14.121 Lecture 5: Externalities

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September 2019

Externalities

Externality: whenever well-being of a consumer or production possibilities of a firm are **directly** affected by the actions of another agent in the economy.

The caveat of directly affected is important because everybody's actions impact everybody else through the price system.

Price-related effects are known as **pecuniary externalities** (Viner 1931) and these have no implications for government intervention.

Externalities can go from producers to consumers, consumers to consumers and producers to producers. They can be negative or positive.

When externalities are present, market failure may arise and this may necessitate government intervention.

The topic of externalities could merit an entire course.

Our plan:

1) Outline a simple model with an externality to illustrate why they cause market failure
2) Discuss the Coase Theorem
3) Discuss the difference between price and quantity regulations to deal with externalities
4) Discuss a particular class of externality problems arising from common property resources

Simple Model of Externalities

Can set this up in many ways (producer-producer, producer-consumer, etc.); lessons will be similar. We will follow MWG 11.

Consider two agents indexed by $i = 1, 2$ who constitute a small-part of economy (so they do not effect prices). Each has wealth w_i.

Suppose there are L traded goods: $(x_{1i}, ..., x_{Li})$.

Consumer 1 takes some action $h \in \mathbb{R}_+$ which effects utility of consumer 2.

h can be

- how loudly consumer 1 plays music
- how much pollution consumer 1 puts into the river

Assume quasi-linear utility with indirect utilities:

$$v_i(p, w_i, h) = \phi_i(h) + w_i$$

where we suppress dependence on p. Assume ϕ twice differentiable and $\phi_i''(\cdot) \leq 0$.

We refer to an **allocation** as $((\mathbf{x}_i)_{i=1,2}, h)$.

At a **competitive equilibrium** (or Walrasian) with prices p, each of the two consumers maximizes her utility given prices and wealth.

Consumer 1 chooses $h \geq 0$ to maximize $\phi_1(h)$. This equilibrium level satisfies

$$\phi_1'(h^*) \leq 0, \quad (= \text{ if } h^* > 0)$$

A **Pareto optimal** allocation is an allocation such that there is no other allocation such that one of the consumers is made strictly better off without hurting the other consumer.

At a PO allocation, it must be impossible to re-allocate wealth so as to make one consumer off without making the other worse off.

Let T be a re-allocation of wealth from consumer 1 to 2. If h^{PO} is the Pareto optimal level of h, then it must be that when $T = 0$ and $h = h^{PO}$ we have a solution of the following:

$$\max_{h,T} \phi_1(h) + w_1 - T \quad \text{s.t.} \quad \phi_2(h) + w_2 + T \geq \bar{u}_2$$

The constraint must hold with equality (if not, we could lower T to improve the value of the program), so substituting for T:

$$\max_{h} \phi_1(h) + w_1 + \phi_2(h) + w_2 - \bar{u}_2$$

or

$$\max_{h} \phi_1(h) + \phi_2(h).$$

The Pareto optimal allocation must maximize the joint surplus of the two consumers:

$$\phi_1'(h^{PO}) \leq -\phi_2'(h^{PO}), \quad (= \text{if } h^{PO} > 0)$$

Optimality does not mean the externality is eliminated. Rather, the externality's level is adjusted to the point that the marginal benefit of an extra unit of the externality ($\phi_1'(h^{PO})$) to consumer 1 is equal to the marginal cost to the consumer 2, $-\phi_2'(h^{PO})$

Assume an interior solution to these two both programs:

$$\phi_1'(h^*) = 0$$
$$\phi_1'(h^{PO}) = -\phi_2'(h^{PO})$$

If there are no external effects, then $\phi_2'(h) = 0$ for all h. Thus, $\phi_1'(h^{PO}) = 0$. So $h^{PO} = h^*$ and the Pareto optimal level of h is the same as the competitive equilibrium.

Otherwise, $\phi_2'(h) \neq 0$. There are two cases.

1) Negative externality $\phi_2'(\cdot) < 0$

$$\phi_1'(h^{PO}) = -\phi_2'(h^{PO}) > 0$$

$\phi_1'(\cdot)$ decreasing, and $\phi_1'(h^*) = 0 \Rightarrow h^* > h^{PO}$

2) Positive externality $\phi_2'(\cdot) > 0$

$$\phi_1'(h^{PO}) = -\phi_2'(h^{PO}) < 0 \quad \Rightarrow h^* < h^{PO}$$

In either case, the competitive provision of h is not equal to the Pareto optimal level $\Rightarrow$ market failure.

Government Intervention

The government can restore efficiency. We investigate two policy instruments i) impose a quota or ii) a tax.

Suppose we are in case 1 (negative externality), so $h^{PO} < h^*$.

Quota: government mandates that h be no larger than h^{PO}. With this constraint, consumer 1 has no choice but to fix the level of the externality at h^{PO}.

Taxes: government can either tax consumer 1 on each unit of h or subsidize the reduction of h.

Suppose consumer 1 made to pay a tax of t_h per unit on h.

The maximization problem in the competitive program is:

$$\max_h \phi_1(h) - t_h \cdot h$$

If $t_h = -\phi_2'(h^{PO}) > 0$, then the competitive equilibrium level of h is

$$\phi_1'(h) = t_h,$$

or

$$\phi_1'(h) = -\phi_2'(h^{PO}),$$

and we know that $h = h^{PO}$ satisfies this condition.

This type of tax is known as a **Pigouvian corrective tax.**

The optimality-restoring tax is the **marginal externality** at the optimal solution.

It equals the amount that consumer 2 would be willing to pay to reduce h slightly from its optimal level h^{PO}.

Consumer 1 **internalizes** the externality that she imposes on consumer 2.

With a positive externality, the per-unit tax that consumer 1 pays simply becomes a per-unit subsidy that consumer 1 receives, instead.

Taxation vs. Subsidizing reduction + lump sum transfer

If government pays a subsidy of $s_h = -\phi_2'(h^{PO}) > 0$ for each unit that consumer 1's choice of h is below h^*, then the maximization problem is

$$\max_h \phi_1(h) + s_h(h^* - h)$$

Subsidy can be thought of as a tax per unit of s_h per unit plus a lump-sum transfer of $s_h h^*$.

Direct vs. indirect taxation

If h=pollution, if we tax output of plant, rather than pollution itself, this will not in general restore optimality. In special case, where there is a monotonic relationship between two, a tax on output is essentially equivalent to tax on emissions.

Information requirements

Government intervention in form of quota or tax requires lots of information about benefits and costs of externality. Breaks down without this information.

Coase Theorem

Coase pointed out that the externality problem fundamentally arose from two factors:

i) lack of clearly specified property rights, and
ii) transactions costs.

To illustrate his point, suppose that we assigned the right to an externality-free environment to consumer 2, so that consumer 1 is unable to engage in externality-producing activity without permission from consumer 2.

Imagine that consumer 2 makes a take-it-or-leave-it offer demanding payment T in exchange for permission to use h.

Consumer 1 agrees iff

$$\phi_1(h) - T \geq \phi_1(0).$$

Thus, consumer 2 choose her offer (h, T) to solve

$$\max_{h,T} \phi_2(h) + T \quad \text{s. t.} \quad \phi_1(h) - T \geq \phi_1(0).$$

Constraint must be binding, so $T = \phi_1(h) - \phi_1(0)$.

Plugging in:

$$\max_{h} \phi_2(h) + \phi_1(h) - \phi_1(0),$$

which yields the socially optima level.

Imagine instead that consumer 1 has the right to generate as much of the externality as he wants.

Consumer 2 will have to pay consumer 1 to have a level less than h^*.

To get externality level h, consumer 1 will agree if and only if $\phi_1(h) - T \geq \phi_1(h^*)$

So the problem is

$$\max_{h,T} \phi_2(h) + T = \max_{h} \phi_2(h) + \phi_1(h) - \phi_1(h^*),$$

which generates the optimal level of the externality.

In first case, consumer 1 pays $\phi_1(h^{PO}) - \phi_1(0) > 0$ to be allowed to set h^{PO}.

In second case, consumer 1 "pays" $\phi_1(h^{PO}) - \phi_1(h^*) < 0$ in return for setting h^{PO}.

The same conclusion emerges - the negotiated level of h would be efficient.

Theorem (Coase)

If property rights are clearly specified and there are no transaction costs, bargaining will lead to an efficient outcome no matter how the rights are allocated.

The allocation of rights has distributional consequences, but no efficiency consequences.

The allocation of rights is crucial because otherwise the participants would be fighting over who should be paying who. If property rights cannot be enforced, then consumer 1 has no need to purchase the right.

Coasians point to the absence of legal institutions as a central impediment to optimality $\Rightarrow$ starting point for law and economics

Stigler (1988, Memoirs of an Unregulated Economist)

"When, in 1960 Ronald Coase criticized Pigou's theory rather casually, [...], Chicago economists could not understand how so fine an economist as Coase could make so obvious a mistake. Since he persisted, we invited Coase to come and give a talk on it. Some twenty economists from the University of Chicago and Roland Coase assembled one evening at the home of Aaron Director. Ronald asked us to assume, for a time, a world without transaction costs. [...] Ronald asked us also to believe a second proposition about this world without transaction costs: Whatever the assignment of legal liability for damages, or whatever the assignment of legal rights of ownership, the assignments would have no effect upon the way economic resources would be used! We strongly objected to this heresy. Milton Friedman did most of the talking, as usual. He also did much of the thinking, as usual. In the course of two hours of argument the vote went from twenty against and one for Coase to twenty-one for Coase. What an exhilarating event! I lamented afterward that we had not had the clairvoyance to tape it."

On the "Property Rights" Doctrine

Ken Arrow (1979): "The property rights theorists do not usually set out their underlying assumptions with the utmost clarity; but it appears that the basic postulate is the same one that underlies the theory of cooperative games, in the original formulation of von Neumann and Morgenstern. That is, whatever else may be true about the outcome of the bargaining process, it will certainly be Pareto-optimal.

The argument is obvious. Suppose A and B are both possible outcomes of the game, achievable by suitable choices of strategies by the players. Suppose the players can bargain about the choices of strategies, including possible side payments, and every player prefers A to B. Then clearly they will not stop at B, since, if nothing else is achievable, they can all improve by going to A."

Some (in)famous applications of Coase:

- **Lighthouse**: many think they should be publicly provided because their use cannot be restricted; but most 19th century British lighthouses were privately provided and ships were charged
- **Marital relations**: A big changes in divorce laws in 1970s was emergence of no-fault unilateral divorce
  - Under consent divorce, both partners must agree
  - Under unilateral divorce, if only one spouse wants, then there will be a divorce
  - Becker (1981, Treatise on Family) argues that unilateral divorce simply reassigns existing property rights between spouses so law change should not change outcomes
- **Slavery**: Fogel and Engerman (1974) claim that southern slave farms were as productive as free farms; some argue that end of slavery should not boost productivity because only reassigning property rights

Some comments:

- We assumed a particular bargaining solution - take-it-or-leave it. Many other complete information bargaining solutions would generate the same prediction in this problem (eg., alternating offers, cooperative solutions)
- In special case where two parties are firms, another solution to let the two firms merge. The resulting firm would fully internalize the externality when maximizing profits.
- Sometimes we refer to Coase as a **decentralization result** (see, e.g. Farrell JEP 1987).

- What are the transaction costs that Coase had in mind?
  - If large number of citizens impacted by externality, then there will be significant transaction costs to bring everybody to the table and start negotiating.
  - If participants have to pay an ex ante cost in order for an agreement to be reached (such as showing up to a meeting) then this can lead to inefficiencies arising for strategic reasons – see Anderlini and Felli, "Costly Bargaining and Renegotiation" (EMA 2001). In this case an agreement need not be reached even if the surplus created from such an agreement would exceed the negotiation costs.
- Information requirements

  Unlike the tax and quota schemes, Coase's approach only requires that the consumers know each others preferences, and not government.

Information Asymmetries

It is well-known that with bilateral asymmetric information, bargaining will not lead to an efficient outcome (Myerson and Sattherwaite, JET 1983).

To illustrate these difficulties, let us return to our example, but assume that h is a discrete choice $h \in \{0, \bar{h}\}$.

Further assume that

$$\phi_1(h) = \phi_1(h; \theta)$$

and

$$\phi_2(h) = \phi_2(h; \eta)$$

where θ and η are random variables with supports $[\underline{\theta}, \bar{\theta}]$ and $[\underline{\eta}, \bar{\eta}]$.

Define

$$\begin{aligned} b(\theta) &= \phi_1(\bar{h}; \theta) - \phi_1(0; \theta) \\ s(\eta) &= \phi_2(0; \eta) - \phi_2(\bar{h}; \eta) > 0 \end{aligned}$$

Therefore, when $b(\theta) > s(\eta)$, the Pareto optimal level is $\bar{h}$.

Let $G(b)$ and $F(s)$ be the CDFs of the variables b and s induced by the random variables θ and η.

Assume consumer 2 has the right not be infringed by 1's consumption, so that without bargaining the outcome will be $h = 0$. This outcome will be inefficient whenever

$$b(\theta) > s(\eta).$$

Now consider the bargaining problem, where 1 offers 2 a transfer T in exchange for letting him consume $\bar{h}$. Consumer 1 knows b, but does not know s.

Consumer 2 will agree if and only if $T \geq s$. The probability of this is $F(T)$.

Thus, given b, consumer 1 will choose T to solve

$$\max_{T} \quad F(T)(b - T)$$

Note that the objective function takes on value 0 at $T = b$ and is strictly positive at $T \in (s(\underline{\eta}), b)$.

Therefore, the solution to this problem T_b^* is such that $T_b^* > s(\underline{\eta})$ if $s(\underline{\eta}) < b$.

If consumer 2's realization is s, and it turns out that

$$b > s > T_b^*$$

then there will be positive probability of inefficiency, because consumer 2 rejects the offer, even though the efficient externality level is $\bar{h}$.

Anti-Coase Theorem

Proposition (Myerson-Sattherthwaite)

"No bargaining procedure can lead to an efficient outcome for all values of b and s when they are private information and independently distributed."

- Proving this result will be done later in first-year micro; challenge is establishing that we cannot construct any bargaining procedure (or "mechanism"), so we have to search over all possible mechanisms
- Begs the question of whether market economies can generate efficient outcomes, if we think private information pervasive
- Turns out that if we have many players, there is a "bargaining procedure" that will implement an efficient outcome – a **double auction** (Rustichini, Sattherthwaite, and Williams 1994)

Missing Markets

Another reaction attributed to Meade is that if we can define property rights on the externality, why isn't there a market?

Suppose that there is a competitive market for the externality, and let p_h be the price of the right to engage in one unit of the activity. In choosing how many of these rights to purchase, h_1, consumer 1 solves

$$\max_{h_1} \phi_1(h_1) - p_h h_1$$

Consumer 2 decides to sell rights, h_2,

$$\max_{h_2} \phi_1(h_2) + p_h h_2$$

Two first-order conditions are:

$$\phi_1'(h_1) = p_h \qquad \phi_2'(h_2) = -p_h.$$

Since the amount of h bought must equal amount sold, $h_1 = h_2$, and

$$\phi_1'(h^{**}) = -\phi_2'(h^{**}),$$

which is the Pareto optimal level.

Comments:

- Here, market works as a particular bargaining procedure for sharing gains from trade
- Externalities are inherently tied to absence of certain competitive markets
- Idea of a competitive market for externality is sometimes unrealistic (esp treating two agents as price takers), but many barriers are evolving

Price vs. Quantity Regulations

In our simple model of externalities, we saw that government intervention in either the form of a tax or a quota could restore efficiency.

In more realistic models, however, there is a difference between price and quantity regulation.

This was pointed out in a famous article by Weitzman, "Prices vs. Quantities" (RES 1974)

"I think it is a fair generalization to say that the average economist in the Western marginal tradition has at least a vague preference towards indirect control by prices, just as the typical noneconomist leans toward the direct regulation of quantities." (p. 477)

This paper is a classic in the theory of externalities and in environmental economics more generally.

Weitzman's Analysis

The government is concerned with pollution reduction.

Let q denote the amount of pollution reduction.

$C(q)$ is the cost of pollution reduction with $C' > 0$ and $C'' > 0$

$B(q)$ is the benefit of pollution reduction with $B' > 0$ and $B'' < 0$

It is assumed that $B'(0) > C'(0)$ so that some amount of pollution reduction is socially desirable.

Note: this framework is fairly general. With an appropriate redefinition of our earlier problem, we can map to this structure.

The optimal level of pollution reduction is

$$q^* = \arg\max\{B(q) - C(q)\}$$

which implies that $B'(q^*) = C'(q^*)$.

The government can achieve q^* either by

(i) quantity regulation: order firms or industry to do q^* units of reduction

(ii) price regulation: pay firms a price p^* for each unit of reduction undertaken (this price could be avoiding a tax)- firms would then choose q to maximize profits):

$$q = \arg\max\{p^* q - C(q)\}$$

So the government just needs to set the price equal to $p^* = B'(q*)$.

Uncertainty

Suppose now that there is uncertainty in the costs and benefits of pollution reduction so that the benefits are $B(q, \theta)$ and the costs are $C(q, \eta)$, where θ and η are realization of independent random variables.

If the government could observe the realizations of θ and η, then it could achieve the first-best reduction in pollution by either a quantity regulation:

$$q^*(\theta, \eta) = \arg\max\{B(q, \theta) - C(q, \eta)\}.$$

or a price regulation

$$p^*(\theta, \eta) = \frac{\partial B(q^*(\theta, \eta), \theta)}{\partial q} = \frac{\partial C(q^*(\theta, \eta), \theta)}{\partial q}.$$

This would be the **first-best** solution.

In reality, however, the government is unlikely to be able to condition policy on the realizations of these shocks.

As a step towards more realism, suppose the government must commit in advance to a required level of pollution reduction q or a price p, knowing only the distributions of θ and η.

In this case, the **optimal quantity** of pollution reduction is

$$q^* = \arg\max E[B(q, \theta) - C(q, \eta)]$$

so the FOC is

$$E\left[\frac{\partial B(q^*, \theta)}{\partial q}\right] = E\left[\frac{\partial C(q^*, \eta)}{\partial q}\right]$$

How about **optimal price** regulation? Given the price regulation p, firms will maximize profits:

$$\hat{q}(p, \eta) = \arg\max_q \{pq - C(q, \eta)\}$$

so the FOC is:

$$p = \frac{\partial C(\hat{q}(p, \eta), \eta)}{\partial q}$$

Then, the optimal price regulation takes firm behavior as given:

$$p^* = \arg\max E[B(\hat{q}(p, \eta), \theta) - C(\hat{q}(p, \eta), \eta)]$$

Note in general it is not going to be the case that

$$\frac{\partial B(q^*, \theta)}{\partial q} = \frac{\partial C(q^*, \eta)}{\partial q}$$

nor is it the case that

$$\frac{\partial B(\hat{q}, \theta)}{\partial q} = \frac{\partial C(\hat{q}, \eta)}{\partial q}.$$

We are in the world of **second-best** and the question is which policy instrument is better.

Define the advantage of price over quantity regulation as:

$$\Delta = E[\{B(\hat{q}(p^*, \eta), \theta) - C(\hat{q}(p^*, \eta), \eta)\} - \{B(q^*, \theta) - C(q^*, \eta)\}]$$

Weitzman assumes the following functional forms for benefits and costs in a neighborhood of q^*:

$$B(q, \theta) = b(\theta) + (B' + \beta(\theta))(q - q^*) + \frac{B''}{2}(q - q^*)^2$$
$$C(q, \eta) = a(\eta) + (C' + \alpha(\eta))(q - q^*) + \frac{C''}{2}(q - q^*)^2$$
$$E[\beta(\theta)] = E[\alpha(\eta)] = 0$$

These can be justified as second order Taylor approximations around the point q^*

With this simplification, Weitzman is able to show that:

Proposition (Weitzman)

The benefit of price regulation over quantity regulation (Δ) is

$$\Delta = \frac{\sigma^2}{2(C'')^2}[B'' + C''] = (+)[(-) + (+)]$$

where

$$\begin{aligned} \sigma^2 &= E[\alpha(\eta)] \\ &= E[\left\{ \frac{\partial C(q^*, \eta)}{\partial q} - E[\frac{\partial C(q^*, \eta)}{\partial q}] \right\}^2] \\ &= \text{ variance of MC at } q^* \end{aligned}$$

This means that price regulation is better than quantity regulation ($\Delta > 0$) if and only if $C'' > |B''|$.

What determines whether $|B''|$ is greater than $|C''|$?

We might expect $|B''|$ is large when we are dealing with pollution with **threshold effects**; i.e. there is some critical level of pollution above which things can get pretty bad, but below things are ok. This would be a case for quantity regulation.

Weitzman's analysis assumes that there is uncertainty. The next generation of analysis looks at what happens when the regulated firm can control the costs with a hidden action (i.e. moral hazard), or there is hidden information (i.e. adverse selection).

Baron and Myerson (1982) initiated this branch of literature; see Laffont and Tirole (1993) for a summary.

All of the analysis on prices vs. quantities analysis assumes perfect enforcement. Becker and Stigler (1974) pointed out that it is important to analyze the costs and incentives of the enforcers of laws.

Common Property Externalities

This type of externality arises whenever there is a commonly owned resource. i.e. fish in the ocean, forests in developing countries.

This is still quite an active area. See for instance Michael Kremer's paper on Elephants (AER 2000). A classic reference is Dasgupta and Heal, Economic Theory and Exhaustible Resources (1979).

Sometimes called the **problem of the commons**, or tragedy of the commons.

Model:

- infinite number of potential fisherman
- each fisherman operates one boat at cost w
- total catch with b boats is $y(s, b)$, where s is the total stock of fish

$$y(s,0) = 0, \frac{\partial y}{\partial s} > 0, \frac{\partial y}{\partial b} > 0, \frac{\partial^2 y}{\partial b^2} < 0$$

- per boat catch is $y(s, b)/b$

  Assume that the per boat catch decreases with number of boats:

$$\frac{\partial}{\partial b}\left(\frac{y(s,b)}{b}\right) < 0$$

  This implies that the marginal is less than the average:

$$\frac{\partial y}{\partial b} < \frac{y}{b}$$

- $x(p)$ is the aggregate demand for fish with inverse $p(x)$

Optimal Number of Boats

The optimal number of boats maximizes aggregate surplus, which is consumer surplus plus fisherman surplus.

$$\max_b \int_0^{y(s,b)} p(x)dx - wb$$

With FOC,

$$p(y(s,b^o))\frac{\partial y}{\partial b}(s,b^o) = w$$

Social marginal benefit of boats is equalized with the social marginal cost.

Equilibrium Number of Boats

An equilibrium is a price of fish, p^*, and a number of boats, b^*, such that demand equals supply of fish and fisherman make zero profits (free-access).

i) $x(p^*) = y(s, b^*)$ $(\Leftrightarrow p^* = p(y(s, b^*)))$

ii) $p^* \left(\frac{y(s,b^*)}{b^*}\right) = w$

In a **free access equilibrium**, each fisherman's catch per boat times the price must equal the cost of operating the boat:

$$p(y(s, b^*))\frac{y(s, b^*)}{b^*} = w.$$

Since average product exceed marginal product, i.e. $y(s, b)/b > \frac{\partial y(s,b)}{\partial b}$,

$$p(y(s, b^*))\frac{\partial y(s, b^*)}{\partial b} < w.$$

So $b^* > b^0$ and there are too many boats.