Economics of mercury pollution control: The case of urban forests around Hartford, CT

Lev Paciorkowski

ECON 520: Environmental Economics

Dr. Jeffrey Wagner

May 3, 2021

1. Introduction

The negative externalities resulting from mercury pollution are well understood and documented through decades of public health research. Human health is seriously affected by exposure to mercury, the primary impact being neurological illnesses (Holmes et al., 2009). Harmful effects are similar for wildlife, with decreased fertility found to be a primary consequence (Rimmer et al., 2005).

In addition to the direct costs to health, there are myriad economic costs to mercury pollution. Tang et al., 2018 found that properties within one mile of “Fish Consumption Advisory” designations in New York State experienced on average a 6-7% decline in value. Mercury pollution also has particularly adverse effects on urban forests, which are essential components for local ecological health. Richardson and Moore, 2020 provide a thorough overview of the benefits of urban forests, which include microclimate mediation (Lin et al., 2018), noise pollution reduction (Islam et al., 2012), and acting as a natural filter for fine particulates (Pouyat et al., 2008).

In order to limit the damages from pollution and preserve local ecosystems, firms are faced with various options for technologies to adopt for compliance to pollution control laws. For a review of different abatement techniques and their relative cost effectiveness, see Ancora et al., 2016, where the authors define a best available technique method for identifying the marginal costs of different abatement techniques in Chinese coal-fired plants.

Previous work in Caputo and Wilen, 1995 developed a dynamic model for cleanup of general hazardous waste in Superfund sites to identify optimal strategies for cleanup. Their approach differs from the alternative pollution control method discussed here of designing strategies for abatement. In Gamper-Rabindran and Timmins, 2011, the authors explore specific benefits to cleaning up hazardous waste pollution in general, finding that removing pollution from neighborhoods significantly increases housing values, share of college graduates, while decreasing the share of high school dropouts.

This paper develops an enhanced version of the pollution tax model, where the government can offer a subsidy to firms to lower their MAC curve. This expands beyond the typical approach of working with the existing MAC curve and incentivizing firm behavior through cap-and-trade systems or regulations.

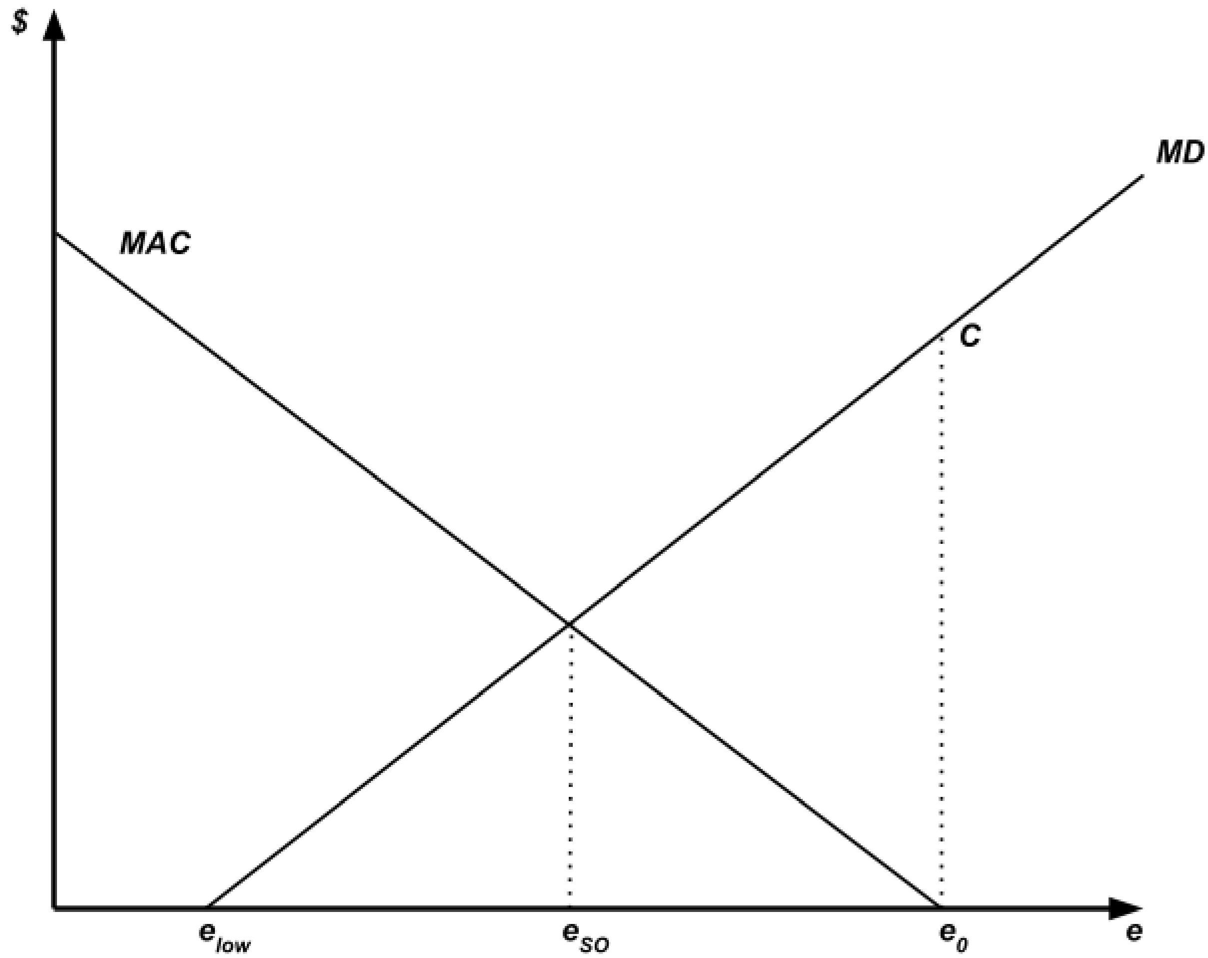
2. The Baseline Model

We start with a baseline model of mercury pollution in urban forests surrounding Hartford, Connecticut. In this model, there is some total level of mercury emissions ***e*** that exists in the city limits. These emissions are assumed to be entirely generated within the geographical area of Hartford, and they are ultimately deposited entirely within this same region. In other words, there is no pollution spillover to or from neighboring geographical areas.

Each unit of ***e*** causes a certain amount of damage, for example consisting of losses of property value, human health costs, and environmental degradation. Let the total damage caused by all ***e*** be given by the Total Damage function ***D(e)***. When considering pollution, it is commonly assumed for this Total Damage function to be increasing at an increasing rate - in other words, $\frac{dD}{de}, \frac{d^2D}{de^2} > 0$. This is because generally, the additional environmental damage from another unit of pollution is positively correlated with the already existing level of pollution. From this Total Damage function we have the Marginal Damage (MD) function as the derivative with respect to ***e***, ***D'(e)***.

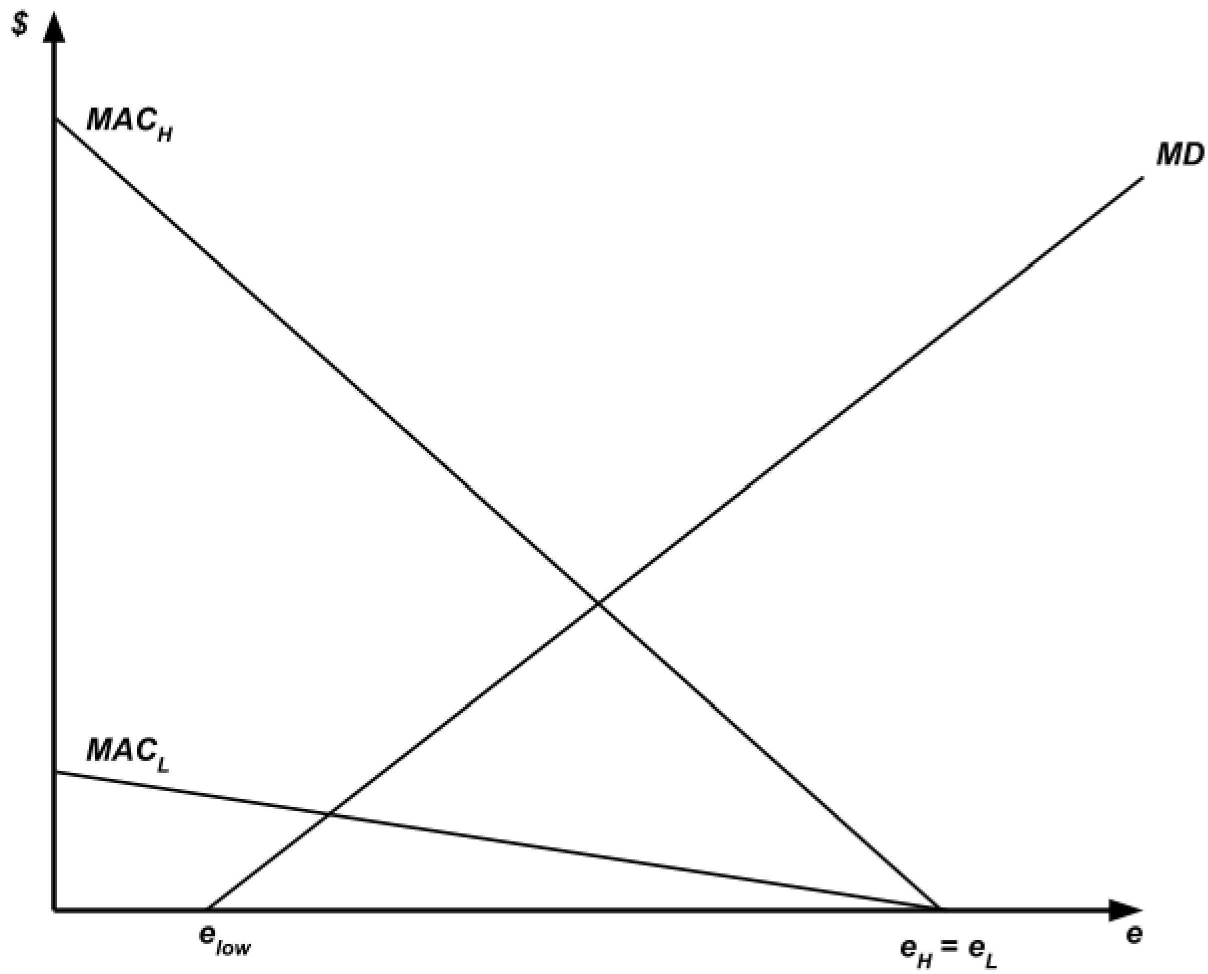
There is a cost to having mercury pollution, but it is also costly for industry to abate pollution. Total Abatement Cost is defined by the function ***C(e)***. Note that this ***e*** is the same as in the Damage Function. Therefore, the more ***e***, the less firms are abating, and the less ***C(e)*** is. When firms abate more, ***e*** falls and ***C(e)*** rises. It is standard to assume that abatement costs increase at an increasing rate with units abated. In other words, the firm will always start by choosing the cheapest methods for abating its first few units, but as it abates more, it must resort to more expensive technology to achieve its goal. Marginal Abatement Cost (MAC) is then ***-C'(e)***, which steadily decreases with ***e***.

In this baseline model, there are two separate optimization problems. The public optimization problem is: $min[e]\colon\ L(e) = C(e) + D(e)$, where *C(e)* is the cost to not having pollution and *D(e)* is the damage caused by pollution. In contrast, the private optimization problem is: $min[e]\colon \pi(e) = C(e)$, where the external damages are not considered. In the private scenario, equilibrium emissions are greater than the socially efficient level derived from the public equation. This baseline model is depicted in Figure 1, showing both the MD and MAC curves.

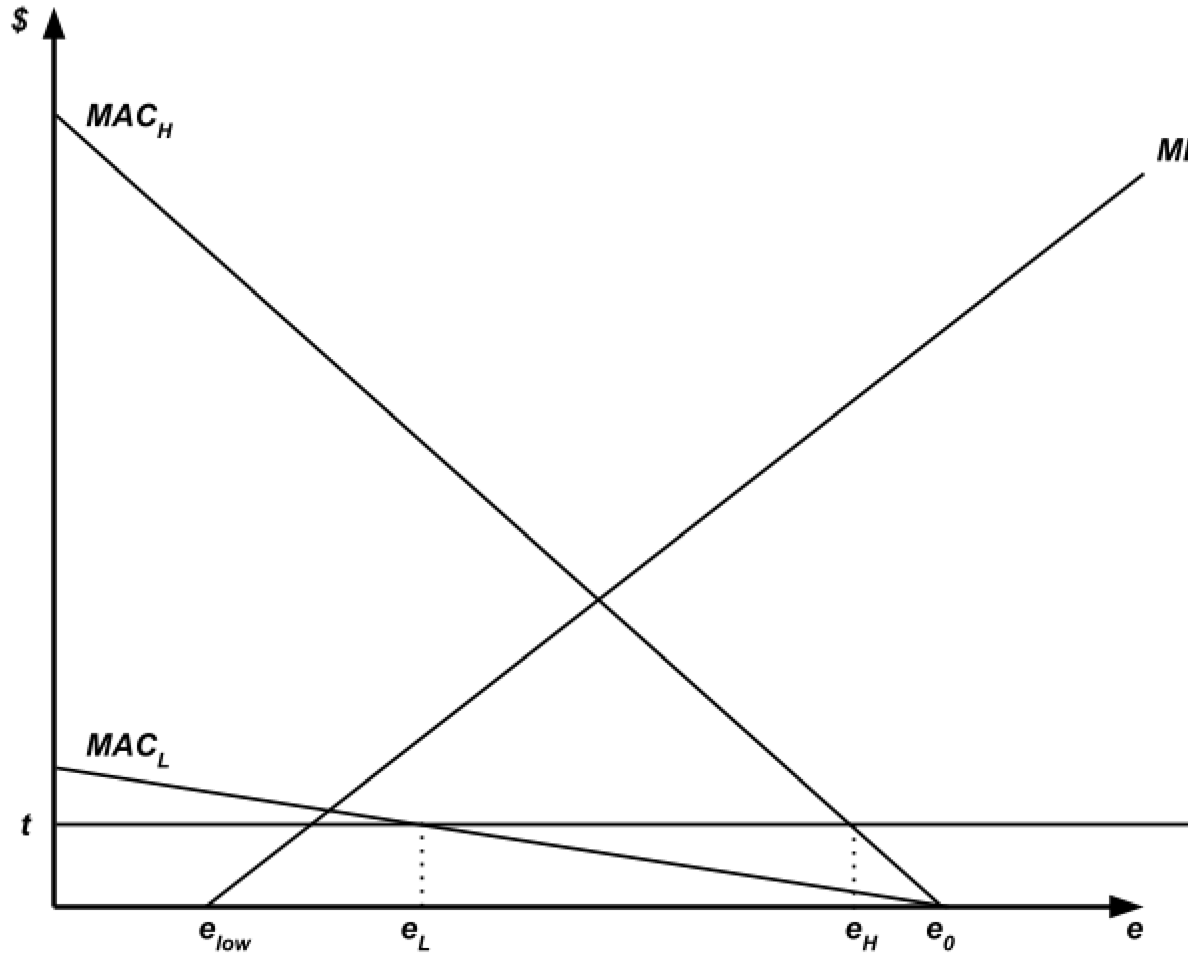


In the “business-as-usual” case, with the industry making no effort to cut back on pollution, total emissions are at $\boldsymbol{e_0}$, which is the result of the cost-minimizing level of output for the firms. This results in a total damage to society equal to the area enclosed in triangle $\triangle e_{low} e_0 C$. Note that $\boldsymbol{e_{low}}$ represents the level of emissions at which economic damage begins to be incurred. The socially optimal level of emissions is at the intersection of MD and MAC, $\boldsymbol{e_{SO}}$.

Now suppose that emissions in our region of interest are generated by two firms - firm ***H*** has a relatively higher cost of abatement given by $\boldsymbol{MAC_H}$, and firm ***L*** has a relatively lower cost of abatement given by $\boldsymbol{MAC_L}$. The two firms are identical in every other regard, and the sum of their individual emissions, $\boldsymbol{e_H} + \boldsymbol{e_L}$ is equal to the region's total emissions $\boldsymbol{e}$**.** This new model is represented in Figure 2.



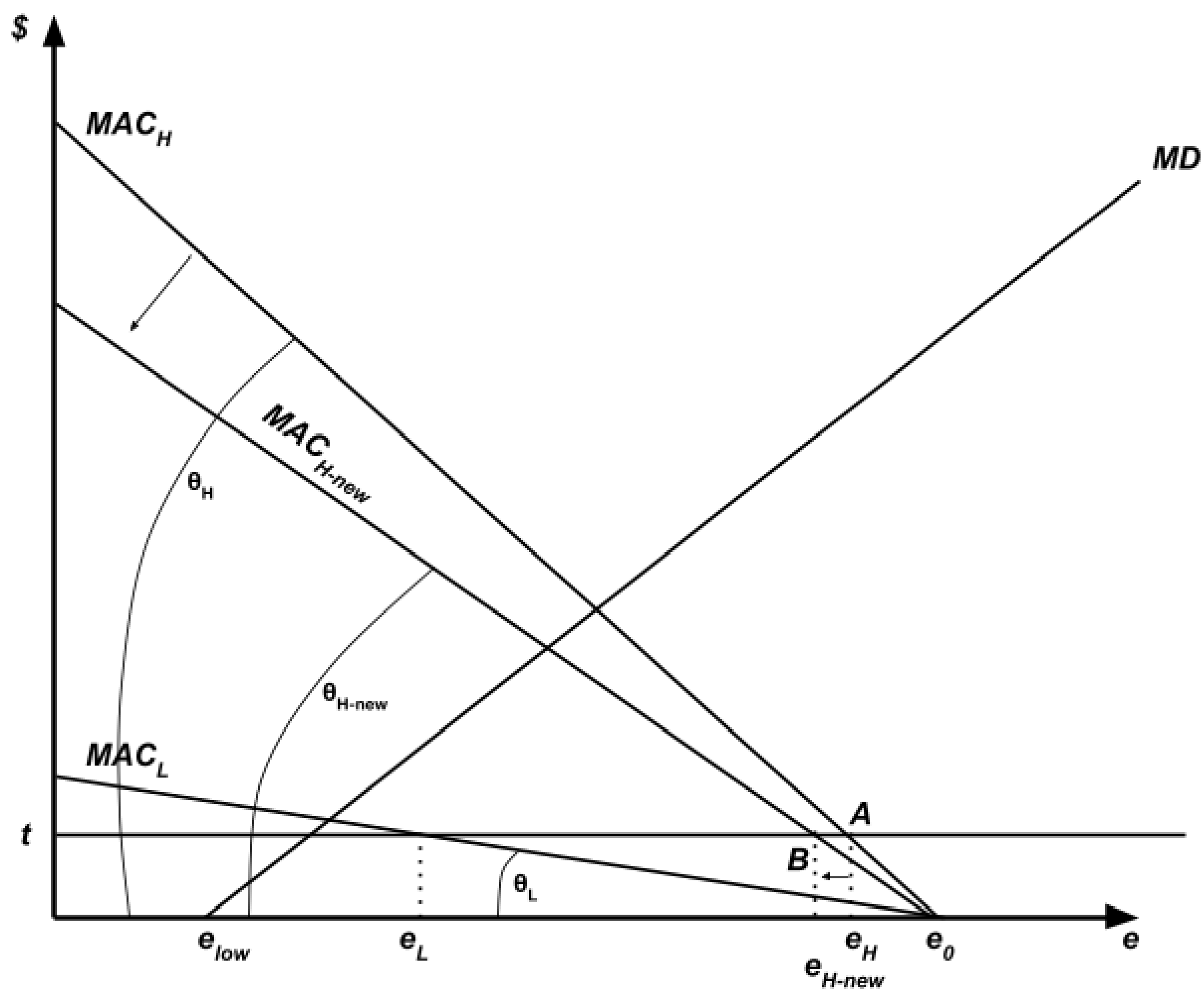
The local government wishes to curb emissions, and it has various strategies it could employ to achieve this goal: regulations, cap-and-trade systems, liability enforcement or taxes, to name a few. It can be a separate discussion which policy is best for a particular situation, but suppose that in this model, the government places a tax $\boldsymbol{t}$ on each unit of $\boldsymbol{e}$ released by each firm. This changes the situation to the one shown in Figure 3.



Under the tax, firm ***L*** chooses to abate down to e_L, since for all emissions between e_L and the original level e_0 it is cheaper for firm ***L*** to pay the marginal abatement cost than to pay the tax of ***t*** per unit of ***e***. On the other hand, firm ***H*** only abates down to e_H, because its abatement costs are higher. For firm ***H***, it would cost more to abate another unit of pollution beyond e_H than to simply pay the tax.

This situation represents an improvement over the business-as-usual case. Both firms have reduced emissions which has reduced the total damage. It is theoretically possible to choose a precise level of tax such that the total resulting emissions equals the socially optimal level from Figure 1. However, there is a stark difference in the level of abatement achieved by the low-cost firm compared to the high-cost firm. If it was possible to lower the abatement cost function for firm ***H***, further improvements might be achievable.

Identify a new parameter, θ, that is the angle between a firm's MAC curve and the horizontal axis. Thus, for firm ***L***, whose abatement costs are already relatively low, θ_L will also be relatively small. For firm ***H***, θ_H is relatively large. Note that while many approaches such as direct taxation, cap-and-trade systems, and liability regulations seek to directly offer "carrot and stick" incentives for emissions reduction, the approach I explore here involves the government indirectly helping the firm by lowering its abatement cost function. This situation is represented in Figure 4, where firm ***H*** decreases its θ to θ^*_H.



Before the θshift, firm ***H*** paid total abatement costs equal to the area in triangle $\triangle e_0 e_H A$. After the shift, firm ***H***'s total abatement costs are equal to triangle $\triangle e_0 e_{H-new} B$. Depending on the exact parameter values, this may or may not be a lower total cost. However, firm ***H*** saves tax payments equal to $t * (e_H - e_{H-new})$, which could possibly more than offset any potential increase in abatement costs. Additionally, from the public's perspective, a certain amount of damage has been further mitigated. Depending on the precise values of marginal abatement costs, emissions tax rate, and marginal damage, it may be worthwhile for the government to invest in lowering firm ***H***'s θ. In fact, it appears that in some circumstances, the firm may see *increasing* marginal benefits to decreases in its θ. This is best demonstrated in the next section which explores policy constructions with a concrete example.

3. Policy

Suppose that in the local region of Hartford, Connecticut there are two firms releasing mercury pollution into the environment. The two firms are identical in every way except for their pollution abatement costs. Firm ***H*** faces $MAC_H = \ - 15e_H + 7500$, while firm ***L*** faces $MAC_L = \ - 3e_L + 1500$. Marginal damage from total units of *e* is given by $MD = 10e - 1000$, where $e = e_H + e_L$. Note that in this case, $e_{low} = 100$. In the business-as-usual case, each firm emits $e_H = e_L = 500$; $e = 1000$. Thus, total damage from emissions in the baseline scenario is

$$\int_{100}^{1000} (10e - 1000)de = \$4,050,000$$

The city of Hartford imposes a per-unit tax of $t = \$925$ for each *e* released into the environment. Each firm reduces emissions to the point where $MAC_i = t \mid i = H, L$. The firms' respective cost minimization equations are:

$- 15e_H + 7500 = 925 \rightarrow e_H^* \approx 438.333 \rightarrow$ *firm **H** abates 61.667 units*

$- 3e_L + 1500 = 925 \rightarrow e_L^* \approx 191.667 \rightarrow$ *firm **L** abates 308.333 units*

Total emissions are now 630, and total damages are

$$\int_{100}^{630} (10e - 1000)de = \$1,404,500$$

The total cost of abatement for both firms is

$$TAC_H = \int_{438.333}^{500} (- 15e_H + 7500)de_H \approx \$28,521.14$$

$$TAC_L = \int_{191.667}^{500} (- 3e_L + 1500)de_L \approx \$142,603.86$$

The total tax paid by each firm is

$$T_H = 438.333 * 925 \approx \$405,458.03$$

$$T_L = 191.667 * 925 \approx \$177,291.98$$

Ultimately, in this simple taxation scenario, total compliance costs are $433,979.17 for firm ***H*** and $319,895.84 for firm ***L***, for a total of $753,875.01. The government collects a total of $582,750 in tax revenue and total damages are $1,404,500. These will be the benchmark figures used for future comparisons.

Next, the government calculates θ for each firm:

$$\theta_H = tan^{-1}(7500/500) \approx 86.186°$$

$$\theta_L = tan^{-1}(1500/500) \approx 71.565°$$

Now, suppose the government can fund a program that subsidizes firm ***H*** to reduce its abatement costs. For example, the program could offer grants for factory renovations or pay salaries for a team of on-site mechanical engineers, each of which would make installation of abatement technology less costly and thus lower θ_H. Suppose the government estimates it can spend some amount S_1 to reduce θ_H by just a single degree, to 85.186°. This alters MAC_H to

$$MAC_H = -tan(85.186°)e_H + 500 * tan(85.186°) \approx -11.874e_H + 5936.943$$

The new cost minimization equation for firm ***H*** is

$-11.874e_H + 5936.943 = 925 \rightarrow e_H^* \approx 422.094 \rightarrow$ *firm **H** abates 77.906 units* ***(+16.239)***

The total cost of abatement for firm ***H*** is

$TAC_H = \int_{422.094}^{500} (-11.874e_H + 5936.943)de_H \approx \$36,029.26$ ***(+$7,508.12)***

Finally, the new total tax paid by firm ***H*** is

$T_H = 422.094 * 925 \approx \$390,436.95$ ***(-$15,021.08)***

Total emissions are now $e_L + e_H = 191.667 + 422.094 = 613.761$, which results in total damages of

$\int_{100}^{613.761} (10e - 1000)de \approx \$1,319,751.83$ ***(-$84,748.17)***

Firm ***H*** pays more in abatement costs, but saves roughly double that amount in tax payments. The net result is that firm ***H***'s total compliance cost decreases by $7,512.96 and the government averts $84,748.17 worth of damages while losing only $15,021.08 in tax revenues, a net public gain of $69,727.09 and a win-win for all parties.

To explore the changes in marginal benefits and costs from such a subsidy program, suppose the government decides to spend a second, presumably greater amount S_2 to effect another one-degree drop in θ_H, from 85.186° to 84.186°. This will alter MAC_H to

$$MAC_H = -tan(84.186°)e_H + 500 * tan(84.186°) \approx -9.821e_H + 4910.474$$

The new cost minimization equation for firm ***H*** is

$-9.821e_H + 4910.474 = 925 \rightarrow e_H^* \approx 405.811 \rightarrow$ *firm* ***H*** *abates 94.189 units* ***(+16.283)***

The total cost of abatement for firm ***H*** is

$$TAC_H = \int_{405.811}^{500} (-9.821e_H + 4910.474)de_H \approx \$43,561.38$$ ***(+\$7,532.12)***

Finally, the new total tax paid by firm ***H*** is

$$T_H = 405.811 * 925 \approx \$375,375.18$$ ***(-\$15,061.77)***

Total emissions are $e_L + e_H = 191.667 + 405.811 = 597.478$, which results in total damages of

$$\int_{100}^{597.478} (10e - 1000)de \approx \$1,237,421.80$$ ***(-\$82,330.03)***

Notably, the total cost of compliance for firm ***H*** decreases by slightly more than the first one-degree θ_H drop. It now saves an additional net \$7,529.65. The public gain is the net of damages averted and tax revenue lost, or \$67,268.26.

From the firm's perspective, it sees increasing marginal benefits to lowering θ. Depending on the values S_1 and S_2 necessary to achieve the one-degree decreases of θ, it may well be a pareto improvement for the government to continue funding such a subsidy program until the sum of the private and public welfare gain is equal to S.

4. Conclusion

In the standard model for pollution taxes, Pareto improvements could be possible if the government is able to subsidize the lowering of a firm's abatement cost function. More specific research on mercury polluters would be needed to obtain accurate estimates of the MAC curve and also the tradeoff between R&D and $\boldsymbol{\theta}$ improvement, which would theoretically enable a government entity to put forth a new policy that leads to less damages to the environment and less compliance costs for a high polluting firm.

References

Ancora, Maria Pia, et al. "Meeting Minamata: Cost-effective compliance options for atmospheric mercury control in Chinese coal-fired power plants." *Energy Policy* 88 (2016): 485-494.

Caputo, Michael R., and James E. Wilen. "Optimal cleanup of hazardous wastes." *International Economic Review* (1995): 217-243.

Gamper-Rabindran, Shanti, and Christopher Timmins. "Hazardous waste cleanup, neighborhood gentrification, and environmental justice: Evidence from restricted access census block data." *American Economic Review* 101.3 (2011): 620-24.

Holmes, Philip, K. A. F. James, and L. S. Levy. "Is low-level environmental mercury exposure of concern to human health?." *Science of the total environment* 408.2 (2009): 171-182.

Islam, Md Nazrul, et al. "Pollution attenuation by roadside greenbelt in and around urban areas." *Urban Forestry & Urban Greening* 11.4 (2012): 460-464.

Lin, Mao, et al. "Heavy metal contamination in green space soils of Beijing, China." *Acta Agriculturae Scandinavica, Section B—Soil & Plant Science* 68.4 (2018): 291-300.

Pouyat, Richard V., et al. "Response of forest soil properties to urbanization gradients in three metropolitan areas." Landscape ecology 23.10 (2008): 1187-1203.

Richardson, Justin B., and Leon Moore. "A tale of three cities: Mercury in urban deciduous foliage and soils across land-uses in Poughkeepsie NY, Hartford CT, and Springfield MA USA." Science of The Total Environment 715 (2020): 136869.

Rimmer, Christopher C., et al. "Mercury concentrations in Bicknell's thrush and other insectivorous passerines in montane forests of northeastern North America." *Ecotoxicology* 14.1 (2005): 223-240.

Tang, Chuan, Martin D. Heintzelman, and Thomas M. Holsen. "Mercury pollution, information, and property values." *Journal of Environmental Economics and Management* 92 (2018): 418-432.