Lecture Note 12 - Externalities, the Coase Theorem, and Market Remedies

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1 Introduction

Many of you willl have encountered the topic of externalities in 14.01 or another introductory economics class. An externality arises when an economic actor does not face the 'correct price' for taking a specific action. The 'correct' price of an action is the marginal social cost of that action. As we discussed during the section on General Equilibrium, when working properly, markets align *private* costs and benefits with *social* costs and benefits. When private benefits differ from social benefits (either higher or lower), externalities result. Some classic externalities include:

- Traffic: When I take the highway, I increase congestion for other drivers, a negative externality. Since the toll on the Mass Turnpike does not vary with traffic conditions, I probably face the wrong price of driving on the highway (too high at non-peak hours, too low at peak hours). As a result, I use the Pike 'too much' during peak hours and not enough during non-peak hours.

- Disease transmission: When parents decide whether to have their children receive flu shots, they probably consider the cost of the inoculation in terms of time, money, discomfort and reduced risk of side effects (or even perceived negative effects). They probably do not consider that by protecting their own children from the flu, they also protect other children at their children's school. Because the private benefit of the shot does not incorporate the external social benefit of the shot, parents will generally be less motivated than they should be (accounting for external benefits) to get their children inoculated. It is therefore likely that too few children receive vaccinations.

  Making matters worse, it is likely that some sophisticated parents recognize that, because most parents *do* get their children inoculated, their own kids may be reasonably protected even without receiving an inoculation. These parents may be even *less* motivated to get a shot than parents who do not consider the positive externality that they are generating. Thus, free-riding makes the externality worse.

  This issue has major public health consequences. Whooping Cough (pertussis), which had largely been eradicated from the U.S., has made a resurgence. The reason is that a small fraction of parents have decided against vaccination because they fear that trace amounts of mercury used as a preservative in vaccines may harm their children. This places their children at risk *and* other children whom they come in contact with. Since children cannot be inoculated against pertussis until they reach an appropriate age, the failure of older kids to vaccinate often leads to younger children becoming infected.[1] Similarly, the recent measles outbreak in Western United States may be related to a growing number of parents resisting vaccinations for their children.

[1] Adding insult to injury, it was subsequently established that the 1988 article by Andrew Wakefield in *The Lancet* that purported to find a link between childhood vaccinations and childhood autism—and which led to the worldwide decline in vaccination rates—was fraudulent.

- Pet clean-up: In 1978, New York had an estimated half-million dogs living in apartment buildings and, not surprisingly, very little grass or open space. People walked their dogs on city sidewalks and almost no one cleaned after them. It was a minefield! In 1978, New York established a "pooper scooper" law, #161.03 of the New York City Health Code, which states, "A person who owns, possesses or controls a dog, cat or other animal shall not permit the animal to commit a nuisance on a sidewalk of any public place." For many New Yorkers, this simple change remarkably improved their quality of life. It's hard to find official statistics on this, but my hunch is that the number of dogs has also declined substantially.

- Water pollution: Bubbly Creek is the nickname given to the South Fork of the Chicago River's South Branch, which runs within the city of Chicago. In the 1860's, after Bubbly Creek became a sewer for the Union Stockyards, the waterway became so thick with carcasses and manure that it sometimes caught fire. Gases bubbling out of the riverbed from the decomposition of blood and entrails dumped into the river by the local stockyards in the early 20th century give the creek its name. It was brought to perpetual notoriety by Upton Sinclair in his exposé *The Jungle* about the American meat packing industry. [Sources: Wikipedia and http://www.theboatingexperience.com/boating_destinations/chicago_river.html.]

2 The Coase Theorem

Are externalities such as those above never internalized by the market? Until the publication of Ronald Coase's 1960 paper, "The Problem of Social Cost," most economists would have answered yes. Coase made them reconsider that view. Coase gave the example of a doctor and a baker who share an office building (actually, his article contains *many* examples, most of them drawn from legal dockets).

> Let us first reconsider the case of *Sturges v. Bridgman*, which I used as an illustration of the general problem in my article on "The Federal Communications Commission." In this case, a confectioner (in Wigmore Street) used two mortars and pestles in connection with his business (one had been in operation in the same position for more than 60 years and the other for more than 26 years). A doctor then came to occupy neighbouring premises (in Wimpole Street). The confectioner's machinery caused the doctor no harm until, eight years after he had first occupied the premises, he built a consulting room at the end of his garden right against the confectioner's kitchen. It was then found that the noise and vibration caused by the confectioner's machinery made it difficult for the doctor to use his new consulting room. "In particular . . . the noise prevented him from examining his patients by auscultations for diseases of the chest. He also found it impossible to engage with effect in any occupation which required thought and attention." The doctor therefore brought a legal action to force the confectioner to stop using his machinery. The courts had little difficulty in granting the doctor the injunction he sought. "Individual cases of hardship may occur in the strict carrying out

of the principle upon which we found our judgment, but the negation of the principle would lead even more to individual hardship, and would at the same time produce a prejudicial effect upon the development of land for residential purposes" (Coase, 1960, pp 8-9).

- The problem in contemporary English: The baker's loud machinery disturbed the doctor's medical practice. The doctor could not treat patients while the baker's machinery was running.

- The standard economic reasoning at the time, voiced by the court, was that the baker should have to compensate the doctor for the harm his machinery was doing, since the baker's equipment was 'causing' the externality. Having the baker provide compensation would correct the externality imposed on the doctor.

- But is this reasoning complete? Coase pointed out that one could re-frame this problem as follows. The baker had been using his machinery for decades without doing any harm. The doctor subsequently set up his office next door and then noticed that the baker's machinery was too loud for him to conduct his practice and demanded that the baker shut down his operation due to the disturbance. (And following the court's decision, this is what occurred.) One could legitimately argue that the doctor was creating an externality by requiring the baker to bake in silence. The baker's noise could be viewed as an 'input' into his production of baked goods. Without it, the baker could not perform his work. So perhaps the doctor should accommodate the baker, either by moving his practice or by installing soundproofing.

- If this reasoning is valid, then who should compensate whom? From a legal point of view, the answer may be clear. From an economic point of view, the answer is indeterminate based only on the information provided.

- Consider the following additional information: The baker could buy quieter machinery for \$50. The Doctor could soundproof his walls for \$100. Economic efficiency demands that the lowest (marginal) cost solution that achieves the objective is the right solution: the baker should buy quieter machinery.

- So, does this mean that the baker should have to pay to abate? It does *not*.

- Consider the following scenarios:

  1. The town council assigns the doctor the right to control the noise level in the building. He notifies the baker that he needs quiet to work. The baker spends \$50 for quieter machinery.
  2. The town council assigns the baker the right to make as much noise as needed to do his work. The doctor complains about the noise and the baker points out that he has the right to make as much noise as he likes. Will the doctor now spend \$100 to sound proof his office? If the doctor and baker can negotiate readily, they should arrange for the doctor to pay the baker \$50 to buy quieter machinery.

- As this example demonstrates, the efficient economic outcome should occur regardless of which party is 'responsible' for the externality. In either case, quieter baking machinery is purchased.

- The legal framework *does* matter, however. If the 'sound rights' are assigned to the doctor, the baker spends \$50. If the sound rights are assigned to the baker, the doctor spends \$50.

- So the Coase theorem says the following. If (1) property rights are complete (so, in our example, one party clearly owns the 'sound rights') and (2) parties can negotiate costlessly (so the doctor and baker don't come to blows), then the parties will be able to negotiate an efficient solution to the externality. The allocation of property rights determines who pays this cost, but the outcome is efficient in either case. Note that although the outcome is efficient in both cases, it need not be identical—more on this below. (Note further the parallels with the Welfare theorems: efficiency and distribution are separable problems.)

- The Coase theorem implies that the market will solve externalities all by itself if: *(1) property rights are complete and (2) negotiating is essentially costless.*

- The Coase theorem is often misinterpreted to suggest that the market *will* solve all externalities. Coase will probably go to his grave railing against the 'Coaseans' who make this claim.[2]

- The correct interpretation of the Coase theorem is that the market can *potentially* solve externalities *if* property rights are clearly assigned *and* negotiation is feasible.

- In some cases, this is clearly infeasible.

  - Airlines cannot realistically negotiate with individual homeowners for overflight rights to their houses, even though these overflights do create externalities.
  - I cannot negotiate with all handicapped drivers for the use of an empty handicap space in an emergency, even though I'd be glad to pay these drivers to rent the parking space.

- A key inference that follows from the Coase Theorem: The best solution to resolving an externality may not be to regulate the externality out of existence (or even at all) but to assign property rights or facilitate bargaining so that the affected parties will achieve an economically efficient solution.

- Similar to the Second Welfare Theorem, the Coase Theorem says that the problem of remedying externalities can be thought of as two separate problems. The first is *what* should be done (should sound insulation be installed, should quieter machinery be purchased?). The second is *who* should pay for it (the doctor, the baker?). The Coase Theorem implies that the answer to the second question is independent of the answer to the first; the first is about efficiency,

[2] Sadly, Coase passed away in 2013. I have it on good authority that was denouncing the Coaseans until his final days.

the latter about transfers (similar to shifting the endowment). As per the Second Welfare Theorem, the question of how to maximize the economic pie and how to divide the pie are distinct.

3 Remedying pollution: Three approaches

- It's useful to use a concrete example of abatement of an externality to see analytically how the Coase Theorem can be used in practice, and how it differs from other abatement mechanisms.
- Consider two oil refineries that both produce fuel, which has a market price of $3 per gallon. Assume that demand is infinitely elastic so that this price is fixed regardless of the quantity produced.
- Assume that each refinery uses $2 in raw inputs (crude oil, electricity, labor) to produce 1 gallon of fuel.
- In addition, each plant produces smog, which creates $0.01 of environmental damage per cubic foot.
- The amount of smog *per gallon of fuel* produced differs at the two plants:

$$\begin{aligned} s_1 &= y_1^2, \\ s_2 &= \frac{1}{2}y_2^2, \end{aligned}$$

  where y_1, y_2 denote the number of gallons of fuel produced at each plant. Plant 2 pollutes only $\frac{1}{2}$ as much as plant 1 for given production.
- Assuming initially that there are no pollution regulations. In this case, each plant will produce as many gallons as possible until it runs out of capacity (since it makes $1 profit per gallon). Assume each plant can produce 200 gallons.

3.1 Competitive outcome

- What will firms choose to produce in the absence of any regulation of carbon output?

$$\begin{aligned} \max_{y_1} \pi_1 &= y_1 \cdot (3-2) \ s.t. \ y_1 \leq 200, \\ \max_{y_2} \pi_2 &= y_2 \cdot (3-2) \ s.t. \ y_2 \leq 200, \\ y_1^* &= y_2^* = 200. \end{aligned}$$

- Each firm ignores the social damage from its smog production (notice that s_1, s_2 do not enter into the firms' profit maximization problems). Hence, pollution is $s_1 = 40,000$, $s_2 = 20,000$. The negative pollution externality is $400 and $200 from plants 1 and 2 respectively.

- What is social surplus in this case? It is consumers' willingness to pay for output ($3 per gallon) minus the resource costs of production minus the social costs of smog output:

$$(200 + 200) \times (3 - 2) - 0.01 \times (40,000 + 20,000) = -200$$

  Thus, in this example, the social damage from the externality swamps the benefits of consumption: we'd be better off producing no fuel at all than producing 200 gallons at each plant.

- Does this mean that we should produce no fuel? *Of course not.*

3.2 Welfare maximizing case

- Not all activities that generate externalities should be stopped. But if these activities generate negative (positive) externalities, then social efficiency generally suggests that we want to do less (more) of them than would occur in the free market equilibrium. Let's determine the optimal level of pollution.

- To get the socially efficient level of fuel production, we want to equate the marginal social benefit of the last gallon of fuel to the marginal social cost.

  - What is the social benefit? It is $3. This comes from the infinitely elastic demand curve.
  - The marginal social cost of production is $2 in raw inputs *plus* whatever pollution is produced.
  - The efficiency condition is $MB_s = MC_s$, marginal social benefit equals marginal social cost.

- We therefore want it to be the case that at the margin, there is no more than $1 of environmental damage done per gallon of fuel produced. Consequently, no plant should produce more than 100 cubic feet of smog per gallon of fuel.

- (Note: no plant should produce *less* than this amount either since the pollution is indirectly beneficial: it is an 'input' into the production process; less pollution means less fuel production).

- Imagine that each plant faced the private *plus* social costs of production. If so, we could rewrite the previous profit maximizing conditions as:

$$\begin{aligned}
\max_{y_1} \ \pi_1 &= y_1 \cdot (3-2) - 0.01 y_1^2 \quad s.t. \ y_1 \leq 200, \\
\max_{y_2} \ \pi_2 &= y_2 \cdot (3-2) \ - \frac{1}{2} \cdot 0.01 y_2^2 \ \ s.t. \ y_2 \leq 200, \\
y_1^{**} &= 50, \ y_2^{*} = 100.
\end{aligned}$$

- When Plant 1 is producing 50 gallons, the marginal gallon produces 100 cubic feet of smog, which causes \$1.00 in environmental damage. More pollution than this would be socially inefficient since fuel sells for \$3 and uses \$2 in raw inputs to produce. For Plant 2, the corresponding production is 100 gallons because this plant produces less smog per gallon.

- What is the social surplus from output in this case?

$$(100 + 50) \times (3 - 2) - 0.01 \times \left(\frac{1}{2} \times 100^2 + 50^2 \right) = \$75$$

- We now have an efficient benchmark for welfare maximization.

- How do we get plants to produce the socially efficient level of pollution? Three classes of regulatory solution are possible. Each has different properties.

3.3 Command and control (quantity) regulation

- Command and control regulation is the traditional approach to limiting externalities. This approach sets numerical *quantity* limits on activities that have external effects. It is often called quantity regulation.

- The most common command and control regulation is simply banning an activity—"though shalt not litter." This is generally not efficient. The fact that an activity has an external effect does not immediately imply that it should be banned outright—only that too much or too little may be done relative to the social optimum.

- Much command and control regulation recognizes this point, and so permits some positive amount of an activity, but less than a private actor would otherwise undertake.

- How does this apply to the example above? We know the optimal quantity of production for each plant from our calculations above. We could therefore pass a law that says "Plant 1 may produce 50 gallons of fuel and Plant 2 may produce 100 gallons of fuel." This will achieve exactly the desired result.

- But this kind of regulation is clumsy. It's difficult to write laws that regulate the behavior of each plant individually. Once passed, such laws are difficult to modify as technology or pollution costs change.

- Even more importantly, quantity regulation generally provides inefficient incentives (or no incentives) at the margin. For example, let's say the regulation made a mistake and assigned $q_1^* = 100,$ and $q_2^* = 50$, that is, the regulator reversed the allocations. Plant 1 would have no incentive to correct the situation—that is, to reduce its pollution—and plant 2 would have no effective means to bargain with plant 1 to increase its allocation since both plants have identical marginal profit from the next gallon of fuel under this regulatory scheme, there are no gains from trade. Notice that because these mistakes are *not* self-correcting, it *must* mean that the incentives provided are inefficient.

- If the law cannot be written to regulate each plant's output differentially, further inefficiencies will result. For example, let's say that the regulator decided to assign each plant the *average* of the efficient output levels (75) since it was not possible to assign them each individual quotas. In this case, total social surplus would be:

$$(75 + 75) \times (3 - 2) - 0.01 \times \left(75^2 + \frac{1}{2}75^2\right) = \$65.63,$$

which is lower than the \$75 in social surplus in the optimal regulation case above.

- It's also interesting to ask as an exercise what the optimal fuel production would be if the regulator is required to apply the same numerical production cap for each plant. One could setup the maximization as follows:

$$\max_q \pi = 2q - 0.01 \times \left(\frac{1}{2}q^2 + q^2\right).$$

Using the first order condition, we obtain $q^* = 66.67$. In this case, social surplus is:

$$2 \times 66.67 - 0.01 \times \left(66.67^2 + \frac{1}{2}66.67^2\right) = \$66.67,$$

which is higher than in the case where the regulator simply chose the "average" efficient output of the two plants.

- Despite its weaknesses, command and control regulation is the most common approach taken for regulating externalities.

3.4 Pigouvian tax (price regulation)

- An alternative approach is to use the price system to internalize the externality.

- We know from above that the marginal social cost of pollution is \$0.01 per cubic foot of smog. If we charged firms for polluting, the social cost would be incorporated in the private cost. Done correctly, firms will make optimal choices.

- This type of tax is known as a Pigouvian tax after the economist Pigou who suggested it.

- Specifically, it we set the pollution tax at $t = \$0.01$ per cubic foot of smog, then each plant would choose the optimal quantities as a result of profit maximization:

$$\begin{aligned} \max_{y_1} \pi &= y_1(3-2) - t \cdot y_1^2, \text{ where } t = 0.01 \to y_1^p = 50 \\ \max_{y_2} \pi &= y_2(3-2) - t \cdot \frac{1}{2}y_1^2, \text{ where } t = 0.01 \to y_2^p = 100 \end{aligned}$$

- This solution achieves the desired result with arguably less complexity. Facing this tax, plants will choose the efficient amount of production. *We do not have to write a separate law for each plant. In fact, we don't even need to know firms' production functions to write this regulation correctly. All we need to do is calculate and price the marginal social damage of pollution (of course, we also need to enforce these regulations—a separate though important issue).*

- Note that this problem is made especially simple by the assumption that the marginal damage of pollution is always $\$0.01$ per cubic foot. If the marginal damage varied with the amount of pollution (plausible), then setting the right tax schedule would be much harder.

- For example, if pollution above a certain threshold caused mass extinction but pollution below this level did little harm, this Pigouvian taxation scheme would be *quite* risky. Setting the tax slightly too low would result in calamity.

3.5 Assigning property rights: The Coasean approach

- The Pigouvian tax idea does not really use the Coase theorem. It aligns private and social costs by pricing the social costs, thereby causing firms to internalize these costs. The tax arguably does use property rights—the state is now selling firms the right to pollution at price $\$0.01$ per cubic foot. But the Pigouvian solution does not create conditions for negotiation among firms. The state sets the price and collects the tax.

- The Coase theorem suggests that we may be able to do even better. If property rights are fully assigned, then the regulatory body should not, in theory, have to be involved. Instead, parties will negotiate among themselves to find the lowest cost solution to correcting the externality.

- How can this insight be applied? Because firms do not own pollution rights, there is not the possibility of an efficient negotiation over the how much pollution is generated. This motivates the idea of *allocating pollution rights.*

- Using the algebra above, we can calculate that the 'optimal amount of pollution' is $50^2 + \frac{1}{2}\left(100^2\right) = 7,500$ cubic feet of smog. This is the socially efficient quantity of pollution that results from producing the optimal quantity of fuel.

- Instead of taxing pollution, the government could issue $7,500$ "permits to pollute" one cubic foot each of smog. These permits could be used by the permit holder to pollute, or could be sold by the permit holder to another refinery so it could pollute instead.

- How would this work? Let's consider the case where the government holds an auction to sell these permits, which works as follows:

  - The Environmental Protection Agency (EPA) announces an initial pollution permit price, p_0

- Each of the two firms announces the number of permits it would like to buy at that price, $q_1(p_0), q_2(p_0)$
- The EPA compares the sum of these quantities to the available supply of $7,500$.
- If the quantity demanded is less than $7,500$, the EPA lowers the price
- If the quantity demanded is above $7,500$, the EPA raises the price
- The EPA solicits a new set of demands
- This process repeats until the EPA has established the market clearing price p^*. At this price, there is no excess demand or supply of permits.

- How much would each plant wish to bid at any price p_0? We can calculate this as follows for each plant:

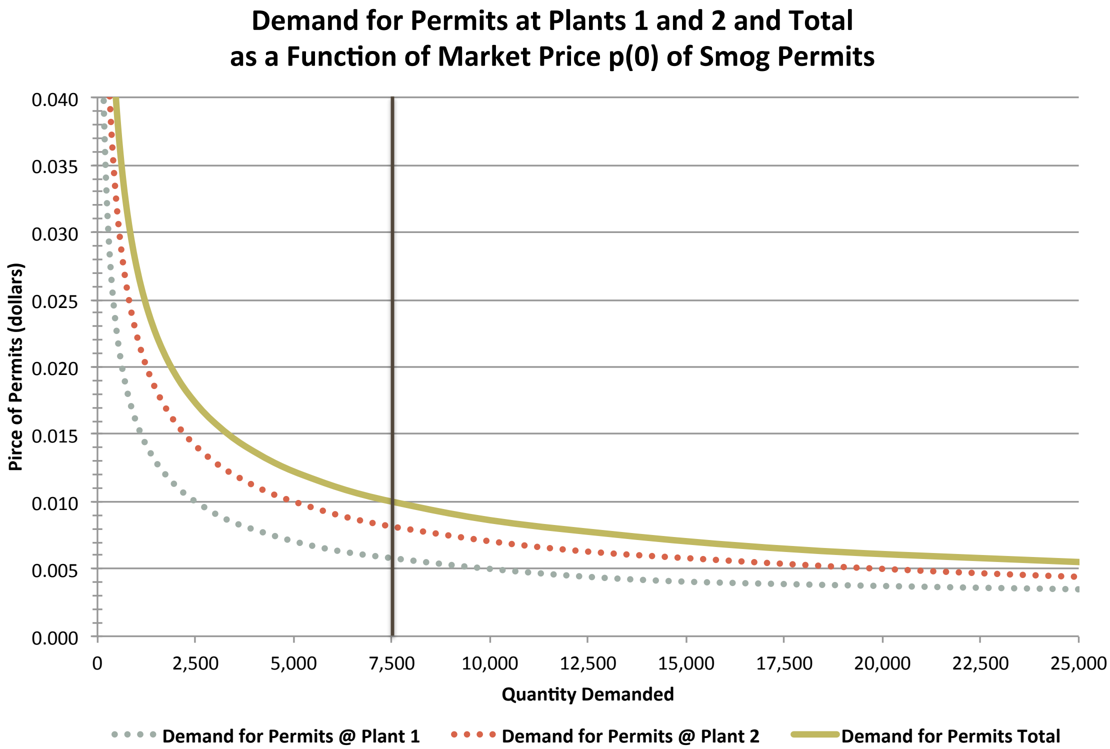
$$\max_{s_1} \pi_1 = s_1^{\frac{1}{2}}(3-2) - p_0 s_1$$
$$s_1^* = \left(\frac{1}{2p_0}\right)^2$$

and

$$\max_{s_2} \pi_2 = (2s_2)^{\frac{1}{2}}(3-2) - p_0 s_2$$
$$s_2^* = \left(\frac{1}{\sqrt{2}p_0}\right)^2$$

[Notice that in setting up these maximization problems, we've rewritten output of fuel in terms of smog permits used. Thus, for plant one $q_1 = s_1^{\frac{1}{2}}$, and for plant two $q_2 = 2s_2^{\frac{1}{2}}$. Thus, each firm chooses the quantity of permits s to purchase as a function of p_0 taking as given that the market price of output minus (non-pollution) inputs is $\$1$ per gallon.]

- We can then plot demand for permits as a function of price $s(p_0) = \left(\frac{1}{2p_0}\right)^2 + \left(\frac{1}{\sqrt{2}p_0}\right)^2$:



- Notice that the market clearing price is \$0.01.

Now let's say the EPA gives the permits to one plant or the other and then lets it trade with the other plant:

1. The permits are all given to Plant 2, the more efficient refinery. It could do the following:

   - Produce 122.4 gallons of fuel (pollution is $\frac{1}{2} \cdot 122.4^2 \simeq 7,500$). Its profits would be \$122.40.
   - Produce 100 gallons of fuel (pollution is $\frac{1}{2} \cdot 100^2 = 5000$) and sell its 2,500 remaining permits to Plant 1 at the market price. With these 2,500 permits, Plant 1 could produce 50 gallons of fuel (pollution will be $50^2 = 2,500$). Since its profits are \$1 per gallon, it would pay up to \$50 for these permits. *Plant 2 would therefore make \$150 in profits by using 5,000 permits and selling 2,500 others.*
   - Plant 2 could also implement any mixture of these two options, including selling all of its permits to Plant 1. But you should be able to demonstrate to yourself that Plant 2 cannot do better than the 2nd option above.

2. Now, instead, assume the permits are given to Plant 1, the less efficient refinery. It could do the following:

   - Produce 86.6 gallons of fuel (pollution is $86.6^2 \simeq 7,500$). Its profits are \$86.60.

  - Sell all of the permits to Plant 2, the more efficient plant. Plant 2 will pay up to $1 per gallon produced. Hence, Plant 1's profits would be $122.4 dollars.
  - It could keep 2, 500 permits and sell 5, 000 to Plant 2. *Here profits would be $150 because Plant 1 would produce 50 gallons and Plant 2 would produce 100 gallons and pay up to $100 for the privilege.*

- The key result: regardless of which plant receives the permits, the main economic outcomes are the same: fuel produced, pollution produced, *and* (surprisingly) the allocation of production of pollution (and fuel) across plants (though clearly not the allocaiton of profits across plants!).

- Why does this equivalence of real economic outcomes (production, pollution) hold? Once pollution property rights are assigned, the plants negotiate to achieve the most efficient solution to the externality. What differs between the two allocations is which plant makes the profits (a transfer among plant owners).

- This cap and trade example demonstrates the power of the Coase theorem. By assigning property rights to pollution, the government allows the market to correct the externality.

- And as the Coase theorem indicates, the exact distribution of property rights to interested parties (Plant 1 or Plant 2) has no effect on economic efficiency. But it does greatly affect the distribution of profits across the two plants (or their owners). This allocation problem is a major political stumbling block to implementing cap and trade regulations generally: how should lawmakers assign the initial ownership rights to pollution (or other negative externalities)?

- One subtlety to bear in mind: The Coase theorem does *not* predict that all economic outcomes will be identical regardless of who receives the property rights to the externality. It simply says that a Pareto efficient allocation will result if these property rights are assigned and bargaining is costless. Think of assigning property rights as moving the endowment in the Edgeworth box. We know that wherever the endowment is located, the parties in the box will trade until they reach a point on the contract curve (under the usual assumptions). But we do *not* expect that the equilibrium point reached on the contract curve is independent of the initial endowment. Moving the endowment usually affects the final allocation as well.

4 Comparison of the three methods of abating an externality

- Implemented optimally, these three methods—command and control, Pigouvian taxation, and cap and trade—all produce efficient outcomes. But they are not identical from a regulatory perspective.

- Command and control regulation requires intimate knowledge of the production structure of each plant. It is cumbersome to implement and to get right. Sometimes it is not feasible or legal to regulate firm's behavior at the plant level, which leads to further inefficiencies.

- The Pigouvian taxation has the advantage that plants will optimally choose the level of pollution that maximizes their profits, including the cost of the Pigouvian tax. However, it requires knowledge of the marginal social cost of pollution.

- Pigouvian taxes are risky when the marginal social cost of pollution varies with the quantity (e.g., carbon monoxide emissions are pretty harmless until they cross a certain threshold, then they are extremely dangerous). In these cases, it is difficult and possibly risky to attempt to set the tax exactly right.

- Cap and trade regulation has the following virtues:

  1. Like command and control, it allows the regulator to set the amount of pollution to whatever level is desirable (the Pigouvian tax will not do this unless the regulator knows the cost structure exactly).
  2. Like the Pigouvian tax, cap and trade is comparatively simple to implement since the regulator does not need to write a separate law for each plant.
  3. Unlike other mechanisms, cap and trade causes firms to optimally reallocate pollution among themselves through trade (as the Coase theorem predicts). Even if the regulator does not know firms' cost structures, the cap and trade system will cause the least polluting firms to do the majority of the production since its cost of production is lowest. Under cap and trade, it's conceivable that one firm would pay all others not to pollute simply because it was the lowest cost polluter at all relevant output levels.

- If the regulator cares specifically about *which* plant does the polluting, however, cap and trade will not generally achieve the desired result. This case might be relevant if introduction of a cap and trade rule caused substantial geographic concentration of pollution (let's say all the low-cost polluters in the U.S. just happen to be located in Kendall Square).

Summarizing

- Externalities are a source of economic inefficiency. But they are also potentially correctable through the market.

- The Coase theorem identifies the two conditions needed for an efficient market solution: complete property rights and zero (or low) transaction costs.

- Sometimes these conditions can be approximated by assigning property rights, thereby creating a market for the externality.

- Understanding why externalities persist in equilibrium comes down to identifying why the Coase theorem does *not* hold in a specific circumstance.

- Rectifying the externality often means finding a way to restore market conditions so the Coase theorem will hold. When that isn't feasible, external quantity regulation (like command and control regulation) may be needed.

Some history on cap and trade regulation

Cap and trade was an idea that came directly from the Coase Theorem. It took three decades to move from theory to policy, and it was largely a success in the one case where it was implemented at scale in the U.S.

The first major use of cap and trade as a regulatory scheme was introduced with the U.S. Clean Air Act Amendments of 1990 (CAAA). The CAAA created a market for Sulfur Dioxide (SO_2) permits that utilities could trade among themselves. To regulators' surprise, SO_2 emissions under the CAAA fell to a far greater extent and at a far lower cost than anyone had expected.

Why were the gains so much larger than anticipated? One reason is that under the prior 'command and control' regulatory regime, firms had an incentive to overstate their costs of abating the externality so that regulators wouldn't set q at a low threshold. Under the cap and trade system, firms faced the incentive to buy permits only until the marginal permit cost equalled their marginal cost of abatement. Implicitly, the market revealed that the marginal costs of abatement were lower than what firms had told regulators. (This is frequently an advantage of a Coasean solution to an externality: minimal information requirements. The Coasean solution usually creates an incentives for parties to implicitly reveal their true costs.)

This was not the only reason, however: deregulation of the U.S. railroads during the same era led to a huge reduction in interstate transportation costs. This made it economical for power producers to purchase low sulfur coal that was mined in the Powder River Basin in southeast Montana and northeast Wyoming. While PRB coal has the advantage of low sulfur content, it is the major coal source in the U.S. that is furthest from most U.S. coal-fired power plants, which primarily lie alongside or east of the Mississippi River. This coincidental change in policy (reducing freight costs) may have been just as important as the cap and trade system in reducing SO_2 output.

A second irony of the SO_2 program is that most of the benefits came about because of an unintended consequence of the program. While SO_2 trading under the CAAA was intended to reduce acid rain, it turns out that the ecological benefits were relatively small because it takes much longer than was initially thought to reverse the acidification of ecosystems. At the same time, an unanticipated benefit of the program was massive: the human health benefits of reduced levels of airborne fine sulfate particles less than 2.5 micrometers in diameter (PM2.5) derived from SO2 emissions. Epidemiological evidence of the harmful human health effects of these fine particulates mounted rapidly in the decade *after* the CAAA was enacted. Recent estimates have pegged annual benefits of the CAAA at between \$59 and \$116 billion, compared with annual costs of \$0.5 to \$2 billion. More than 95 percent of these benefits are associated with improved human health from reductions in airborne fine particulates.[3]

[3] Schmalensee, Richard and Robert N. Stavins. 2013. "The SO_2 Allowance Trading System: The Ironic History of

A final irony is that following the successful national experiment with pollution markets, U.S. politics on pollution abatement have strayed further and further from economics. While cap and trade regulation was initially embraced by mainstream Republicans as a free market solution to a problem that Democrats had traditionally sought to address using command-and-control regulation (recall that the SO_2 trading program was enacted in 1990 under the Republican George H.W. Bush administration), more recent generations of "free market" conservatives have denounced cap and trade regulations as a harmful "tax" on economic activity.

5 Externalities in General Equilibrium: The Smoky Edgeworth Box

Externalities are naturally a general equilibrium (GE) problem because they are fundamentally about individuals facing the "wrong" prices for their actions. It is therefore useful to view to the subject of externalities through the lens of the GE model.

Consider the case of Ed and Fiona, whose utility is defined over two 'goods,' beans and tobacco smoke.[4] Both Ed and Fiona like beans. Ed likes to smoke and has an unlimited supply of free tobacco. Fiona hates smoke. Ed's smoking poses an externality on Fiona. So, tobacco is a 'good' for Ed and a 'bad' for Fiona.

We can represent their utility functions as:

$$U^E(S, B_E),$$
$$U^F(S, B_F).$$

The set of feasible allocations (S, B_E, B_F) are those that satisfy

$$B_E + B_F = W_E + W_F,$$

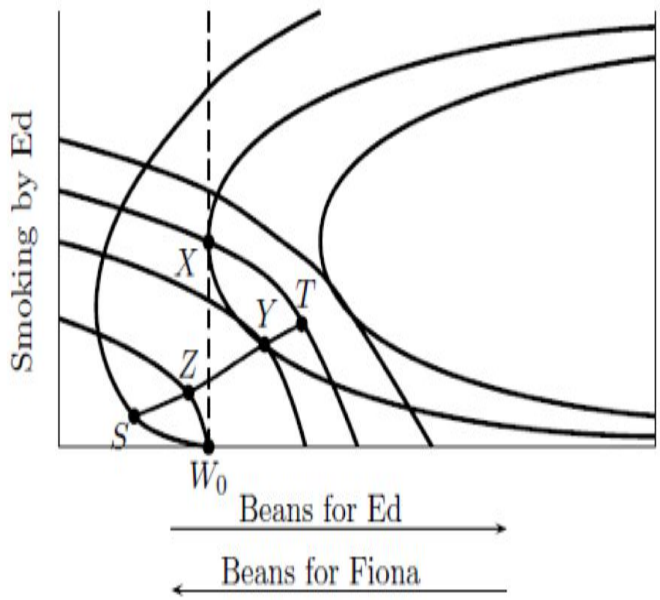
where W_i is the wealth of i measured in terms of the numeraire good. In this case, there is only one such good, Beans. We can normalize its price at $1.$

To represent the exchange possibilities for Ed and Fiona, Bergstrom proposes an Edgeworth Box where the $x-$axis ('floor') represents beans and the $y-$axis represents smoking. This special Edgeworth box lacks a roof because Ed has an inexhaustible supply of tobacco. The diagram below from Bergstrom shows the feasible allocations:

a Grand Policy Experiment," *Journal of Economic Perspectives*, 27(1), Winter, 103–121.

[4] The notes below draw on the lecture on externalities by Theodore Bergstrom (also on Canvas), which provide a novel representation of externalities in the Edgeworth box. I've not seen this tool used elsewhere, so I credit Prof. Bergstrom.

Figure 5.1: A One-Sided Externality



Let W_0 equal the initial endowment. Ed's indifference curves start on the lower-left and his utility increases as we move northeast. Fiona's indifference curves start from the upper-right and her utility increases as we move southwest.

If there were only one good in this economy (beans), there would be no gains from trade; any initial allocation of beans would be Pareto efficient, and could not be improved upon through decentralized trade (that is, there are no gains from trade to be achieved by Ed and Fiona exchanging beans for beans).

5.1 Equilibrium with externalities

Consider what occurs with two goods (Beans and Smoke), one of which is non-priced. Assume initially that Ed can smoke as much as he desires and Fiona has no mechanism to prevent him from doing so. Starting from W_0, how much will Ed smoke?

Implicitly, his budget set is the vertical line emanating from point W_0. That is, for any endowment of beans, Ed can choose $S \geq 0$ to maximize his utility. (Notice by the way that Ed's indifference curves exhibit near-satiation in smoking; beyond a certain amount of smoke, his marginal willingness to trade for beans is near-infinite. He probably starts to feel sick when he smokes too much). If so, he will choose point X, which corresponds to the highest attainable indifference curve on his budget set.

Notice that Fiona is strictly worse off at point (W_0, X) than she would be at $(W_0, 0)$. To see this, note that her indifference curve that passes through (W_0, X) is closer to the origin of her indifference map than is the indifference curve passing through $(W_0, 0)$.

Is the equilibrium of (W_0, X) Pareto efficient? Clearly not. Ed and Fiona's indifference curves are not tangent at (W_0, X), which suggests there might be gains from trade. In particular, we can draw a lens downward from point X (encompassing points T and Y), and each of these points in the lens will be Pareto improving relative to (W_0, X). Consider the contract curve that includes the points T and Y. If Ed and Fiona can trade from point (W_0, X), they will reach one of the points on the CC. (Observe also that Fiona is *worse* off at the equilibrium X than she was at the initial endowment W_0. This should not occur in competitive equilibrium *unless* there is a market failure.)

5.2 What's the problem?

Why are they not reaching a point on the CC initially? The answer is that, unlike for beans, there are no property rights assigned to smoking. This absence of property rights is represented in the box by the absence of a roof, implying that the total allocation is not closed. Fiona could 'buy' some smoke from Ed but he could simply produce more, so this wouldn't be meaningful. It's not the unboundedness per se that's problematic (for example, Fiona could be given the right to enjoying smoke-free air); it's that without a clear definition of property rights, the allocation of smoke between Ed and Fiona is not subject to trade within the Edgeworth economy.

5.3 Property rights to Ed

Let's give Ed the right to smoke as much as he likes, while allowing Fiona to buy from Ed the right to clean air. This means essentially that Fiona will be paying to close the box. Where will they end up?

Absent compensation from Fiona, Ed would choose point X. Thus, giving ownership of the right to smoke to Ed implicitly sets the initial endowment at X units of smoke for Ed, while giving Fiona the right to *not* experience *more than* X units of smoke. Any final allocation must leave Ed weakly better off than he is at point X, and similarly for Fiona. Clearly, if they trade beans and smoke starting from this new endowment, now with well defined property rights, they will end up somewhere on the CC along the locus YT. At this equilibrium point, Fiona will have beans than at W_0 and also less smoke than at X. And Ed will obtain more beans and less smoke.

Notice that when Fiona 'consumes' smoke, she consumes it by *not* allowing it to be generated. Thus, the $y-$axis in the figure has the unusual interpretation that as we move Northward, both Fiona and Ed consume more smoke, and as we move Southward, both consume less. But since Ed values smoke and Fiona values *non-smoke*, a Northward movement makes Ed better off and Fiona worse off, and vice versa for Southward. This is identical to a standard Edgeworth diagram in which a Northward movement denotes a transfer of the $y-$axis good from the top-right party (here, Fiona) to the bottom-left party (here, Ed).

5.4 Property rights to Fiona

Let's say instead that we gave the right to a smoke free environment to Fiona. This means that the allocation is initially $(W_0, 0)$, where Fiona owns all smoking rights and can trade them with Ed for beans if she chooses to do so. From this point, the feasible points on the contract curve lie along the locus SZ.

Notice that some smoking occurs regardless of who gets the initial property rights (Ed or Fiona) and that the final allocation is Pareto efficient—implying that the externality has been internalized. But of course, the initial allocation has a large effect on the welfare of each party. Ed has more smoke and more beans in the first case, and Fiona has more non-smoke and more beans in the latter case.

5.5 What about the Coase theorem?

You may be wondering: doesn't the Coase theorem say that the amount of smoke produced should be invariant to whom we give the property rights? If so, we are in trouble, because clearly, less smoking occurs in the second case than the first. (Thinking back to the example of the baker and the doctor, the amount spent on noise abatement was independent of whether the baker was given the right to make noise or the doctor the right to experience quiet.)

Actually, the Coase theorem does *not* say that the quantity of the externality-generating activity will be invariant to who receives the property right (though this may often be true). What it says is that if there are no bargaining costs, any complete allocation of property rights will lead to a Pareto efficient solution. Both of the cases above *are* Pareto efficient. They differ, however, in the amount of smoke produced/consumed in equilibrium for a subtle but important reason: income effects.

When Ed receives the property rights, he's much richer and Fiona much poorer than the case when Fiona gets the property right. Assuming that both beans and smoke (or non-smoke for Fiona) are normal goods, we'd expect Fiona to buy fewer beans *and* endure more smoke when she's poor than when she's rich. Similarly for Ed, we'd expect him to consume more beans *and* pay Fiona to endure more smoke in the case where he's relatively wealthy than where he's relatively poor. And this pattern is exactly what we see by comparing the loci YT with SZ. Along SZ, Fiona consumes more beans and endures less smoke than long YT. Hence, the Coase theorem *does* hold in this example. But its application is subtle. Because of income effects in consumption, transfer of property rights in this example *does* affect the amount of the externality generating activity performed. In either case, however, the outcome is Pareto efficient

One important difference between producers and consumers in economic theory is that producers do not have income effects in their utility functions. More precisely, producers have profit functions not utility functions, and profit is only defined in one unit (money), which has no taste component. Thus, if we consider an example like the Ed-Fiona problem above where producers rather than consumers trade in an externality-producing good, we conjecture that the *amount* of smoke will be invariant to the allocation of pollution rights (as will Pareto efficiency). By contrast, for Ed and Fiona, we have established that Pareto efficiency is invariant to the allocation of property rights, but the quantity of smoke is not.

6 The Coase theorem in U.S. history: Barbed wire, property rights, and agricultural development (Hornbeck, 2010)

The 2010 paper by Rick Hornbeck presents an ingenious application of economic theory to economic history. English common law made livestock owners responsible for damages done by roaming livestock. In effect, the common law assigned herders the responsibility to either fence in their livestock or compensate farmers for the damage the livestock did.

In contrast, the American colonies adopted legal codes that required farmers to fence out others' livestock. Without a "lawful fence," farmers had no formal entitlement to compensation for damages by others' livestock. As new states joined the Union, the legal codes they adopted continued to require that farmers fence out livestock, and gave technical specifications for what constituted a lawful fence. Fundamentally, farmers did not own the right to *not* have their crops grazed by errant cattle unless they built fencing. Instead, cattle herders owned the right to graze on unfenced farmlands.

Absent fencing or legal protection, farm crops were vulnerable to grazing by livestock. Grazing would reduce farmers' return on planting crops, which would in turn reduce the incentive for farmers to "improve land" (irrigate, desalinate, fertilize, control erosion, build access roads) for planting. Thus, absent fencing, farm productivity to be depressed for two reasons: (a) non-improved land is less productive than improved land; and (b) freely grazing cattle consume significant shares of what was planted.

6.1 Applying the Coase Theorem

- Reasoning from the Coase theorem, would we expect the production of crops and amount of cattle grazing in the U.S. to be efficient?

- Not necessarily. Although property rights were arguably complete, transactions costs were extremely high. A farmer could not plausibly negotiate with each cattle owner whose livestock might wander onto his or her land. This meant that there was no low cost mechanism available for cattle-owners and farmers to negotiate, which meant that the there was not an efficient market mechanism for correcting these externalities. Yes, farmers had an incentive to fence in their property to avoid errant cattle. But it's not clear that this solution was first best efficient. In some cases, the efficient solution might have been for farmers to pay cattle owners to restrict their cattle's mobility (if transactions costs didn't prevent this).

- These issues would be unimportant if the cost of fencing were negligible. But it was not. *In 1872, the value of fencing capital stock in the United States was roughly equal to the value of all livestock, the national debt, or the railroads. Annual fencing repair costs were greater than combined annual tax receipts at all levels of government.*

- Moreover, fencing became increasingly costly as settlement moved into areas with little woodland. An 1871 guide for immigrants focused on three main characteristics of farmland in Plains counties: its price, the amount of timber available, and the amount of land fenced. Farmers mainly adjusted to fencing material availability by settling in areas with nearby timber plots.

- Under these circumstances, the invention of barbed wire was revolutionary—like cell phones for Indian fisherman in Kerala. Barbed wire offered a cheap substitute for lumber in areas without nearby timber stocks. The most practical and ultimately successful design for barbed wire was patented in 1874 by Joseph Glidden, a farmer in DeKalb, Illinois. Glidden's design had three important characteristics: (1) barbs prevented cattle from breaking the fence; (2) twisted wires tolerated temperature changes; and (3) the design was easy to manufacture.

6.2 Hornbeck's research idea

- The ingenious idea of Rick Hornbeck's 2010 paper is to use the introduction of barbed wire to measure how a reduction in the cost of securing property rights affects agricultural investment and productivity. The introduction of barbed wire serves as a natural experiment for analyzing how the falling cost of property protection in timber-scarce relative to timber-rich areas affected agricultural investment and productivity during the period 1880-1900. As Hornbeck writes:

  > "A decrease in the price of barbed wire will decrease the marginal cost of protection more in counties with less woodland and higher timber prices. Once the price of barbed wire declines sufficiently that timber is no longer used, further price declines have no differential effect across counties with different woodland levels. Thus, barbed wire especially reduces the cost of protection in timber-scarce areas during the period from its widespread introduction (1880–1900) until its universal adoption. If protection directly encourages investment, then investment should increase during this time period and especially in timber-scarce areas."

- The simple theoretical model in the paper makes three predictions:

  1. The optimal choice of investment in land to produce agricultural goods is increasing in the level of protection (i.e., fencing or other barriers) because a greater proportion of the marginal return to that investment will be kept.
  2. The optimal choice of protection is increasing in the level of land investment (that is, land improvement) because total output is greater. That is, if you're going to be investing in the land, it becomes more valuable to protect the land.
  3. Higher land quality directly increases both investment and protection by raising the marginal return to investment and total output.

- A key implication of this model is that if land investment increases when the marginal cost of protection falls (i.e., due to the introduction of barbed wire fencing), then investment will rise when barbed wire becomes cheap and widely available. This is they key implication that Hornbeck will test.

6.3 Empirical approach

- Hornbeck's empirical approach is to group U.S. counties into three woodland categories: low (0%–4%), medium (4%–8%), and high (8%–12%).
- The "low" counties are roughly those most constrained by timber scarcity, whereas "medium" counties could partially adjust to woodland scarcity by efficient landholding, and those above this threshold ("high counties") would have abundant woodland resources. Thus, we expect scarce and medium woodland counties to differentially benefit from the introduction of barbed wire fencing relative to counties with abundant woodland.
- The empirical analysis focuses on three main land-use outcomes:
  1. The fraction of county land used for farming
  2. The fraction of county land that is improved
  3. The fraction of land in farms that is improved.
- The fraction of county land in farms represents the extensive margin of settlement, which reflects farmers' expected returns to converting land from the public domain.
- The fraction of farmland improved represents the intensive margin, which reflects farmers' willingness to fix investments in land.
- Improved land is "all land regularly tilled or mowed, land in pasture which has been cleared or tilled, land lying fallow, land in nurseries, gardens, vineyards, and orchards, and land occupied by farm buildings" as reported in the 1880 - 1900 U.S. Agricultural Censuses.

6.4 Results

- Tables and figures will be discussed in class.
- From 1880 to 1890, average crop productivity increased relatively by 23% in counties with the least woodland, controlling for crop-specific differences among counties and crop-specific statewide shocks. The increased productivity was entirely among crops more susceptible to damage from roaming livestock, as opposed to hay. Farmers shifted the allocation of farmland toward crops and, in particular, crops more at risk.
- Agricultural development increased along intensive margins (a larger fraction of farmland was improved), even as counties with the least woodland expanded along the extensive margin of total farmland settled.

- There were substantial and robust increases in total improved land, combining both intensive and extensive margins.

- Increases in agricultural development were capitalized in higher land values, totaling among sample counties roughly 0.9% of national GDP.

6.5 Interpretation of Hornbeck's results (it's subtle)

There is little question from these results that the introduction of barbed wire fencing increased agricultural investment and productivity in low woodland areas of the U.S., substantially increasing land values in these locations.

A harder question is what these results tell us about economic efficiency in farming and cattle grazing *prior to* the invention of inexpensive barbed wire. Property rights *were* clearly defined prior to barbed wire, so the first condition of the Coase Theorem was satisfied. The question is whether we should think of the introduction of barbed wire as primarily reducing transactions costs or primarily reducing abatement costs. We'll use the following stylized example to clarify thinking.

A stylized example

- In a low woodland area, the profit a farmer makes is $\pi_{NG} = 100$ if the farmland is not grazed by cattle and $\pi_G = 50$ if it is grazed by cattle.

- The cost of building a wood timber fence for the farmer is $C_A^W = 60$, where the A subscript denotes the cost of abatement and W indicates wood fencing.

- We see that it would not be profitable for the farmer to build the fence since $\pi_{NG} - \pi_G < C_A^W$.

- Let's say that when barbed wire is introduced, the cost of abatement falls to $C_A^B = 20$, where the B superscript indicates barbed wire.

- Now it will be profitable to abate since $\pi_{NG} - \pi_G > C_A^B$. Agricultural output will rise by 50 and net profits will rise by $\Delta\pi = 30$ (the rise in output minus the cost of the fence). Clearly, the introduction of barbed wire benefits the farmer.

- Let's further assume that fencing has no adverse effect on cattle owners. There is enough open land that fencing a portion of it has a negligible impact on the cattle's food supply. This means that the net gain in profits for the farmer is also equal to the social gain.

Was the initial equilibrium (prior to barbed wire) inefficient?

- The fact that farm production and investment rose after the introduction of barbed wire indicates that cattle *were* grazing on farmlands. Farmers had not negotiated a deal with cattle owners to restrict their grazing on farmlands.

- Why didn't they? There are two major potential explanations. One is that the cost of negotiations was prohibitive—that is, transaction costs were too high. Another possibility (and these are not mutually exclusive) is that the cost to cattle grazers of policing their cattle so that they didn't roam on unfenced land was simply too high to allow for a Pareto improving bargain. It's not implausible that these monitoring costs were in fact high since cattle owners couldn't readily implant their cows with GPS tracking devices.

- To take the next step in determining the efficiency of the initial equilibrium, three additional parameters will come into play:

  1. The cost to cattle owners of abating the externality by restricting their herds' grazing areas C_A^{NG}.
  2. The transaction costs in negotiating a bargain between farmers and cattle herders C_T.
  3. The profits that cattle owners make from their livestock π_C.

- These parameters give rise to three interesting cases

Inefficient coexistence

- Let's say that $\pi_C = 40$. That is, the profits that cattle herders earn from their herding is less than the *harm* they do to farmers, i.e., since $\pi_G - \pi_{NG} = -50$.

- In this case, it was clearly inefficient for cattle to graze on unfenced farmland since it would have been efficient for farmers to pay cattle herders to shut down their operations.

- The fact that cattle were herded and grazed on unfenced farmland (which Hornbeck's results establish) implies that transaction costs *must* have been too high to prevent an efficient deal, that is $C_T > 50$.

- You ask: what if the cost of abatement for herders C_A^{NG} was quite high (say 60)? That's not actually relevant here. Herders could simply have accepted payment of 40 to shut down.

- Thus, in this case, the introduction of barbed wire fencing would have corrected an inefficiency stemming from high transaction costs.

- While this case seems unlikely—i.e, that it was inefficient for farming and cattle grazing to coexist absent barbed wire fencing—it is quite plausible that transactions costs for reaching a deal were prohibitively high. Cattle could range great distances. And large herds were moved across the great plains annually seeking (at various times) grazing areas and markets for final sale. (That was what "cowboys" did for a living.) It would be difficult for a farmer to negotiate with all potential herders who might ultimately wander on her land.

Inefficient herding

- Let's say instead that $\pi_C = 100$, so the profits from grazing exceed the amount of the externality (i.e., the net social benefit of grazing is positive). This implies that, at a minimum, both farming and grazing should coexist.

- Now, assume that $C_A^{NG} = 25$, that is, herders could keep their herds off of non-fenced land at a cost of 25. In this case, in a transactions cost-free world, farmers would pay herders 25 to restrict grazing. Farmer profits would be $\pi_{NG} - C_A^{NG} = 75$ and herder profits would be $\pi_C - C_A^{NG} + C_A^{NG} = 100$, and total social surplus would be 175.

- This is preferable to the case in which farmers and herders do *not* strike a deal since social surplus in that case is $\pi_G + \pi_C = 150$.

- If farmer and herders do not strike a deal despite these potential gains from trade, we would infer that $C_T > 25$. That is, the combination of abatement costs for herders and transaction costs from negotiating a deal exceeded the potential gains from trade: $C_T + C_A^{NG} > (\pi_{NG} - \pi_G)$.

- In this case, the introduction of barbed wire fencing *also* corrects an inefficiency stemming from high transaction costs.

Efficient coexistence

- Let's finally consider a case where $\pi_C = 100$ as above and $C_A^{NG} > 50$. Here, the cost of abating the externality for herders exceeds the benefits to farmers.

- In this case, the potential transactions costs that would be involved in striking a deal are not relevant because there is no efficient deal to be struck. The initial equilibrium was efficient given the available abatement technologies, *even if* transaction costs were prohibitive.

- Here, the introduction of barbed wire also improves welfare but it does *not* correct an initial inefficiency. Although the externality was present initially, the parties could not have improved on the initial allocation even with full property rights and zero transaction costs.

Summary

- These cases (and some others) are summarized in the table below. Try to work through the reasoning for each of the parameters.

Conclusion: Which case accurately depicts history?

- The short answer is that we don't know.

- It seems very likely that transactions costs were *too high* for parties to have struck an efficient bargain if one were available.

Table 1: Efficiency of Herding

π_C	c_A	c_A^{NG}	c_T	**Efficient outcome**	**Farmer's condition for a deal**	**Herder's condition for a deal**	**Result**
40	60 (wooden fence)	Very high	>10	Herder shuts down the operation, farmer farms in a non-grazed farm	$\pi_{NG} - P - c_T > \pi_G$ $\Longleftrightarrow P < 50 - c_T$	(If deal, herder shuts down the operation and gets P) $P > \pi_C$ $\Longleftrightarrow P > 40$	Since $c_T > 10$, there is no deal: *Inefficient coexistence*
100		25	>25	Herder invests in abatement, farmer farms in a non-grazed farm	$\pi_{NG} - P - c_T > \pi_G$ $\Longleftrightarrow P < 50 - c_T$	(If deal, herder invests in abatement and gets P) $\pi_C + P - c_A^{NG} > \pi_C$ $\Longleftrightarrow P > 25$	Since $c_T > 25$, there is no deal: *Inefficient herding*
100		>50	0	No abatement, farmer farms in a grazed farm	$\pi_{NG} - P - c_T > \pi_G$ $\Longleftrightarrow P < 50$	(If deal, herder invests in abatement and gets P) $\pi_C + P - c_A^{NG} > \pi_C$ $\Longleftrightarrow P > c_A^{NG}$	Since $c_A^{NG} > 50$, there is no deal: *Efficient coexistence (without abatement)*
40	20 (barbed wire)	Very high	>10	Farmer invests in abatement, farmer farms in a non-grazed farm	Any deal requires: $P > min\,\{\pi_C, c_A^{NG}\} > c_A = 20$. Knowing this, the farmer will not attempt to deal, and simply invest in the barbed wire.		*Efficiency with abatement*
100		25	>25				
100		>50	0				

- But even if transactions costs were zero, it's quite possible that the costs to cattle herders of restricting their herds was sufficiently high that farmers would have been unwilling to pay them to do so (that is, the costs would have exceeded the benefits).
- In that case: (a) the initial equilibrium was efficient; and (b) a property allocation that gave farmers the right *not* to have their fields grazed would have been inefficient (assuming transaction costs prevented farmers selling those rights to herders).
- In summary, the Hornbeck paper provides a superb illustration of how externalities affect production. It does not tell us whether the introduction of barbed wire corrected an initial market inefficiency or simply moved the equilibrium from one efficient point to a new, superior point that was unavailable prior to this technological innovation.