I Taxes and permits with uncertainty

We saw in the previous notes that taxes and tradeable permits are identical, except that the government may allocate the initial permits and therefore not collect any revenue. Of course, tax revenue can always be rebated to the same individuals who would have been designated to get the permits. We will see that when the regulator is uncertain about firm marginal costs, price (tax) and quantity (permit) regulation give different allocations.

Typically, the polluter will claim reducing emissions is very expensive, while the environmental lobby will claim emissions can be reduced without cost. For example, prior to creation of the SO_2 tradeable permit market, industry claimed emissions reduction would cost \$300 per ton, while the environmental lobby claimed the costs would be zero. How is the regulator to set the tax or quantity of permits under such uncertainty?

A Taxes and uncertainty

Suppose a firm may have either high (MC_H) or low (MC_L) marginal costs of reducing emissions, with the average being $\bar{MC}$. Suppose the regulator sets the tax so that marginal damages equal average marginal costs:

$$t = MD\left(E^*\right) = \bar{MC}\left(E^*\right) \tag{52}$$

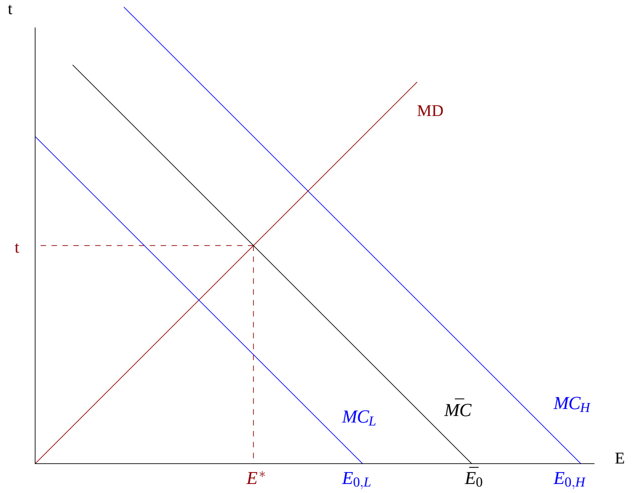

Figure 36: Tax regulation when marginal costs are uncertain.

Now the actual marginal costs will be either higher or lower than the average. The firm reduces emissions until the price (the tax) equals marginal costs:

$$t = MC_H\left(E_H\right), \tag{53}$$

if marginal costs are high and

$$t = MC_L\left(E_L\right), \tag{54}$$

if marginal costs are low. Thus the tax will be either too high or too low, creating welfare losses:

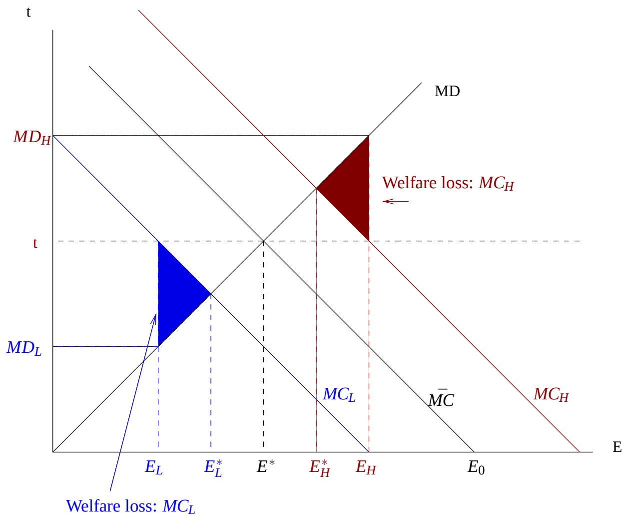

Figure 37: Welfare losses from tax regulation when marginal costs are uncertain.

If marginal costs are low, the firm will reduce emissions a lot as it is cheaper than paying the tax. So we see too much emissions reduction, and marginal costs are above marginal damages. Conversely if marginal costs are high, the firm does too little emissions reduction as it pays the low tax rather than reducing emissions. Marginal damages are above marginal costs.

The average welfare loss is average of the area of the two triangles.

B Permits and uncertainty

Suppose we now impose a tradeable permit system in which we set the number of permits E^* so that marginal damages equal average marginal costs:

$$\bar{MC}(E^*) = MD(E^*) \tag{55}$$

Now if marginal costs turn out to be high, demand for permits will increase, raising the price of permits to p_H in Figure 38. Marginal costs will be above marginal damages, creating welfare loss. Conversely, if the marginal costs are low, little demand for permits results, pushing the price down. Marginal costs are below marginal damages.

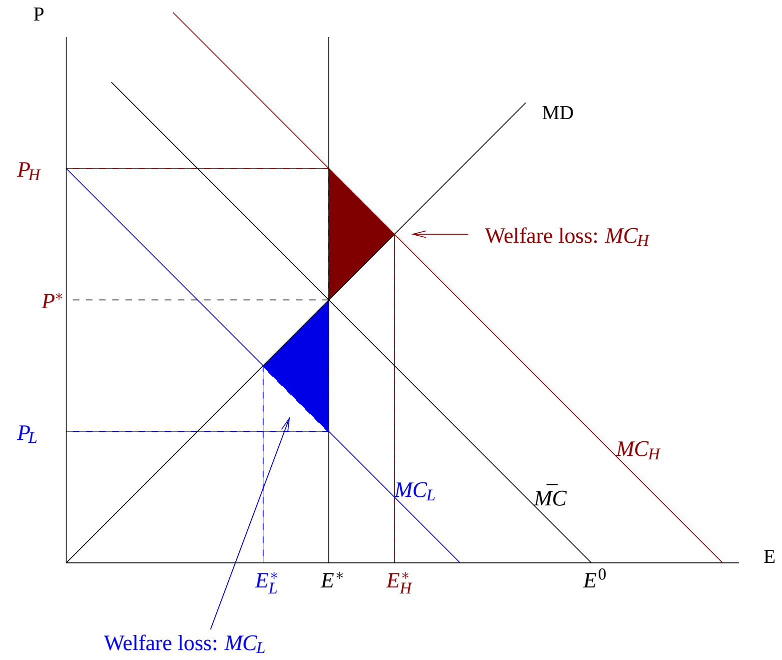

Figure 38: Welfare losses from permit regulation when marginal costs are uncertain.

The average welfare loss is again the average of the areas of the triangles.

Notice that taxes and permits are not equivalent.

- With taxes, the tax stays constant but emissions vary. With permits, the emissions are constant, but the permit price varies.
- When marginal costs are high, emissions are too high under the tax, and too low under the permit system.
- But most importantly, the size of the triangles are different.

C Minimizing welfare loss

We would like to choose the regulation system that has the smallest average welfare loss. Consider two examples:

1 Marginal damages are sensitive to emissions

Suppose a small increase in emissions causes huge increases in marginal damages. An example would be a runaway greenhouse effect. At a certain level of CO_2, temperatures rise uncontrollably which fries the planet.

In this case, marginal damages are nearly vertical. Price and permit welfare losses are:

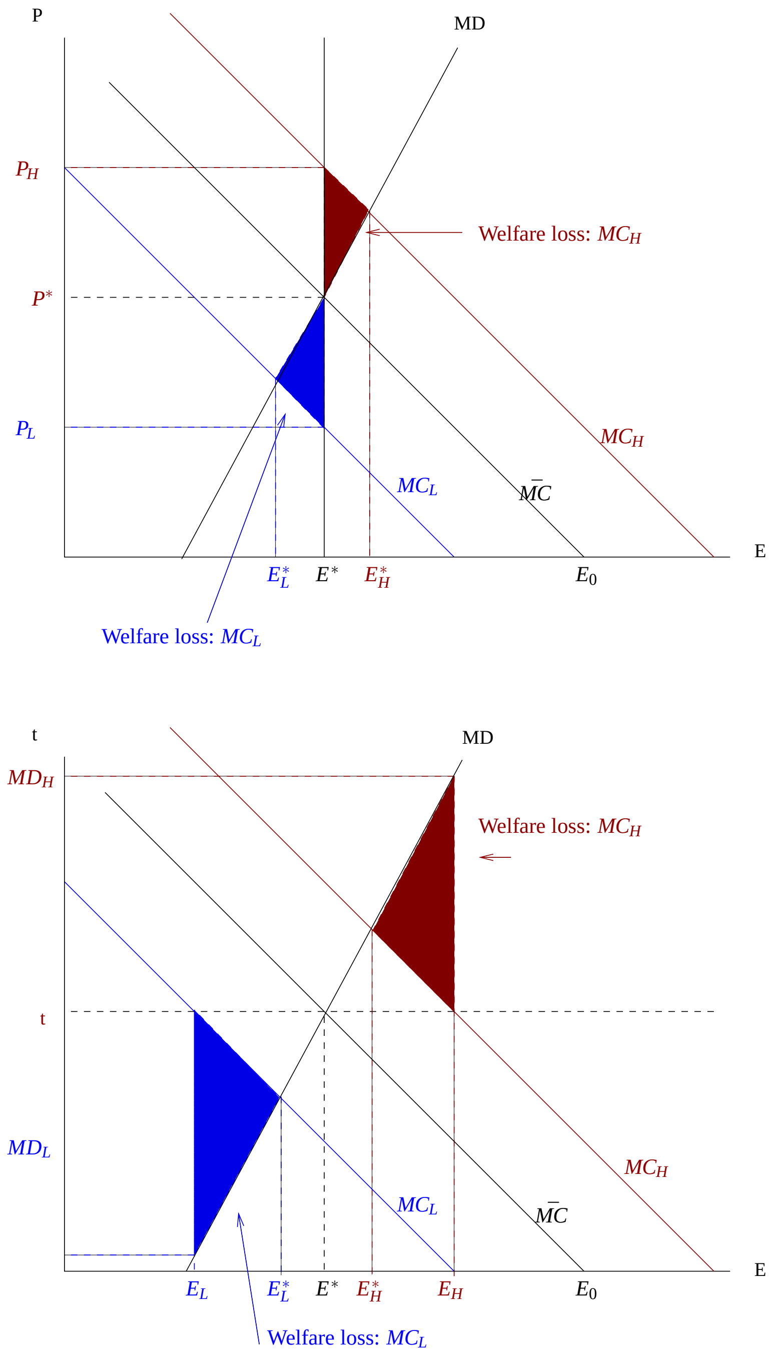

Figure 39: Welfare losses from tax and permit regulation when marginal damages are vertical.

The welfare losses from the tax are huge, but the permit system has little welfare loss. Because emissions vary with the tax, we will have too much or too little emissions, causing welfare losses. Conversely, the permit system can ensure emissions are at the efficient level.

2 Marginal costs are sensitive to emissions

Suppose now that few good substitutes for a pollutant exist. The marginal cost of reducing emissions might be very steep. In this case, given permit regulation, if marginal costs are high, the permit price would rise substantially, and firms would pay very high costs of emissions reduction or very high costs of buying permits, perhaps bankrupting the industry. Conversely, with the tax firms can always just pay the tax at a modest cost. So tax regulation is better.

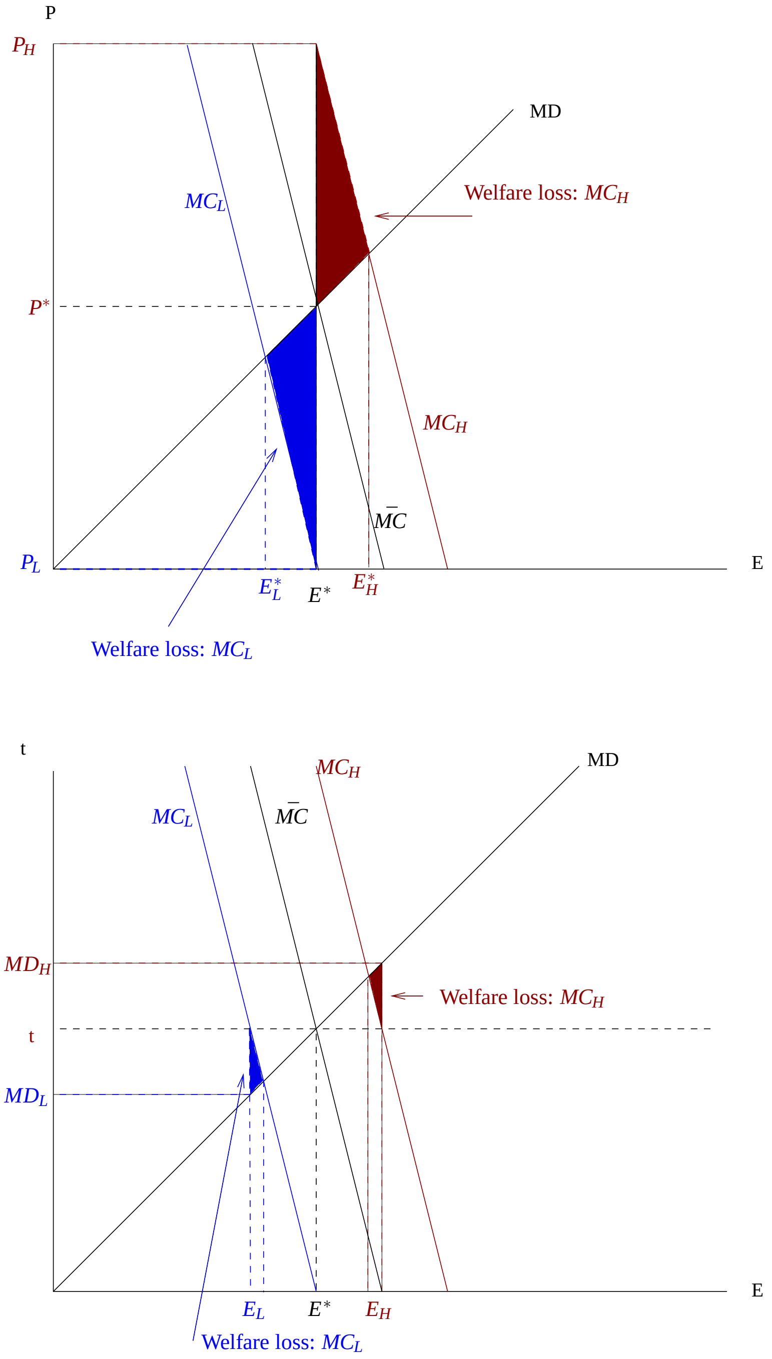

Figure 40: Welfare losses from tax and permit regulation when marginal costs are nearly vertical.

3 General Condition

THEOREM 4 *Weitzman's theorem: If marginal damages are more steeply sloped than marginal costs, emissions permits have lower welfare losses than taxes. If marginal damages are less steeply sloped than marginal costs, taxes have lower welfare losses than emissions permits.*

When are marginal damages steeply sloped?

- Consider a poison that has a modest effect below a threshold and causes death above a threshold. The slope of the marginal damages increases near the threshold.
- Most researchers believe marginal damages for climate change are flat: small changes in emissions have little effect on the aggregate concentrations, and therefore cause small changes in temperature. Thus most economists advocate carbon taxes over cap and trade.

On the other hand, marginal costs may be steeply sloped when few good substitutes for the pollutant exist.

D Safety valves and other hybrids

Hybrid policies combine tax and permit regulations. For example a SAFETY VALVE increases the number of permits issued when the permit price hits a threshold so that the permit price remains constant. Since the price is constant but the quantity varies, when the permit price rises, we have tax regulation.

Suppose marginal damages are initially steep (favoring permits) and then flat (favoring taxes):

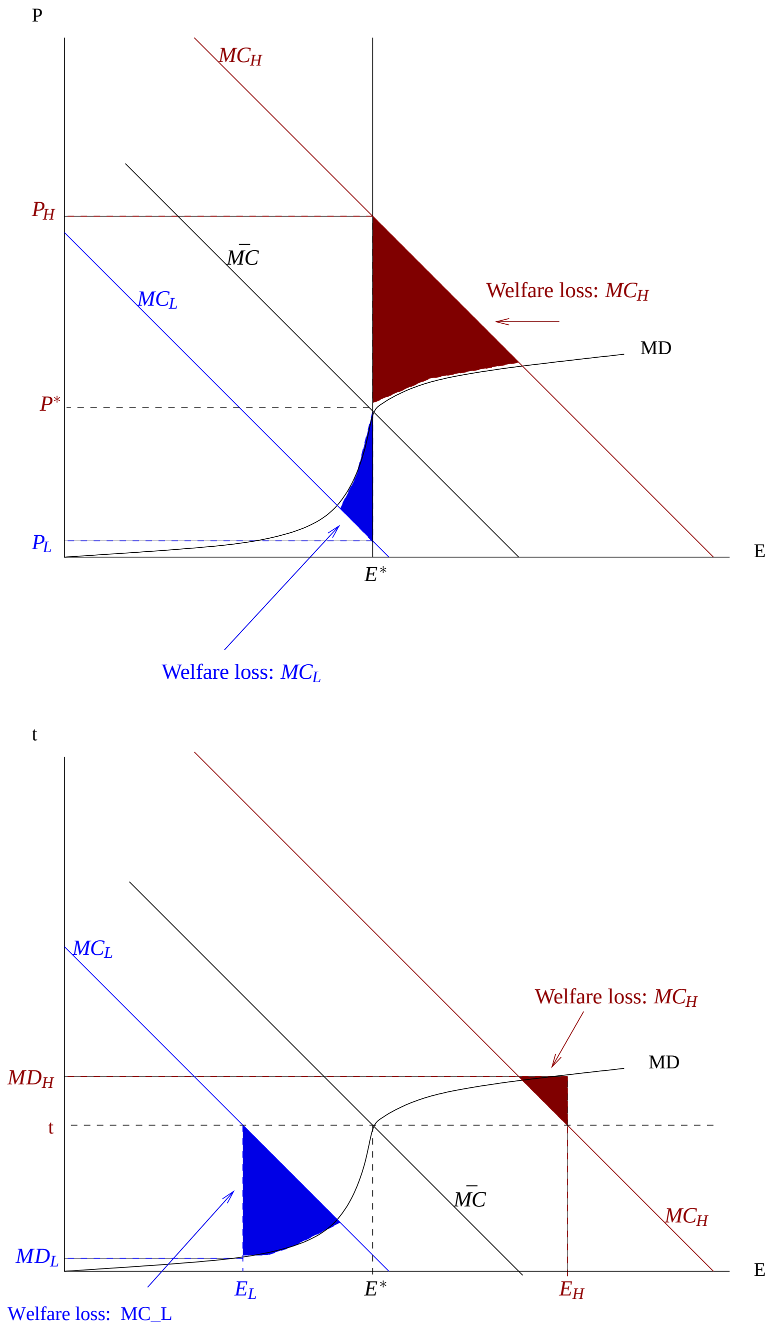

Figure 41: Tax and permit regulation with 'S' shaped marginal damages.

Permits are better if marginal costs turn out to be low because in that case the MD curve is steep. Conversely, if marginal costs turn out to be high, we are on a flat part of the MD curve, in which case taxes are better. Now compare to a hybrid policy. That is, use permits, but issues more permits when the prices rise to, say, MD_H on the tax graph of

Figure 41. In fact, the government issues enough permits so that the price remains constant at MD_H, but emissions rise to $E = E_H$. We then have a tax for MC_H and permits for MC_L:

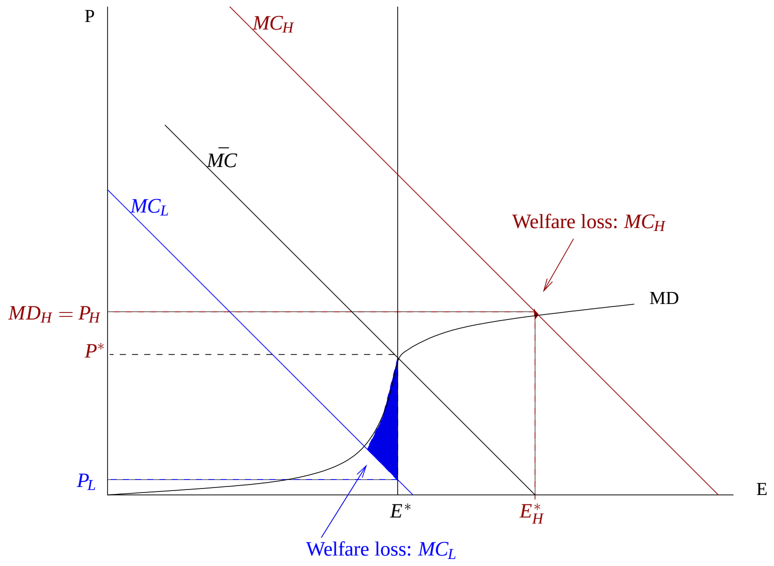

Figure 42: Permit regulation with a safety valve.

In Figure 42, the safety valve does better than either a pure tax or permit regulation since the slope of the marginal damages varies. A permit system is better if marginal costs are low, and a tax is better if marginal costs are high. The safety valve allows the regulation type to effectively switch.

Can we design a system which eliminates welfare losses? Consider a tax-subsidy hybrid that encourages emissions reduction when costs are low and vice versa. Specifically, suppose we have a tax, t which is paid when pollution is above E^* and a subsidy, s, which is paid when pollution is below E^*. Total payments are:

$$\text{total payments} = \begin{cases} s\left(E - E^*\right) & E < E^* \\ t\left(E - E^*\right) & E > E^* \end{cases} \tag{56}$$

Notice that payments are negative when $E < E^*$ because we have a subsidy. Now suppose marginal costs are high. From Figure 43, the firm certainly will reduce pollution to E_H as it is cheaper than paying the tax. It will not reduce pollution below E^* since the cost of emissions reduction is well above the subsidy. Similarly, if marginal costs are low, the firm will certainly reduce below E^* to avoid paying the tax. The firm will continue reducing pollution, as the subsidy is greater than the marginal cost of reducing emissions, until E_H

is reached.

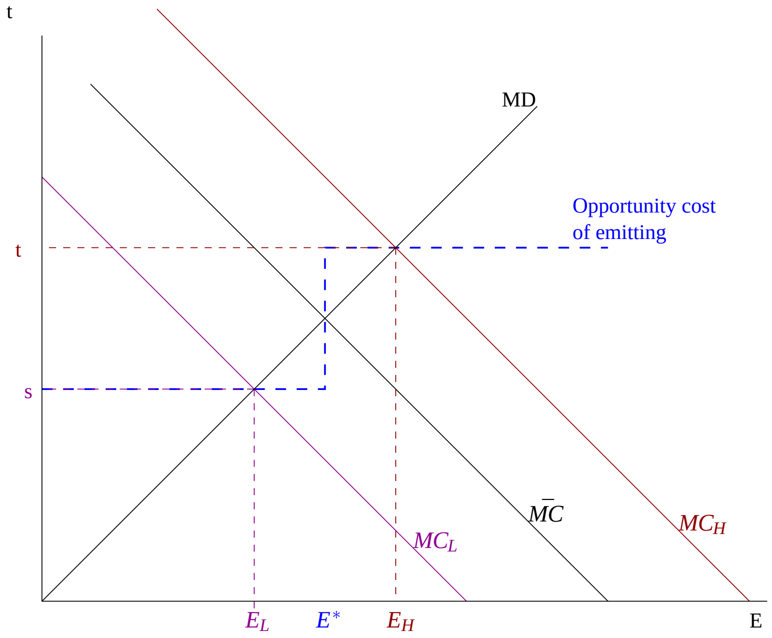

Figure 43: Hybrid tax-subsidy policy.

We therefore have no welfare loss under the hybrid system as emissions is at the optimal level regardless of how marginal costs turn out. By adding flexibility, we reduce welfare losses. This is the advantage of hybrid policies.

Issues:

1. Hybrids get progressively more complicated as uncertainty increases. If marginal costs are not high or low, but instead have n possible outcomes, the regulator would need n sets of taxes and subsidies.

2. RATCHET EFFECT: If firms know they are the low marginal cost types, and reduce emissions to get the subsidy, they reveal to the regulator that costs are low. The regulator then has an incentive to switch to single tax $t = s$. Knowing this, firms may emit more to falsely signal that emissions reduction is costly.

II Monitoring

We now consider the case where firm emissions cannot be perfectly observed. There are many possibilities:

1. Total emissions are observable, but individual firm emissions are not.
2. Emissions are not observable, but some pollution reducing activities, such as buying a scrubber, are.
3. Emissions are not observable, but the firm can be audited at some cost to the regulator, revealing actual emissions.

Each case is slightly different and there are many other cases as well. We will consider (1) and (3).

A Monitoring total emissions

Consider a case similar to previous cases where two firms emit, but now suppose the regulator can monitor only total emissions. For example, suppose runoff from two farms ends up in a river. The EPA monitors total river pollution downstream.

We know that the ideal regulation is tax (or permit) system in which each firm pays t per unit of pollution where:

$$t = MD\left(E^{*}\right) = MC_{1}\left(E_{1}^{*}\right) = MC_{2}\left(E_{2}^{*}\right) \tag{57}$$

But this supposes the firm can monitor individual firm emissions to assign the tax payments.

Suppose we instead charge a tax based on total emissions. Specifically, let:

$$\text{Tax}_{1} = \text{Tax}_{2} = tE \tag{58}$$

$$E = E_{1} + E_{2} \tag{59}$$

RULE: Regulation must be conditional only on what the regulator observes.

Here the regulator observes E but not E_1 or E_2, and so the regulation is based on E.

Now consider firm 1 in Figure 44. It faces the tax/subsidy rule (58). At $E_{0,1}$, the firm can reduce emissions at low marginal cost. Now if the firm does not reduce emissions by one from $E_{0,1}$ total emissions rise and both firms will end up paying an additional t taxes. Since $t > MC$ at $E_{0,1}$, the firm reduces emissions. Continuing this logic, firm one reduces to E_1^* and firm two reduces to E_2^*. We therefore have the efficient emissions:

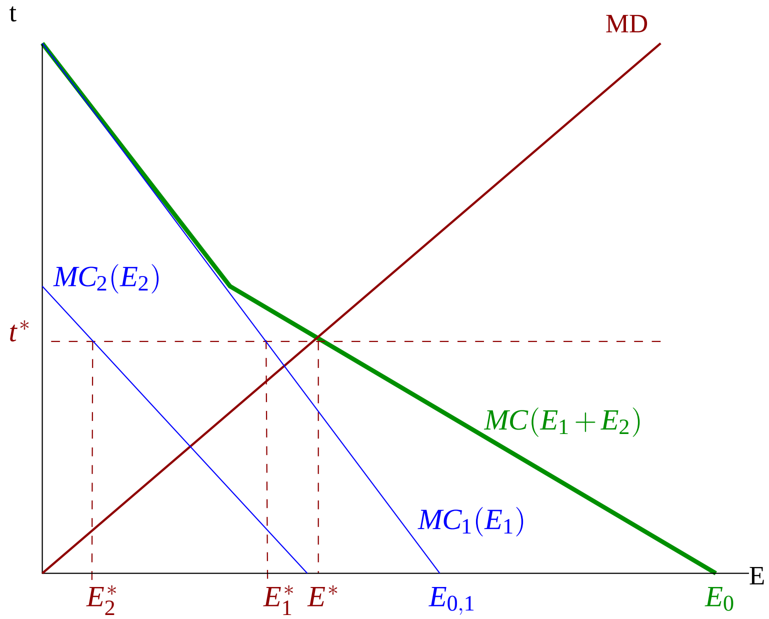

Figure 44: Pigouvian tax on total emissions.

The intuition is that the tax makes both firms pay for each firm's emissions. Firm 1 therefore pays taxes on his own emissions. However, firm 1 cannot control firm 2's emissions, so the fact that firm 1 also pays taxes on firm 2's emissions is irrelevant.

The only issue here concerns when the number of polluters increases significantly. In that case:

1. One firm's contribution to the total emissions might be so small as to be not measurable. In this case, the firm can increase emissions without increasing tax payments.
2. It might be infeasible to make one firm pay taxes on all firm's emissions because the total tax payments might exceed the firm's revenues.

B Auditing

Suppose the regulator can observe firm emissions only via a random audit. The regulator sets the probability of the audit, π and the fine f, per unit of emissions. So the cost to the firm is:

$$\text{total payments } = \begin{cases} fE & \text{with probability } \pi \\ 0 & \text{otherwise} \end{cases} \tag{60}$$

Average payment is thus:

$$\text{Ave}\,[\text{ payments }] = \pi f E + (1-\pi)\,0 \tag{61}$$

We would like a 'tax' per unit of emissions equal to the marginal damage:

$$t = MD\,(E^{*}) \tag{62}$$

Looking at equation (61), setting $\pi f = t$ works. For each unit of emissions, the firm on average pays πf. So the firm will reduce emissions until $\pi f = MC$. So we set:

$$\pi f = MC\,(E^{*}) = MD\,(E^{*}) \tag{63}$$

Suppose for example that, due to limited funds, the EPA can monitor only on average every other period. Then the EPA need only double the fine/tax to provide enough incentives to reduce emissions.

Further auditing issues:

1. The regulator may reduce audit costs by monitoring violators more frequently than non-violators. Non-violators will have increased incentives to remain that way. A violation now results in the firm being moved to the group which is audited more frequently. Because the non-violators have incentives to remain that way, they can be monitored less frequently.
2. Studies show EPAs in developing countries monitor more closely when they get to keep the fine.

III Allocating Initial Permits

The allocation of initial permits does not matter for efficiency. However, this result depends on perfect competition. In the absence of perfect competition, firms may use the initial allocation to hurt competitors. Three cases are important to consider:

1. The political process. Competitive firms are small and therefore cannot affect the political process. A large firm can. By lobbying, large firms can try to block environmental regulation. By allocating the initial permits to large firms, their incentives to engage in lobbying are reduced and the environmental regulation is more likely to go through.

2. New entrants are typically not allocated permits. Thus, large firms can use the permit regulation to restrict competition from new entrants and thus increase their prices.

3. Large firms can manipulate the price of permits.

We will look closely at the third issue. Suppose we have a single large firm and a group of small competitive firms, which we will call the competitive fringe. This industry structure is very common. Now for simplicity allocate all the E^* permits to the large firm. The large firm must therefore decide how much to emit and how many permits to sell to the fringe. The number of permits is fixed at E^*, so we have: $E_L + E_F = E^*$.

For the large firm, the marginal cost of reducing emissions is $MC_L(E_L) = MC_L(E^* - E_F)$. By reducing emissions by one, the large firm gets one more permit to sell. Starting from $E_{0,L}$, reducing the first unit of emissions is cheap, and becomes more costly the more emissions are reduced. Thus supplying permits becomes more and more expensive.

For the fringe, the demand or marginal willingness to pay for a permit is equal to the marginal cost of reducing emissions $MC_F(E_F)$.

A Perfect Competition

If the large firm acted in a competitive manner, we would have:

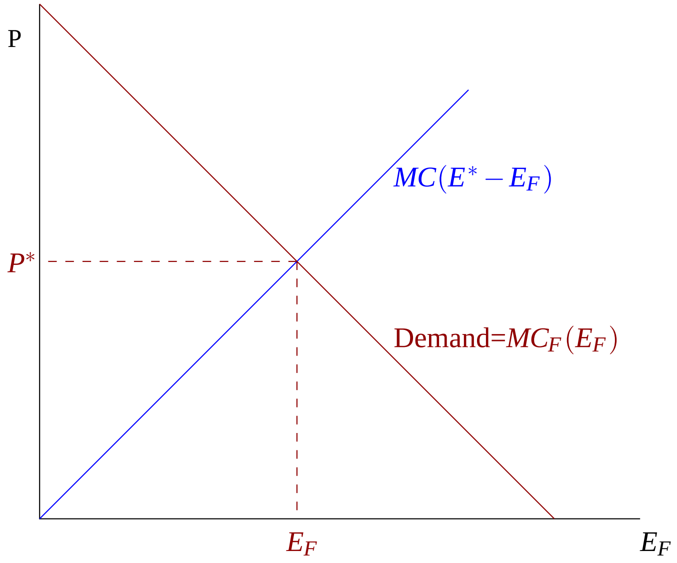

Figure 45: Emissions by the competitive firm when the large firm is allocated the permits and behaves competitively.

Notice that the efficient outcome results. The large firm is allocated the permits. However, if it behaves competitively, it sells some of the rights to the fringe until the marginal costs are equalized at E_F. This is the Coase theorem in action. We have:

$$MC_L(E_L) = MC_F(E_F) = MC(E^*) = MD(E^*) \tag{64}$$

B Imperfect Competition

Suppose now the large firm acts like a monopolist. It could sell E_F permits to the fringe, but if it keeps more permits, the monopolist can drive up the price and make more revenues from the permit sales. Further, by keeping some permits, the monopolist has to do less emissions reduction. So instead the large firm reduces emissions and sells permits until the marginal costs equal the marginal revenue:

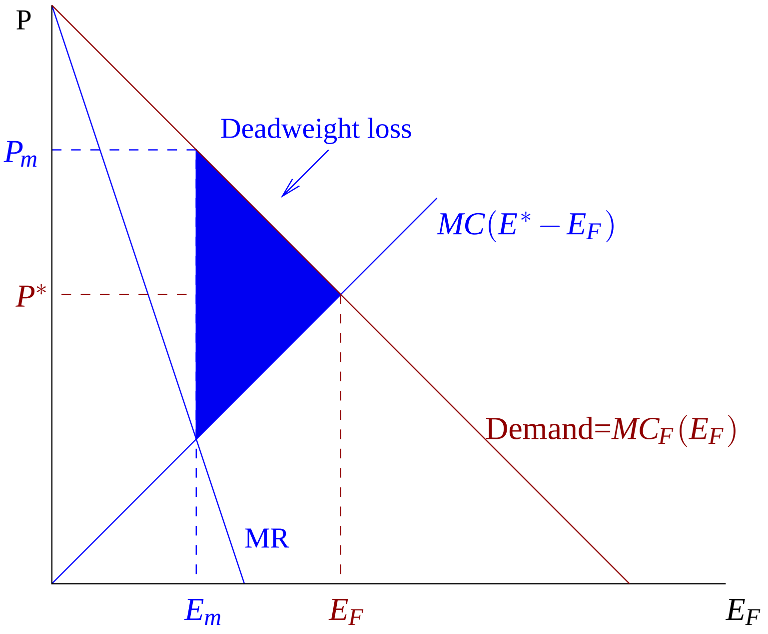

Figure 46: Welfare loss from allocating initial permits to monopolist.

At $E_m < E_F$, the monopolist has driven the price up to p_m and increased revenues. The large firm keeps the extra permits, and so does less emissions reduction. Therefore, we have:

$$MC_L(E_L^m) < MC_F(E_F^m) \tag{65}$$

Although the efficient total emissions E^* still results, too little emissions reduction is done by the large firm. Welfare loss is given by the triangle that represents the difference between the actual cost of reducing emissions and the efficient cost.

C Optimal initial allocation under imperfect competition

We saw above that allocating the permits to the large firm does not work, as the large firm withholds some permits from the market, causing the permit price to increase, which raises profits for the large firm. Since the large firm has too many permits, too little emissions reduction is done by the large firm, and too much by the small firm.

Suppose we instead initially allocated all the permits to the fringe. Then we would have the reverse problem. The large firm would demand too little permits to keep the price of permits down. The large firm ends up with too few permits, and thus too much emissions reduction, relative to the fringe.

What if we allocate E_F^* to the fringe and the rest to the large firm? At price $P = MC_F\left(E_F^*\right) = MC_L\left(E_L^*\right)$, the fringe does not want to sell any permits since it would get only P for selling the permits and have to pay $MC_F > P$ to reduce emissions below E_F^*. The fringe does not want to buy any permits at P, since for emissions greater than E_L^* we have $P > MC_F$. The same is true for the large firm. Thus if we perfectly allocate the initial permits, we can acheive efficiency.

However, this imposes a lot of required knowledge on the part of government: they must know all firms' costs. The advantage of the permit system is that the government can rely on the market to determine where emissions reduction is cheapest. In other words, we might as well have a standard which varies across firms.

Finally, note that the same problem applies to auctioned initial permits. For example, the large firm can simply bid zero or not participate in the auction. All permits then go to the fringe, which the large firm can buy at a low price.

IV Double Dividend

Governments need to raise revenue to fund public goods. However, any tax causes welfare losses. If we tax wages or income, then people work less. People are not happy because they are working less than they want to, so as to avoid the tax. The government gets no revenue from people not working. Everyone loses. Suppose we instead tax bads. Now if people create less bads because they are taxed, we have a welfare gain, not a loss.

Definition 22 *The DOUBLE DIVIDEND HYPOTHESIS states that replacing taxes on goods with taxes on bads creates a welfare gain.*

Note that the double dividend applies only to taxes and auctioned permits. Other forms of environmental regulation do not raise revenue.

Consider a labor market with a tax per hour worked paid by the firm. We have a welfare loss because people work less than is optimal, just to avoid paying the tax. The government revenues are

$$\text{REV} \;= \bar{r} = t_H H, \tag{66}$$

which is the rectangle in Figure 47. The welfare loss is the triangle.

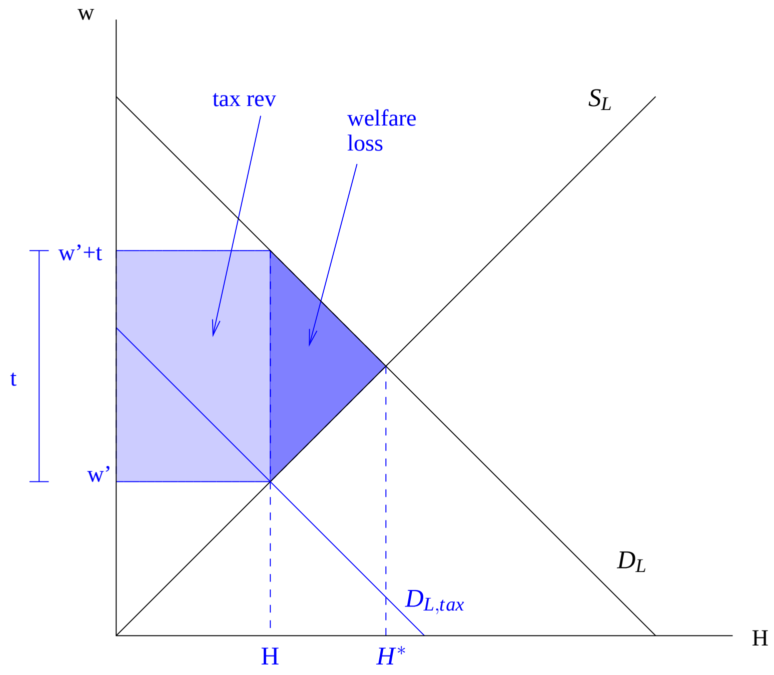

Figure 47: Welfare loss from a tax on hours.

A Pigouvian Effect

Now consider a good with a pollution externality. The optimal tax generates revenues given by the rectangle in Figure 48.

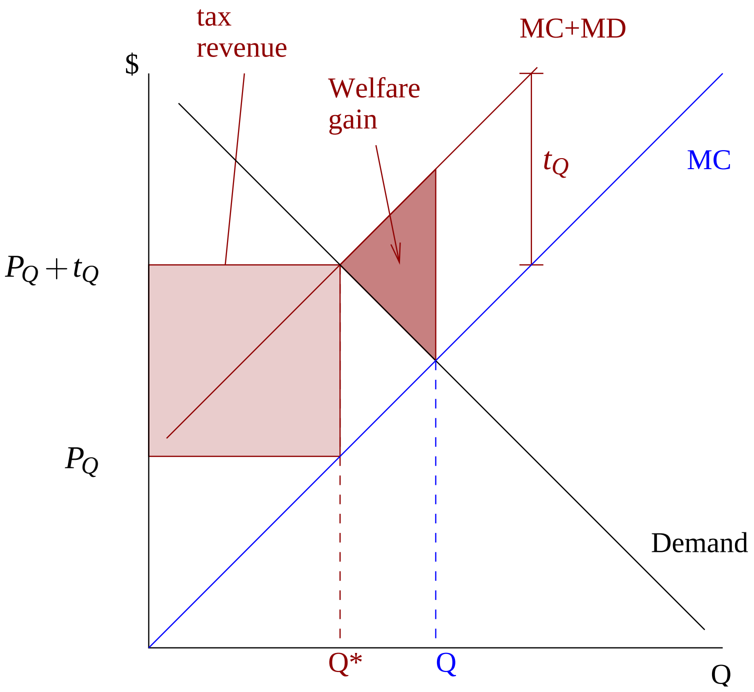

Figure 48: Pigouvian tax on emissions.

Note that we have a welfare gain because we are now equating marginal social costs and willingness to pay. We call the welfare gain from lower pollution the PIGOUVIAN EFFECT (PE). The welfare gain is the triangle in Figure 48.

B Revenue Recycling Effect

Now let us recycle the revenues by reducing the labor tax rate so as to keep overall revenues constant. We now have:

$$t'_H H' = \bar{r} - t_Q Q \tag{67}$$

Definition 23 *The REVENUE RECYCLING EFFECT (RRE) is the welfare gain from replacing the labor tax with the environmental tax.*

The RRE is the difference between the two triangles in Figure 49 (the darker, blue area):

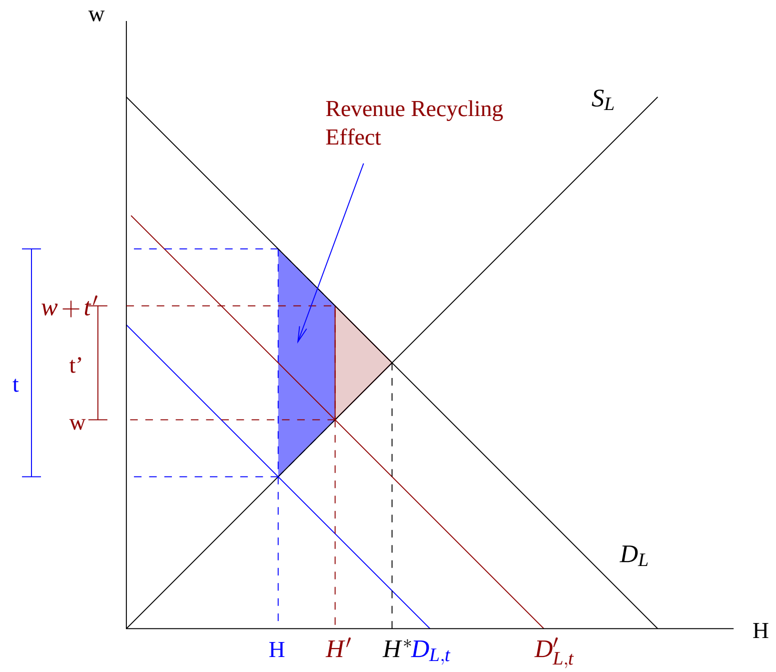

Figure 49: The revenue recycling effect.

So far, we have two welfare gains (a double dividend). If these were the only two considerations, we could increase the tax on the good with an externality above the Pigouvian level and still increase welfare.

C Tax Interaction Effect

However, the increase in the price of Q affects our demand for leisure. In general, we would expect demand for leisure to increase. Working is less attractive because our wages buy less goods. We substitute towards leisure. So the supply of labor shifts to the left. This is a problem because we lose tax revenues, which must be made up by increasing the labor tax rate, and therefore the welfare loss. Let H'' denote the labor supply at the tax rate t''_H. Then we have:

$$t''_H H'' = \bar{r} - t_Q Q \tag{68}$$

Since $H'' < H'$, the tax rate has to be greater, than t' and the welfare loss larger.

Definition 24 *The TAX-INTERACTION EFFECT (TIE) says that Pigouvian taxes decrease the supply of labor, necessitating higher taxes to keep revenues constant.*

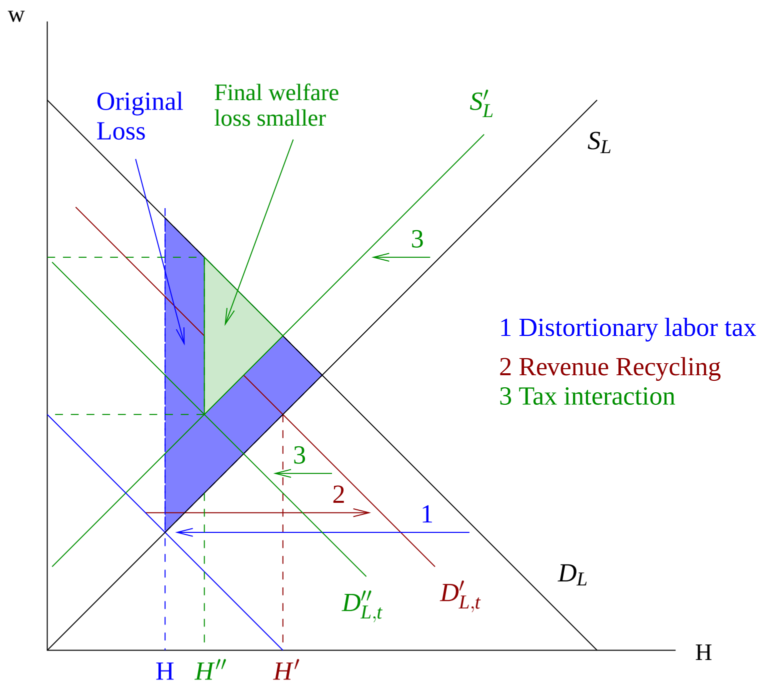

Figure 50: The tax interaction effect.

In Figure 50, the tax interaction effect is the difference between the green and red triangles. It represents the welfare loss from changing taxes from t' to t'', so as to keep revenues constant. If the change in labor supply is large, the green triangle, which represents total welfare loss, can be greater than the blue triangle. In this case, it is optimal to set the environmental tax below the Pigouvian level.

Thus a double dividend may or may not result. Ian Parry (1995) indicates not: the optimal pollution tax in the U.S. should be only $0.63 \cdot MD$. The tax interaction effect exceeds the revenue recycling effect. One thing is certain. In the absence of a revenue recycling effect (for example a standard or a permit system in which the permits are given away), the optimal pollution tax must be less than the marginal damage, when the tax interaction effect is accounted for.

Notes:

1. We are assuming the government sets other taxes incorrectly, but taxes pollution correctly. For example, it is better to tax consumption than wages. It is unlikely that a government can be very good at pollution taxes and very bad at setting labor taxes.

2. The wage tax tends to reduce consumption of the polluting good, perhaps all the way to the optimal level.

3. The revenue recycling effect makes a strong case for auctioning permits (rather than giving them away) and using the revenues to reduce other kinds of taxes. Without the auction, we lose the welfare gain of the revenue recycling effect.