with a Pigovian tax on regular sources (and no subsidy for alternative sources). Note also that since the optimal S, given any T, is S = $\frac{j \cdot (MEC-T)}{j+b}$, if T = MEC, the optimal S = 0.

What about other combinations of taxes on dirty sources and subsidies for clean sources? For example, suppose political considerations allow the tax (T) to be set at \$15 per unit of dirty output. The optimal subsidy (S) per unit of clean output would be S = $\frac{j \cdot (MEC-T)}{j+b}$. Given the values of the parameters in our example, the S that maximizes NSB would be S = \$5.714, resulting in

$P_c = \frac{\frac{a+T}{b}+\frac{e-S}{f}+\frac{h}{j}}{\frac{1}{b}+\frac{1}{f}+\frac{1}{j}}$ =\$39.549

$P_r = P_c - T$ = \$24.549

$P_a = P_c + S$ = \$45.263

$Q_r = \frac{Pr-a}{b} = 9.699$

$Q_a = \frac{Pa-e}{f}$ = 20.526

$Q_T = Q_r + Q_a = Q_d$ = 30.226

TEC = MEC·Q_r = \$242.481

CS = h·Q_d – 0.5·j·Q_d^2 –P_c·Q_d = \$913.585

PS_r = P_r·Q_r –(a·Q_r + 0.5·b·Q_r^2) = \$70.557

PS_a = P_a·Q_a – (e·Q_a +0.5·f·Q_a^2) = \$105.332

Total Subsidy = S·Q_a =\$117.188

Total Tax Collected = T·Q_r = \$145.489

NSB = \$875.188

As T increases (and S decreases in response), NSB increases, although it still falls short of the level when T = MEC and S = 0. The accompanying table and diagram show the relationship between T (and the corresponding S) and NSB.

Tax	Subsidy	NSB
0	14.28571	800.188
5	11.42857	832.331
10	8.571429	857.331
15	5.714286	875.188
20	2.857143	885.902
25	0	889.474

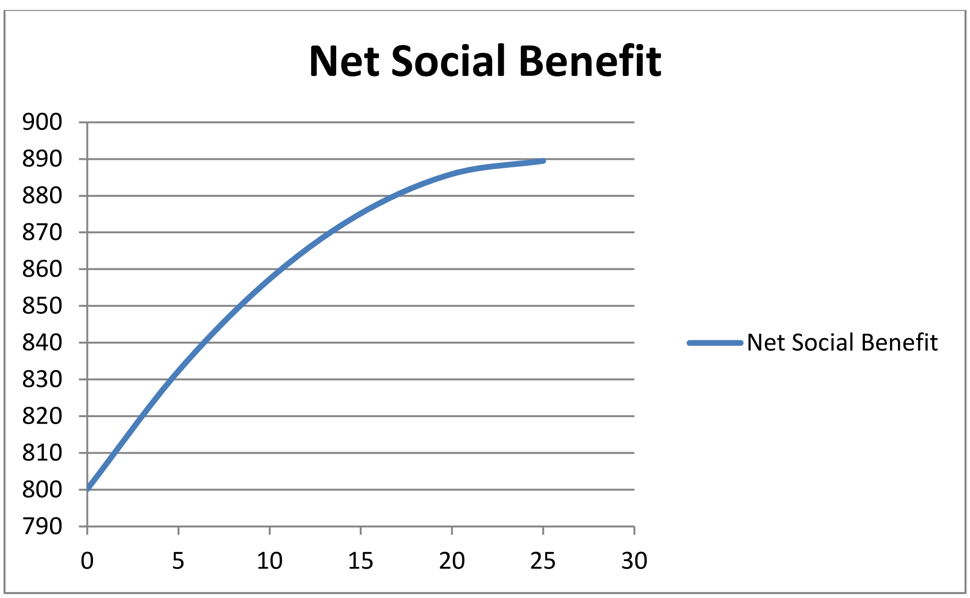

Figure 1 Relationship between Tax and Net Social Benefit

A surprising feature of the linear model is that when S is chosen to maximize NSB, given any value for T, then P_a—the effective price received by suppliers of alternative (clean) good—is invariant to changes in T. This means that the quantity of alternative good produced is the same, regardless of the value of T, as long as S is set so as to maximize NSB, given whatever T is chosen. The amount of alternative good produced in all cases is equal to the amount that would be produced with a Pigovian tax of T on regular sources (and no subsidy for alternative sources).

Proof that P_a (and therefore Q_a) is invariant to changes in T

We start with the expression for P_c (the price consumers pay). We get this from the equilibrium in the markets, given T and S.

Supply

Regular (dirty): Alternative (clean):

$P_r = a + bQr$	$P_a = e + fQ_a$
$Q_r = (P_r – a)/b$	$Q_a = (P_a – e)/f$
$P_r = P_c - T$	$P_a = P_c + S$
$Q_r = (P_c – a – T)/b$	$Q_a = (P_c + S – e)/f$

$Q_T = Q_r + Q_a = \frac{Pc-a-T}{b} + \frac{Pc+S-c}{f}$

Demand

$P_c = h – j\cdot(Q_a + Q_r) = h – j\cdot(Q_T) \Rightarrow Q_T = (h – P_c)/j$

Equilibrium

$$\frac{h-Pc}{j} = \frac{Pc-a-T}{b} + \frac{Pc+S-e}{f}$$

$$\frac{h}{j} + \frac{a+T}{b} + \frac{e-S}{f} = Pc\cdot\left(\frac{1}{b}+\frac{1}{f}+\frac{1}{j}\right)$$

$$Pc = \frac{\frac{a+T}{b}+\frac{e-S}{f}+\frac{h}{j}}{\frac{1}{b}+\frac{1}{f}+\frac{1}{j}} = \frac{\frac{afj+Tfj+ebj-Sbj+hbf}{bfj}}{\frac{fj+bj+bf}{bfj}} = \frac{afj+Tfj+ebj-Sbj+hbf}{fj+bj+bf}$$

Since $P_a = P_c + S$,

$P_a = \frac{afj+Tfj+ebj-Sbj+hbf+S\cdot(fj+bj+bf)}{fj+bj+bf} = \frac{afj+Tfj+ebj+hbf+S\cdot(fj+bf)}{fj+bj+bf}$

This expression shows that P_a depends on T and S, but we also assume that we adjust S, given any value for T, so as to reach the highest possible level of NSB, so S depends on T.

We are interested in

$$\frac{dPa}{dT} = \frac{\partial Pa}{\partial T} + \frac{\partial Pa}{\partial S} \cdot \frac{dS}{dT}$$

Using the expression above for P_a:

$$\frac{\partial Pa}{\partial T} = \frac{fj}{fj + bj + bf}$$

$$\frac{\partial Pa}{\partial S} = \frac{fj + bf}{fj + bj + bf} = \frac{f(j + b)}{fj + bj + bf}$$

Recall that the optimal S, given any T, is given by:

$$S = \frac{j}{j + b} \cdot (MEC - T)$$

Then

$$\frac{dS}{dT} = \frac{-j}{j + b}$$

So

$$\frac{dPa}{dT} = \frac{fj}{fj + bj + bf} + \frac{f(j + b)}{fj + bj + bf} \cdot \frac{-j}{j + b} = \frac{fj}{fj + bj + bf} - \frac{fj}{fj + bj + bf} = 0$$

Setting the Subsidy first, then the Tax

If the subsidy for alternative sources is set at any particular level, there is an "optimal" tax that would maximize NSB, given the level of the subsidy. As noted above, the optimal T, given any S can be obtained by setting the derivative of NSB with respect to T equal to zero and solving the resulting equation. Using this procedure, we find that T = MEC - $\frac{S \cdot j}{j+r}$. Then $\frac{dT}{dS} = -\frac{j}{j+f}$. Given the values of the parameters in the example, $\frac{dT}{dS}$ = - 0.8. If S = 0, the optimal T = MEC = $25. As S increases, the optimal T falls by $.80 for every $1 increase in S. This means that S + T > MEC. (More on this below.)

For example, if the subsidy is set at S = $10, then the optimal tax will be T = MEC - $\frac{S \cdot j}{j+r}$ = $17.

$P_c = \dfrac{\frac{a+T}{b} + \frac{e-S}{f} + \frac{h}{j}}{\frac{1}{b} + \frac{1}{f} + \frac{1}{j}}$ =$37.263

$P_r = P_c - T$ = $20.263

$P_a = P_c + S$ = $47.263

$Q_r = \frac{Pr-a}{b} = 6.842$

$Q_a = \frac{Pa-e}{f} = 24.526$

$Q_T = Q_r + Q_a = Q_d = 31.368$

$TEC = MEC \cdot Q_r$ = \$171.053

$CS = h \cdot Q_d - 0.5 \cdot j \cdot Q_d^2 - P_c \cdot Q_d$ = \$983.978

$PS_r = P_r \cdot Q_r - (a \cdot Q_r + 0.5 \cdot b \cdot Q_r^2)$ = \$35.111

$PS_a = P_a \cdot Q_a - (e \cdot Q_a + 0.5 \cdot f \cdot Q_a^2)$ = \$150.385

Total Tax Collected = $T \cdot Q_r$ = \$116.316

Total Subsidy = $S \cdot Q_a$ =\$245.263

NSB = \$869.474

Just as P_a (and as a result Q_a) is invariant to changes in T, when S is adjusted optimally, so P_r (and as a result Q_r) is invariant to changes in S, when T is adjusted optimally.

Using the same approach as above, we can show that $P_r = \frac{afj+Tfj+efj+ebj-Sbj+hbf-T\cdot(fj+bj+bf)}{fj+bj+bf}$

When we take the total derivative of P_r with respect to S, we find that regardless of the value of S, T is adjusted so that P_r is unaffected by the value of S. Thus the amount of Q_r supplied will be the same, regardless of the level of S, as long as T is adjusted optimally in response to the level of S.

$$\frac{dPr}{dS} = \frac{\partial Pr}{\partial S} + \frac{\partial Pr}{\partial T} \cdot \frac{dT}{dS}$$

$$\frac{dPr}{dS} = \frac{-bj}{fj+bj+bf} + \frac{fj-fj-bj-bf}{fj+bj+bf} \cdot \frac{-j}{j+f} = \frac{-bj}{fj+bj+bf} + \frac{bj}{fj+bj+bf} = 0$$

Cost Effectiveness

If we (for political reasons) set T at \$15, the S that maximizes Net Social Benefit is $S = \frac{j\cdot(MEC-T)}{j+b}$ =

\$5.714, given the illustrative values chosen for the example. But if S is set at \$5.714, the value of T that maximizes NSB is $MEC - \frac{S\cdot j}{j+r}$ =25 – 0.8·(5.714) = \$20.429, given the values assumed. Furthermore, the sum of S and T will be different if T is set first than if S is determined first. If T is set arbitrarily and then S is chosen so as to maximize NSB, the sum of S and T will be $T + S = \frac{j}{j+b} \cdot MEC + T \cdot \frac{b}{j+b}$. Thus T+S is a weighted average of MEC and T, with the weights equal to $\frac{j}{j+b}$ and $\frac{b}{j+b}$, respectively. As long as T < MEC, T+S < MEC. If T = 0, T+ S = $\frac{j}{j+b} \cdot MEC$. The fact that T+ S < MEC means that the allocation of total output of the good is not cost-effective: it does not minimize the aggregate cost of producing the total output in question. This is because cost-effectiveness is achieved when the Marginal Social Cost of producing another unit of output from traditional sources (the Marginal Private Cost plus the MEC) equals the Marginal Social Cost of producing another unit from alternative sources. Since traditional suppliers equate their MPC to P_r and alternative suppliers equate their MPC = MSC to P_a, then $P_a – P_r$ = S + T must equal MEC. If T is chosen first, followed by S, then T+S < MEC, which means "too much" of the total output produced comes from traditional sources. Similarly, if S is chosen first, followed by a selection of T to maximize NSB, then S+T > MEC. Recall that the NSB-maximizing value of T, given S, is $T = MEC - S \cdot \frac{j}{j+f}$. Then $S + T = S \cdot \left(1 - \frac{j}{j+f}\right) + \ MEC$. This means that the aggregate cost of producing the total output that is produced not minimized—too much of it is being produced by alternative suppliers and not enough by traditional suppliers.

Policy Choices as a "Game"?

The fact that the two approaches to establishing S and T do not give the same answers suggests that we might get some insight into the problem by envisioning the policy setting process as a game. Perhaps we could imagine that one branch of government is responsible for setting taxes on polluters, while another has responsibility for establishing subsidies for non-polluting firms. Imagine that each operates independently, and neither can do the other's job. Given the parameters of the example we have been using in this paper, we can determine the "best response" of the subsidizing agency (a particular value of S) to any tax (T) set by the taxing agency. Similarly we can determine the best response of the taxing agency (a certain value of T) to any level of S set by the subsidizing agency. As we showed earlier, S* $= \frac{j}{j+b} \cdot (MEC - T)$ and $\frac{dS*}{dT} = \ -\frac{j}{j+b}$. Similarly T*= $MEC - S \cdot (\frac{j}{j+f})$ and $\frac{dT*}{dS} = \left(-\frac{j}{j+f}\right)$. Figure 2 shows the two best response lines in a space with T on the horizontal axis and S on the vertical.

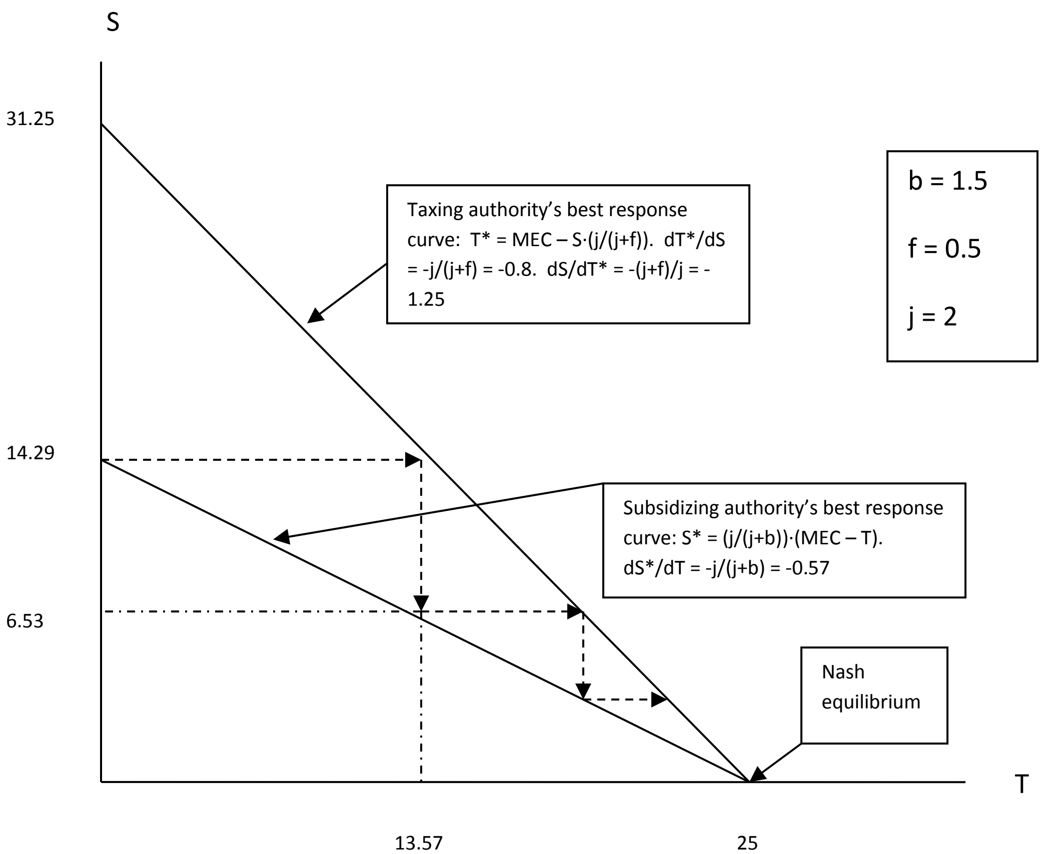

Figure 2. Showing the interaction between "optimal" tax and "optimal" subsidy as a game.

We can see how the “game” might work if we note that, if T were zero, the best S would be 14.29. On the other hand, if the subsidizing authority were to set a subsidy for clean energy of 14.29, the taxing authority would find that its best tax would be T* = 13.57. But if the taxing authority set a tax of 13.57, the subsidy that would maximize NSB would be S* = 6.53. In response to that subsidy, the best tax would be 19.78. The process would continue, as indicated by the arrow lines. The one location where the taxing authority is setting the best tax it can, given S, and the subsidizing authority is setting the best subsidy it can, given T, is the point with T = 25 (equal to MEC) and S = 0. Since each authority is doing the best it can, given what the other authority is doing, this outcome appears to be a Nash equilibrium. Unlike many Nash equilibria, this one is fully efficient.

Conclusion

This paper attempts to gain insight into the issues involved in taxing polluting suppliers and/or subsidizing non-polluting suppliers of the same good by creating a simple linear demand and supply model for an industry with polluting and non-polluting suppliers. The output of the polluting suppliers generates a constant Marginal External Cost (MEC). As others have shown, the first best policy response is to impose a Pigovian tax equal to MEC on the output of polluting suppliers. This policy results in the highest level of Net Social Benefit (NSB), consisting of the Producer Surpluses of the two types of suppliers, Consumer Surplus and Tax Revenue, minus Total Exernal Costs imposed by polluters and subsidies paid, if any. If imposition of the full Pigovian tax is politically infeasible, the provision of a subsidy for non-polluting sources can increase NSB, relative to the non-intervention equilibrium and relative to the case with only a tax T < MEC, but the largest NSB obtainable by this policy is less than would be achieved with the appropriate Pigovian tax. There is an “optimal” subsidy corresponding to any level of Pigovian tax. As the size of the tax increases, the optimal subsidy decreases, and NSB increases, but no level of tax other than MEC (and zero subsidy) gives as large an NSB as T = MEC and S = 0. If the subsidy is chosen to maximize NSB, given the level of tax, the effective price suppliers of non-polluting goods receive (and therefore the amount of non-polluting good produced) is unaffected by the size of the tax. The sum of tax and subsidy, when the subsidy is chosen so as to maximize NSB (given the level of tax) is less than MEC, unless T = MEC. This means that the mix of polluting and non-polluting outputs is not cost effective and contains too much of the polluting good.

If the tax on polluting output is set so as to maximize NSB, given the level of subsidy imposed, the effective price suppliers of polluting good receive (and therefore the amount of polluting good produced) is unaffected by the size of the subsidy. The sum of tax and subsidy, when tax is chosen so as to maximize NSB (given the level of subsidy) is greater than MEC, unless S = 0. This means that the mix of polluting and non-polluting outputs is not cost effective and contains too much of the non-polluting good.

The interaction of government decision makers, one of whom attempts to maximize NSB by setting S, given the level of T, and the other of whom attempts to maximize NSB by setting T, given S, can be viewed as a game. The Nash equilibrium of the game appears to be the outcome at which T = MEC and S = 0.

BIBLIOGRAPHY

Galitano, Gregmar I., and Jonathan K. Yoder. "An Integrated Tax-Subsidy Policy for Carbon Emission Reduction." *Resource and Energy Economics* XXXII (2010): 310-326.

Main, Robert S. "Simple Pigovian Taxes vs. Emission Fees to Control Negative Externalities: A Pedagogical Note." *The American Economist* LV, no. 2 (2010): 104-110.

Metcalf, Gilbert E. "Tax Policies for Low-Carbon Technologies." *National Tax Journal* LXii, no. 3 (September 2009): 519-533.

Parry, Ian W. H. "A Second Best Analysis of Environmental Subsidies." *International Tax and Public Finance* V, no. 2 (May 1998): 153-170.

Sandmo, Agnar. "Optimal Taxation in the Presence of Externalities." *Swedish Journal of Economics* LXXVII, no. 1 (1975): 86-98.

END NOTES

[1] See, for example, Galitano and Yoder (Galitano and Yoder 2010), Parry (Parry 1998), Sandmo (Sandmo 1975), and Metcalf (Metcalf 2009).

[2] As Main (Main 2010) shows, the MEC per unit of output can be reduced by incurring some costs. Taxing the pollution directly by means of an effluent charge, rather than employing a tax on the output of the good, would be more efficient. In this paper, that possibility is assumed away for simplicity.

[3] Parry (Parry 1998) points out that a more complete analysis would take account of the fact that subsidies must be paid for by distortionary taxes.

[4] Policy makers are assumed to know the demand for the good and the supply curves of the two sources of supply, as well as the MEC for the polluting source.