Externalities : (d) Remedies

The Problem

There are two firms. Firm 1's use of coal (Z_1 represents the quantity of coal used by firm 1) affects the profits of firm 2. The higher is Z_1 , the lower is firm 2's profit π_2 . Efficiency requires a level Z_1^* of coal usage by firm such that

$$p_1 \frac{\partial F^1}{\partial Z_1} = w_Z - p_2 \frac{\partial F^2}{\partial Z_1} \qquad (eff)$$

where F^i is the production function of firm i, and w_Z is the price per tonne for coal. This equation could also be written

$$MB^1 = MPC^1 + MD^2 \equiv MSC \qquad (eff')$$

where MB^1 stands for the marginal benefit to firm 1 of using a little more coal, MPC^1 stands for firm 1's marginal private cost, MD^2 is the marginal damage done to firm 2 by a little more coal usage by firm 1, and MSC stands for "marginal social cost".

The problem is that, acting on its own, and ignoring the externality, firm 1 cares only about its own private costs, so maximizes its own profits by choosing a level Z_1^{eq} of coal usage such that

$$p_1 \frac{\partial F^1}{\partial Z_1} = w_Z \qquad (eq)$$

or

$$MB^1 = MPC^1 \qquad (eq')$$

Since $MD^2 > 0$, $Z_1^{eq} > Z_1^*$.

How to get firm 1 to internalize the externality?

There are many ways, but I will start with the "standard" public economics solution.

Pigouvian Taxes

Taxes which induce firms (or people) to internalize externality are often referred to as "Pigouvian" taxes, after the British economist (and spy) Pigou, who proposed them as a remedy for externalities.

Suppose that the government levies a tax of t per tonne of coal. I will assume that the supply curve of coal to firms is perfectly horizontal, so that partial equilibrium tax incidence models (covered in AP/ECON 4070) show that this tax will be born entirely by coal buyers. The effect of the tax is to increase the cost per tonne paid by firm 1 from w_Z to $w_Z + t$. So firm 1 now chooses a level of coal consumption Z_1 which satisfies the equation

$$p_1 \frac{\partial F^1}{\partial Z_1} = w_Z + t \qquad (tax)$$

The higher is the tax rate, the lower is firm 1's optimal coal usage. (The tax just shifts up the horizontal "price of input" curve in figure 2.) In particular, if

$$t = MD^2 = -p_2 \frac{\partial F^2}{\partial Z_1} \qquad (pigou)$$

then equations (tax) and (eff) are the same. A tax per tonne which exactly equals the marginal externality damage will induce firm 1 to choose the efficient level of coal consumption.

In a sense, the tax induces the firm to internalize the externality by taking into account the harm it is doing to firm 2 : it is being charged a tax which exactly equals the dollar value of that damage.

So the Pigouvian tax rate should equal the distance between the MSC curve, and the MPC^1 curve, at the efficient level of coal usage, Z_1^*.

Pigouvian Subsidies

Rather than penalizing firm 1 for increasing its coal usage, we could instead reward firm 1 for reducing its coal usage. That is, we could pay firm 1 a subsidy of s per tonne, for any reduction it makes in coal usage below Z_1^{eq} . So if firm 1 uses $Z_1 < Z_1^{eq}$ tonnes of coal, then it would collect a subsidy of $s(Z_1^{eq} - Z_1)$ for the reduction in coal usage. Now firm 1's total profit, including the subsidy money it collects, would be

$$p_1 F^1(L_1, Z_1) + s(Z_1^{eq} - Z_1) - w_L L_1 - w_Z Z_1 \qquad (1)$$

If firm 1 chooses its usage of coal Z_1 and of labour L_1 to maximize its profit as defined by equation (1), then its first-order conditions for profit maximization (the partial derivatives of expression (1) being set equal to zero) are

$$p_1 \frac{\partial F^1}{\partial L_1} = w_L \qquad (2)$$

$$p_1 \frac{\partial F^1}{\partial Z_1} - s = w_Z \qquad (3)$$

Equation (3) can be written

$$p_1 F_Z^1 = w_Z + s \qquad (sub)$$

so that if the subsidy rate s per tonne is set equal to the marginal damage,

$$s = -p_2 \frac{\partial F^2}{\partial Z_1} = MD^2 \qquad (4)$$

then the Z_1 which solves profit maximization condition (sub) will be the efficient Z_1^* which solves equation (eff). Setting a subsidy rate equal to the marginal damage to the other firm again will induce firm 1 to internalize the externality.

With a subsidy, firm 1 still faces a new **cost** of using more coal : the more coal it uses, the lower its subsidy will be. Each tonne increase in coal consumption lowers its subsidy by s, so that when $s = MD^2$, the extra cost per additional tonne of coal equals the extra damage being done.

A More Direct Solution

The problem is trying to get firm 1 to reduce its coal usage to what we know is the efficient solution, $Z_1 = Z_1^*$. Why not do this directly? A government which can force the firm to pay Pigouvian taxes can also force the firm to cut its coal production. Why not simply order the firm to cut its coal production to Z_1^*? Alternatively, specify a maximum coal usage : Z_1^*. If the government really does have information about all the relevant variables — particularly the production technology of firm 1 — then it knows the efficient level of Z_1 . In this case, directly ordering the efficient quantity is just as good (and perhaps a bit simpler) than achieving it indirectly through taxes or subsidies.

Prices versus Quantities

In many cases, there may be an advantage to using "price" based methods — that is, taxes — to control externalities, as opposed to quantity-based methods.

Often the regulator may not have very good information.

More particularly, it is probably the technology of firm 1 about which the regulator has the worst information.

If the government does not know the exact shape of firm 1's MB1 curve (the curve labelled "benefit to firm 1" in figure 2), then it does not know what is the efficient level of output Z_1^*. Note that a higher marginal benefit curve leads to a higher efficient level of output Z_1^*, and it also leads to a higher value for the level MD^2 of the marginal damage to firm 2, at the efficient solution.

The regulator might have to rely on information from firm 1, to find out exactly what is the marginal benefit curve.

Can it rely on firm 1 to provide the right information? Not unless the regulator is fairly clever. Just as individuals had an incentive to misrepresent their preferences for public goods if fairly simple tax rules were used (as in section 2 of the course), so firm 1 would have an incentive to misrepresent its technology if it knew the regulator was going to use this information for one of the procedures described above.

For example, if the regulator were planning quantity controls, then the firm would have an incentive to exaggerate the marginal benefits it derived from coal use. Looking at figure 2 should (I hope) convince you that shifting up firm 1's marginal benefit curve will move right the efficient level of coal usage Z_1^*. As long as $Z_1 < Z_1^{eq}$, firm 1 profits from increasing coal use : its **true** marginal benefit exceeds the price w_Z per tonne. So, if the firm suspected that the regulator was planning quantity controls, then it would exaggerate the benefits it derived from the externality-

causing activity. That sort of exaggeration is quite consistent with the way industry spokespeople behave at public hearings on regulation. They try and persuade regulators that more stringent quantity regulation will be very costly (to the firm and to others) : that is the same as saying the benefits of allowing more of the externality–causing activity are high.

On the other hand, if the regulator were using Pigouvian taxes, then the firm would actually want to understate its benefits from coal usage. The optimal Pigouvian unit tax is the height of the MD^2 curve, at the level Z_1^* where the MSC curve intersects the MB^1 curve (as in figure 3). Shifting down the MB^1 curve moves the point of intersection left, and so would **lower** the tax, since the MD^2 curve slopes up.

The regulator can actually get the firm to reveal truthfully its technology, if it uses a fairly clever combination of taxes and quantity regulation. What the regulator needs to do is to design a mechanism so that the firm's own interest is served by truthful information regulation. Just as in the case of demands for public goods considered in section 2, this can be done. For example, a paper by E. Kwerel in the *Review of Economics Studies* in 1977 provides a relatively simple example of this kind of mechanism.

But if the regulator cannot get the information on firm 1's private benefits, it may be easier to calculate the marginal damage done by the firm's coal usage. For example, the victim of the externality might not be another firm, but instead a large number of people suffering health risks. The best estimates of the costs of such an externality might be provided from publicly available government-sponsored studies.

So if the regulator know the MD^2 curve, but not the MB^1 curve, then it cannot implement quantity regulation exactly. It can implement a sort of Pigouvian tax, although it does have to change matters a little. The Pigouvian tax t derived above was meant as a **constant unit** tax, t dollars for each and every tonne of coal used by firm 1. The optimal level for this constant unit tax is the height of the MD^2 curve at Z_1^*, as in figure 3. To set this unit tax, the regulator therefore has to know Z_1^*, which requires knowledge of the firm's MB^1 curve.

On the other hand, the regulator could simply assess a charge equal to the actual damage done by each tonne of coal used. This is a more complicated tax to administer, the tax for each tonne of coal used would be $MD^2(Z_1)$, that is a tax in which the marginal rate varied, increasing with the coal usage. Not only is such a tax more complicated, it would not work if there were more than one polluter. (Then, we could not identify which firm produced the "first" unit of pollution, and which the "second".) But, with one externality-causing firm, and with a variable tax rate, it is possible to use taxes to achieve the efficient outcome, even when the externality-causing firm's technology is not known, whereas it is not possible to use quantity regulation.

So the choice between price and quantity regulation may matter, if information is not available, or is uncertain. And which sort of regulation is better will depend on the nature of the uncertainty, or the quality of the information.

The more firm 1 produces, the more coal it will use. The Pigouvian tax described above taxed the level of the firm's input, specifically the level of the input which caused the externality. What about taxing the level of the firm's output?

If the firm is forced to pay a tax of τ per unit of output sold, then its profit becomes

$$\pi_1 = (p_1 - \tau)F^1(Z_1, L_1) - w_L L_1 - w_Z Z_1 \tag{5}$$

Maximization of profits by the firm now yields the first-order conditions

$$(p_1 - \tau)F^1_L = w_L \tag{6}$$

$$(p_1 - \tau)F^1_Z = w_Z \tag{7}$$

Equation (7) can be re-arranged to

$$p_1 F^1_Z = \tau F^1_Z + w_Z \tag{8}$$

Comparing equations (eff) and (8), it appears that the efficient outcome could be obtained by setting the output tax τ in such a way that

$$\tau F^1_Z(L_1, Z_1) = -p_2 \frac{\partial F^2}{\partial Z_1} \tag{9}$$

However this conclusion is wrong. An output tax satisfying (9) will not get firm 1 to make an efficient choice. Nor will any other output tax.

The problem here is that there is another input to production, labour, which here is not causing an externality. The efficient solution involves finding both a quantity of coal Z_1 for firm 1, but also an efficient quantity of labour L_1 — as well as an efficient quantity of labour L_2 for firm 2. Efficiency involves picking L_1 , Z_1 and L_2 such that the three first-order conditions for maximization of the firms' joint profits are satisfied,

$$p_1 \frac{\partial F^1}{\partial Z_1} = w_Z - p_2 \frac{\partial F^2}{\partial Z_1} \tag{eff}$$

$$p_1 \frac{\partial F^1}{\partial L_1} = w_L \tag{$effL1$}$$

$$p_2 \frac{\partial F^2}{\partial L_2} = w_L \tag{$effL2$}$$

Taxing output at the rate τ would induce firm 1 to choose labour usage such that equation (6) above holds. Equations (6) and $(effL1)$ can be the same only if $\tau = 0$.

The problem is, we want the firm to reduce its coal usage, not its labour usage. Taxing the output of the firm induces it to reduce usage of both inputs, and so cannot lead to an efficient

solution. Put otherwise, we would like the firm to **substitute** some labour for coal, that is to use a less polluting technology. Taxing output levels alone offers no inducement for the firm to substitute in this way.

Since substituting labour for coal is a good idea, how about subsidizing labour instead of taxing coal? That is, suppose that we put a subsidy of σ per person-hour of labour hired by firm 1? Then its profits will be

$$\pi_1 = p_1 F^1(L_1, Z_1) - w_L L_1 - w_Z Z_1 + \sigma L_1 \tag{11}$$

Maximizing (11) leads to first-order conditions

$$p_1 \frac{\partial F^1}{\partial L_1} = w_L - \sigma \tag{12}$$

$$p_1 \frac{\partial F^1}{\partial Z_1} = w_Z \tag{13}$$

Comparison of (12) and (13) with $(effL1)$ and (eff) shows that there is no labour subsidy rate σ which will induce firm 1 to choose the efficient input combination.

Although an output tax is not as good as a direct tax on the externality-causing input, it turns out that a small output tax must be better than nothing, if direct taxes on Z_1 cannot be levied. That is, the overall measure of welfare, the sum of the two firms' profits

$$\pi_1 + \pi_2 = p_1 F^1(L_1, Z_1) + p_2 F^2(L_2, Z_1) - w_L(L_1 + L_2) - w_Z Z_1 \tag{14}$$

must increase with the output tax τ as that tax is raised above 0.

Why? An output tax will get firm 1 to change both its labour use L_1 , and its coal use Z_1 , as well (perhaps) as getting firm 2 to change its labour use. So the overall change in joint profits is

$$\frac{\partial[\pi_1 + \pi_2]}{\partial \tau} = [p_1 \frac{\partial F^1}{\partial L_1} - w_L]\frac{dL1}{d\tau} + [p_2 \frac{\partial F^2}{\partial L_2} - w_L]\frac{dL2}{d\tau} + [p_1 \frac{\partial F^1}{\partial Z_1} + p_2 \frac{\partial F^2}{\partial Z1} - w_Z]\frac{dZ_1}{d\tau} \tag{15}$$

Suppose we start out with no regulation or taxes at all, and put in a small output tax τ on firm 1. The right side of equation (15) measures the effect that this small increase in the tax rate (starting from a zero tax rate) will have on joint profits.

But the first two terms in square brackets on the right side of (15) are both 0. That follows from firms' profit maximization : they hire labour up to the point at which the value of its marginal product equals its unit cost. (Those conditions were derived as equations (2) and (5) in part 3 of this section.) The third term in square brackets — the one associated with firm 1's coal use — is not zero. Ignoring the externality, firm 1 chooses Z_1 so that

$$p_1 \frac{\partial F^1}{\partial Z_1} = w_Z \tag{eq}$$

which means that the third term in square brackets in (15) equals

$$p_2 \frac{\partial F^2}{\partial Z_1}$$

That's a negative number : more coal use by firm 1 hurts productivity at firm 2. So the right side of equation (15) equals

$$p_2 \frac{\partial F^2}{\partial Z_1} \frac{dZ_1}{d\tau} \tag{16}$$

Expression (16) must be a positive number if (and only if) $dZ_1/d\tau < 0$. But that's always going to be true : taxing the firm's output at the positive rate τ will lead the firm to reduce production, so that it hires less labour, and uses less coal.

[Wait a minute! My measure of joint profits of the firm did not subtract off the taxes that firm 1 would have to pay, if it were subject to an output tax. Shouldn't that be subtracted?

No! The output tax is collected from firm 1, but it is revenue to the government, not the other firm. So the transfer of money from the firm to the government does not affect my overall measure of welfare. I could have subtracted that off the joint profits, but then I would also have to change my measure of social welfare as profits to the firms plus tax revenue collected by the government. The loss to firm 1 is cancelled by the gain by the government, so that (15) is the correct measure of the change in overall welfare.]

Conclusion : an output tax is not as good as a direct tax on the externality-causing input, but a small output tax is better than nothing.

Merger

The measure of social welfare used here (and in the preceding part 3 of the section) is the joint profits of the two firms. This measure takes into account the negative impact firm 1's coal usage has on the value of the output of firm 2.

So if both firms had the same owner, then the owner would take account of this impact : she would realize that the more coal she used in her division 1 (the former firm 1), the lower profits would be at division 2 (formerly firm 2).

So common ownership of the two firms will completely internalize the externality.

Of course, it has been assumed here that both firms were perfect competitors. If the firms were not, that is, if each of the firms were large enough to have some market power, then a merger could increase that market power (if the two firms produced similar outputs, or both hired some inputs on the same market). The benefits of internalizing the externality would have to be weighed against the costs of the anti-competitive aspects of the merger. But these issues do not arise if the firms are perfect competitors.

Is Merger Necessary for Coordination?

If firm 1 really does neglect the effect of its own coal usage on firm 2, then it seems to be acting pretty stupidly.

Suppose that it does neglect this effect, and it chooses a coal usage level of Z_1^{eq} . What would be the effects of a slight decrease in its coal usage? Its own profits would fall by $p_1 \frac{\partial F^1}{\partial Z_1} - w_Z$ per tonne. But at $Z_1 = Z_1^{eq}$, this expression is zero. Reducing coal usage slightly has very little effect on the firm's own profits, since the value of the marginal product of the last few tonnes used is very close to the cost to the firm.

On the other hand, reducing Z_1 slightly below Z_1^{eq} would significantly increase the profitability of firm 2. That is, the loss to firm 1 from a slight reduction in Z_1 is much less than the gain to firm 2. (That's why Z_1^{eq} is not the efficient level of coal usage.) Even if the two firms do not merge, there should be some sort of deal that they can make. A payment from firm 2 to firm 1, in exchange for a slight reduction in Z_1 , seems a deal that would be good for both firms.

It is this possibility of **negotiation** among parties to an externality that plays a major role in the first part of R. H. Coase's analysis of externalities. That analysis is discussed briefly in the next part.