I Social Choice: How much environmental protection?

A Utility

Recall that environmental protection costs resources. How are we to decide how much resources to allocate to environmental protection and how much to allocate to other goods? We start by treating environmental protection much like any other good.

Let x be a set of goods and e be the quality of the environment. A CONSUMPTION BUNDLE or ALLOCATION is a set (x, e).

Just like we get enjoyment or utility from conventional goods, we get utility from a clean environment. Let $u_i(x, e)$ denote the utility person i gets from the allocation (x, e).

1 Utility value of environmental goods

The reasons people get utility from a clean environment vary from person to person and include:

1. HEALTH BENEFITS of clean air and water. These include lower incidences of asthma, bronchitis, lung cancer cholera, etc.

2. USE VALUE. Enjoyment from visiting or viewing a clean environment. This includes things like whale watching, fishing, or simply looking out your window and not seeing smog.

3. EXISTENCE VALUE. Utility achieved without using the environment in any material way. Like a car that has a top speed of 200 mph, we value some things because they are there, even if we do not plan to use them.

4. ALTRUISM: we care that someone else has a good environment. $u_i(x, e) = u_i(x, u_j(e))$.

5. PRODUCTIVITY VALUE: A clean environment makes producing non-environmental goods easier. Climate change matters almost exclusively to the extent that it causes production losses. For example, CO_2 emissions raise temperatures which cause crop losses in agriculture, and damage to industries such skiing. $u_i(x, e) = u_i(x(e))$.

So we need to think carefully in each context about what e represents. The "consumption" of e could be "healthiness," which declines with pollution, or e could be "fishing," which declines with mercury emissions, or e could be the knowledge that the Arctic wildlife refuge is pristine.

In addition, we can switch our thinking:

- GOODS: consumption of a good gives utility.
- BADS: consumption of a bad lowers utility.

It makes no difference whether we think of clean water as the good or mercury emissions as a bad. We will use whichever is easier, but here e is the good.

2 Indifference Curves

Recall INDIFFERENCE CURVES represent different allocations which give the same utility. If $u(x, e) = u(x', e') = u$, then both allocations lie on the same indifference curves:

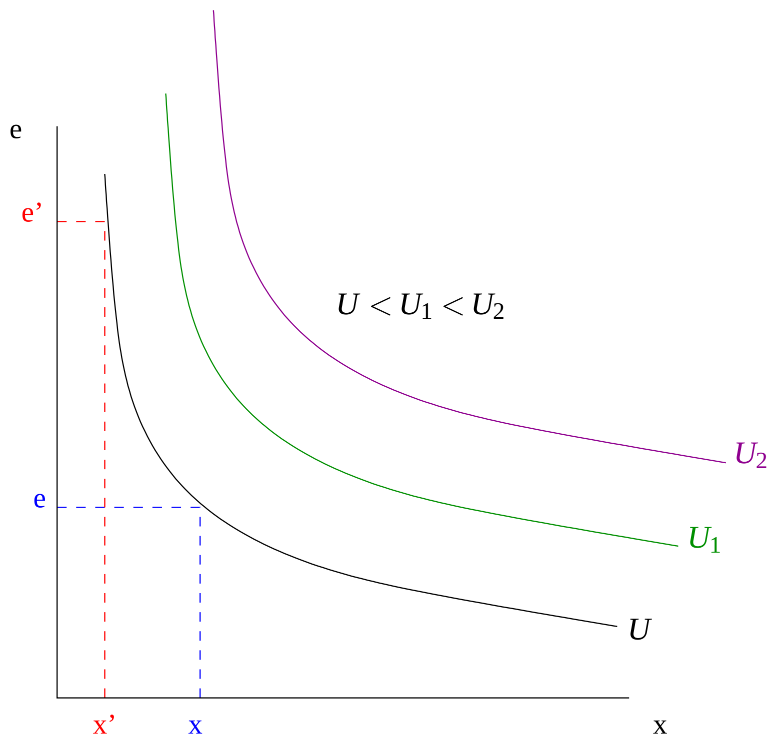

Figure 7: Indifference Curves.

Notice utility increases as we move either up or to the right. More goods implies higher utility. Notice also I have drawn convex indifference curves. This results from diminishing returns. If we have already many televisions then we do not value additional televisions very much. If an allocation has many televisions and a poor environment, then to we can get the same utility by giving up a television for a very small improvement in the environment.

3 Social Choice Set

The choice set are all feasible allocations. The allocation defines consumption for all persons: $x = x_1, x_2, ...$, with associate utilities $u_1(x_1, e), u_2(x_2, e), ...$ Then the SOCIAL CHOICE SET are all feasible utilities:

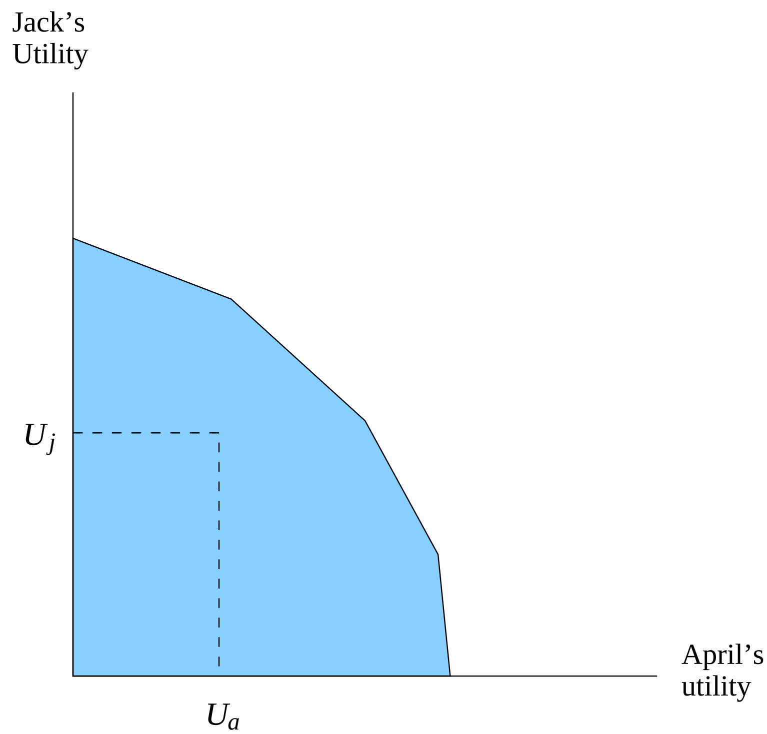

Figure 8: Social choice set.

Suppose we can achieve any of these utilities in the shaded region of Figure 8. Which should society choose?

B Pareto Criterion

Definition 4 *Let $a = (x, e)$ and $a' = (x', e')$. Then a' is PARETO PREFERRED to a if, for every individual i, $u_i(a') \geq u_i(a)$ with $u_j(a') > u_j(a)$ for at least one individual j.*

The Pareto criterion is a minimum standard for social choice. If we can come up with an allocation a' that makes at least one person better off without making anyone worse off than another allocation a, then we should choose a'. In Figure 9 We should choose D over B and A. However, we cannot compare C with A, B, or D as they all have April better off but Jack worse off.

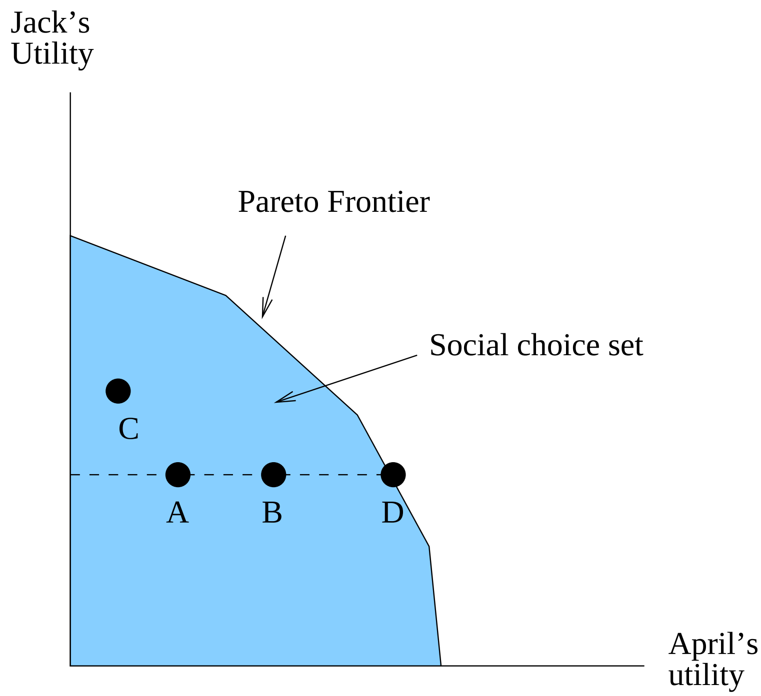

Figure 9: Indifference Curves.

We can say that no allocation is Pareto preferred to D. Any movement down and to the right from D makes Jack worse off, while any movement above and to the left makes April worse off.

Definition 5 *The PARETO FRONTIER or CONTRACT CURVE consists of all allocations for which no Pareto preferred allocations exist.*

Definition 6 *An allocation is EFFICIENT or PARETO OPTIMAL if the allocation is on the Pareto frontier.*

A choice on the Pareto frontier is a minimum criteria for optimality. An election between B and D would produce a unanimous vote for D. The allocation is efficient in the sense that no wasted utility exists.

Obviously, few environmental policies receive unanimous votes. But many times, side payments can be used to ensure no one is worse off. Think of one of the x goods as money.

Suppose we are at B and that April prefers a cleaner environment at the expense of less goods, but Jack does not care at all about the environment. Then we may be able to move to the frontier by reducing the number goods produced and increasing the quality of the environment, by transferring some money from April to Jack. Think of the cap-and-trade bill in Congress which allocates many permits to industry. These payoffs help move the bill toward unanimity while still reducing emissions.

C Social welfare function

Can we go further and establish a stronger optimality criterion that rules out some Pareto optimal allocations which do not seem like good choices (for example, Jack gets everything and April nothing)? Not easily. Anything else requires us to weight individuals (for example Jack's utility counts twice as much as April's), something that is uncomfortable. Even if we weight people equally (majority rule), then a policy that a minority dislikes immensely may pass. Hence we will stick to Pareto optimality as our definition of the optimal choice.

II Efficiency of the Market Economy

Our goal is to determine under what conditions (if any) the market economy is efficient: under what conditions does the equilibrium market economy have the property that no person or group can be made strictly better off without making someone else worse off? If the market economy is not efficient, then we have a justification for government regulation (if the government can fix the inefficiency).

Three types of inefficiencies may exist in a market economy.

1. INEFFICIENCY IN EXCHANGE: Some goods could be traded between groups or individuals to produce a Pareto preferred allocation.

2. INEFFICIENCY OF PRODUCTION INPUTS: Some production inputs could be moved between firms so as to produce more of a good.

3. INEFFICIENCY OF PRODUCTION OUTPUTS: Some inputs could be moved between firms or between production of different types of goods so as to produce more of one good without producing less of another good.

A Efficiency of Exchange

Figure 7 shows that utility is increasing as we move either up or to the right since more goods implies higher utility. Suppose now we add another individual for which zero consumption is in the upper right corner.

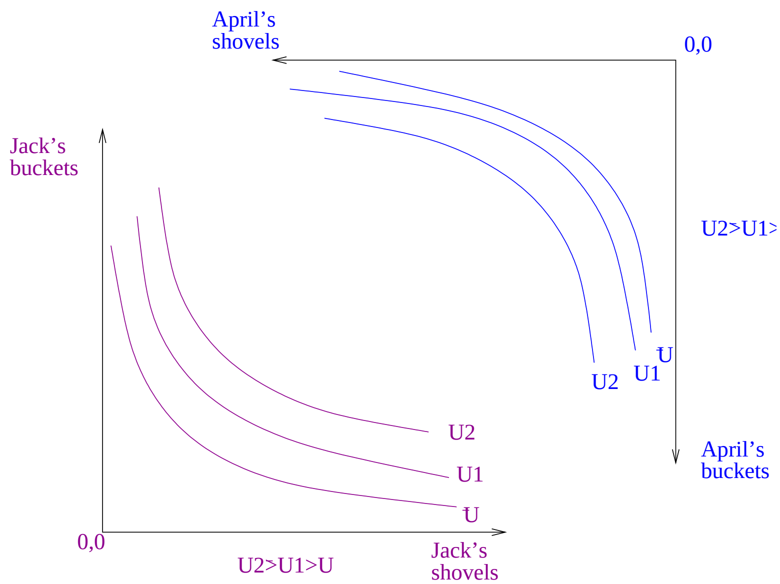

Figure 10: Edgeworth Box: indifference curves for two individuals.

Figure 11 connects the axes so as to make an Edgeworth box.

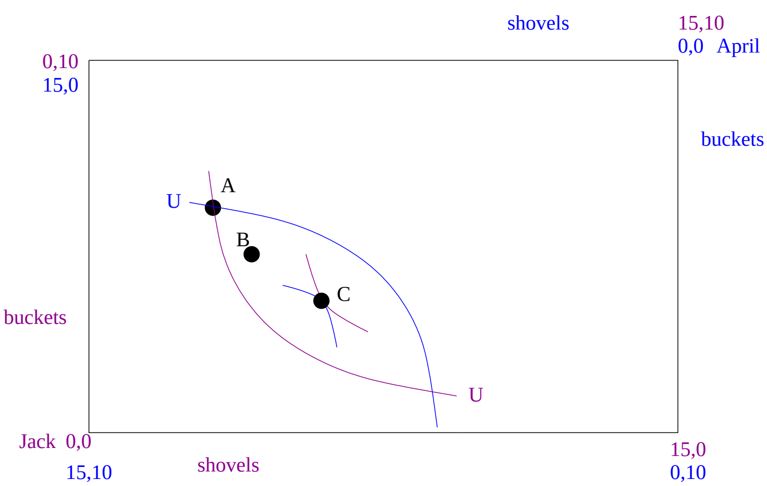

Figure 11: Edgeworth Box: tangent indifference curves indicates efficiency.

Consider any fixed amount of goods, say 15 shovels and 10 buckets. Then any point inside the box is a feasible allocation. Now consider any allocation, say point A on Figure

11. This point gives Jack lots of buckets but few shovels and vice versa for April. Now point A cannot be efficient. Any point between the two indifference curves gives higher utility to both Jack and April. All points between the indifference curves move shovels, which give little utility to April, to Jack and buckets, which give little utility to Jack, to April.

At point C the indifference curves are tangent, so there is no area between the indifference curves. Thus C is efficient. Recall that "April gets everything," is also efficient and the same for Jack. Thus the contract curve is the dotted line in Figure 12:

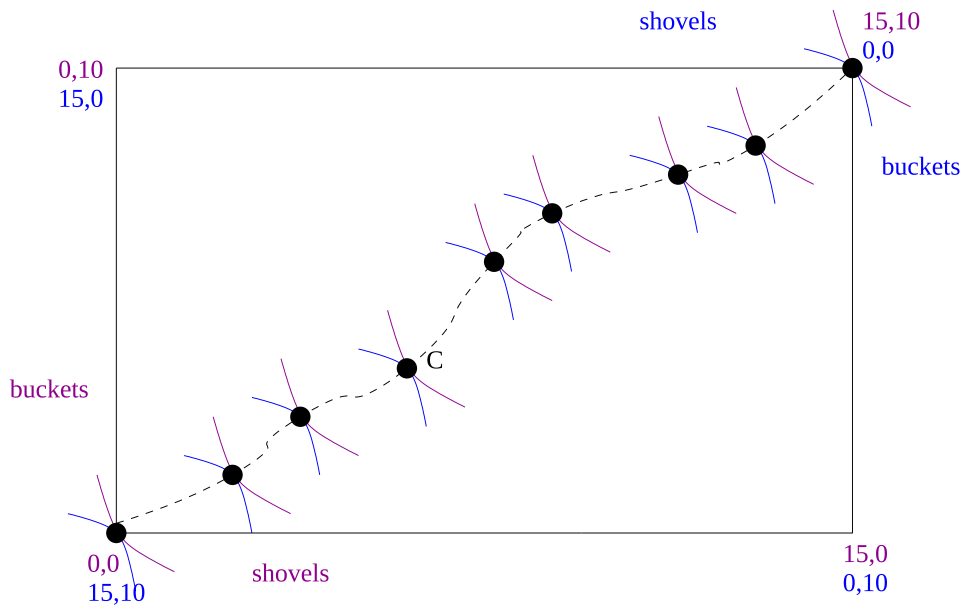

Figure 12: Pareto frontier or contract curve.

B Exchange and the Market Economy

Here we suppose production is complete. The only question is how to allocate the goods we have produced. Let us create a market economy in which we only look at exchange, not how goods are produced. In a market economy, markets and prices exist for each good and households take the prices as given. Notice that it is the price system which is central to a market economy.

Suppose we have an initial allocation corresponding to point A on Figure 11. Let b_0 and s_0 be Jack's initial allocation. Suppose Jack and April can supply and/or demand shovels and buckets in their respective markets. Suppose Jack sells all his buckets and shovels. His income is $p_b b_0 + p_s s_0$. Now suppose Jack buys buckets and shovels with his income. His purchases are $p_b b + p_s s$, where b and s are his final allocations. Thus, Jack's budget constraint is:

$$p_b b + p_s s = p_b b_0 + p_s s_0 \tag{1}$$

Clearly keeping a shovel is equivalent to selling a shovel and then buying it back. Therefore, we have not restricted Jack's options and the initial endowment satisfies the budget constraint. Rearranging gives:

$$b = \frac{p_b b_0 + p_s s_0}{p_b} - \frac{p_s}{p_b} s \tag{2}$$

Now the slope of Jack's budget line is negative and indicates how many buckets must be given up to get a shovel. To get an idea of the *willingness* of Jack to give up buckets for shovels we use:

Definition 7 *The* Marginal Rate of Substitution*, MRS_{xy} indicates how many units of y the consumer is willing to give up to get one unit of x.*

The MRS is the slope of the indifference curve. Looking at Figure 13 point A, Jack has lots of buckets so he is willing to give up many buckets for a shovel (MRS_{sb}^J is large, where s is shovels and b is buckets). The slope of the indifference curve is steep. But because the price ratio is less steep, he does not have to give up that many buckets to get a shovel. He can give up fewer, and have some income left over. Thus, given the price ratio, Jack will buy more shovels than he sells and increase utility until the MRS equals the price ratio at point C. Of course April faces the same prices, and thus the same slope of the budget constraint, which also goes through point A. So she will be selling shovels and buying buckets until we reach point C.

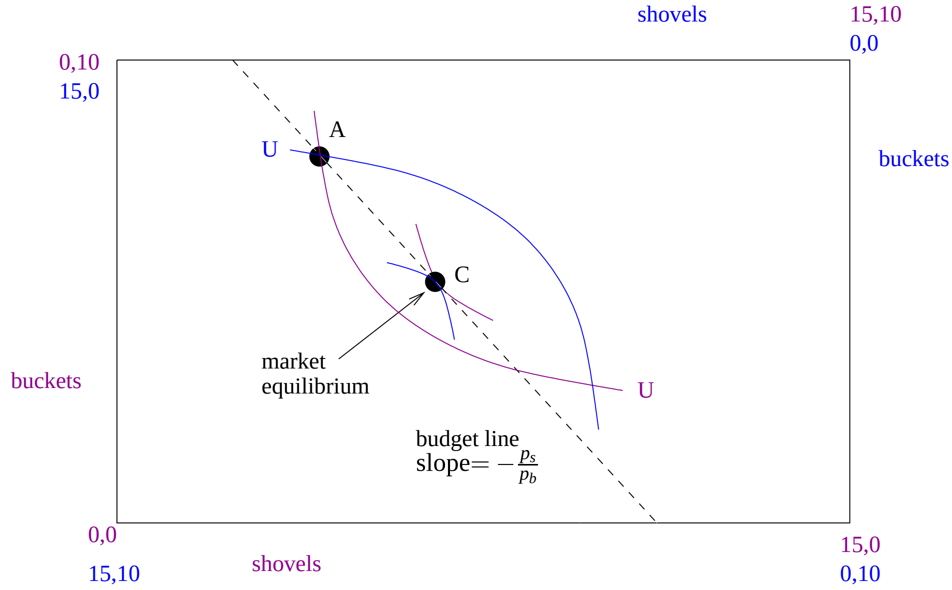

Figure 13: The market equilibrium produces efficiency of exchange.

Thus we can say that the market economy produces efficiency of exchange, with the MRS equal to the price ratio for all households. Which point on the contract curve we end up at depends on the initial endowments.

C Efficiency of Production Inputs

Now suppose we consider production of buckets and shovels, produced from inputs capital and labor. We would like to allocate labor and capital across firms so as to produce as much as possible.

An ISOQUANT represents all points which give the same production. These curves are convex because of diminishing returns: with a lot of capital and few workers many machines are needed to produced the same output as a single worker. The isoquant curves are increasing since more inputs means more production.

The firms costs are:

$$C = rK + wL, \tag{3}$$

where K is capital, r is the interest rate, w is the wage, and L is labor. Therefore:

$$K = \frac{C}{r} - \frac{w}{r}L. \tag{4}$$

An ISOCOST line gives all combinations of K and L with the same cost C. The isocost line is also downward sloping.

Definition 8 *The* Marginal Rate of Technical Substitution, $MRTS_{xy}$ *measures how much of* y *must be added to replace one unit of* x *while keeping production constant.*

The $MRTS_{LK}$ gives the amount capital can be reduced when we add one unit of labor so as to keep overall production constant. In point A of Figure 14, we see that Firm 1's MRTS exceeds the input price ratio.

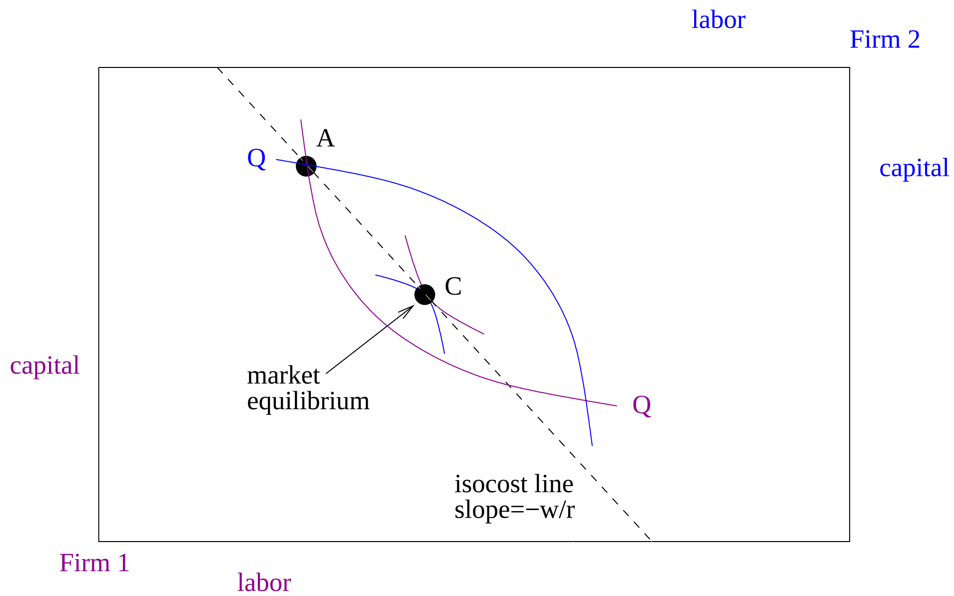

Figure 14: The market equilibrium produces efficiency of input usage.

The firm is using too much capital and not enough labor. By increasing labor by one unit and decreasing capital by w/r, the firm keeps costs the same, yet produces more output. Since profits rise, the firm will reduce capital until the MRTS and the price ratio are equal (point C). Since all firms face the same isocost curve slope, all firms will have identical MRTS.

Any point which does not have the MRTS equal to the input price ratio for all firms contains an inefficiency: more goods could be produced with the same inputs. At point A, more goods could be produced by moving capital from firm one to firm two, and the reverse for labor.

Thus the market economy attains efficiency in production inputs.

D Efficiency of Production Outputs

Here we decide what to produce. The PRODUCTION POSSIBILITIES FRONTIER represents all possible combinations of goods produced such that we cannot produce more of one good without producing less of another. Figure 15 shows the frontier. By moving from A to B we can produce more shovels without reducing bucket production. The slope of the production possibilities frontier is the MARGINAL RATE OF TRANSFORMATION (MRT).

Definition 9 *The* Marginal Rate of Transformation *(MRT) is the number of units of good y that may be produced if one less unit of good x is produced.*

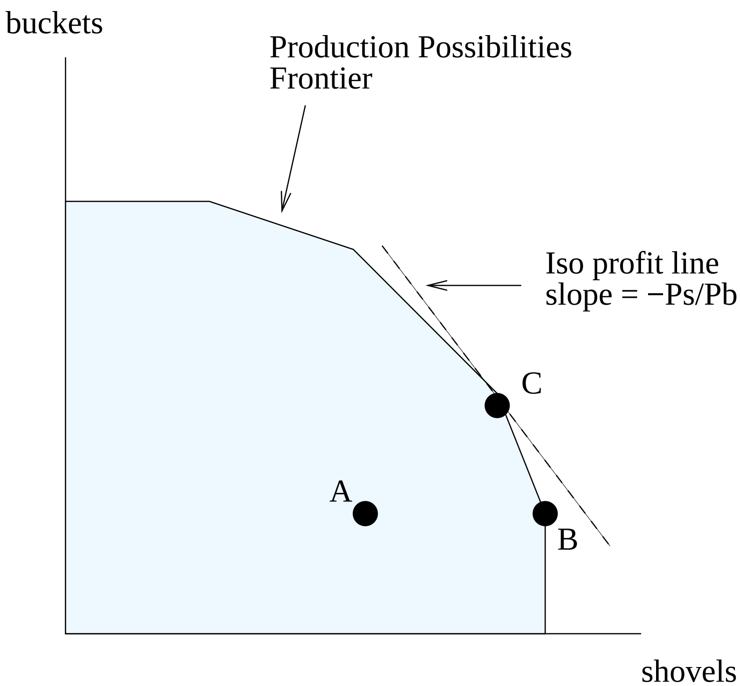

Figure 15: The market equilibrium produces efficiency of input usage.

The ISOPROFIT line represents all sets of goods produced with the same profits:

$$\pi = p_b b + p_s s - C \tag{5}$$

Here π are profits and C are total costs, which are also fixed, since we are just reallocating a fixed amount of capital and labor between the production of different goods.

$$b = \frac{\pi + C}{p_b} - \frac{p_s}{p_b} s \tag{6}$$

In point B of Figure 15, we see that the MRT exceeds the price ratio. The firm could reallocate resources so as to produce more buckets and a few less shovels (point C). Costs would remain unchanged, but revenues would rise, since the price of buckets relative to shovels is high enough.

So the market economy achieves output production efficiency. In fact, since the MRT equals the MRS, we can see that the market economy produces the set of goods that gives the highest utility to consumers.

E Welfare Theorems

We now present the welfare theorems. Under certain conditions outlined below we have these theorems:

THEOREM 1 *FIRST FUNDAMENTAL THEOREM OF WELFARE ECONOMICS: The competitive equilibrium of a market economy is efficient.*

THEOREM 2 *SECOND FUNDAMENTAL THEOREM OF WELFARE ECONOMICS: Any efficient allocation can be achieved by a market economy provided resources are appropriately distributed before the market operates.*

The welfare theorems are the $E = mc^2$ of economics, except far more important. The first theorem we have just proved in a heuristic way: a market economy will have no inefficiencies. We cannot make someone better off without making another worse off. The second theorem notes that if you have a different initial allocation, perhaps somewhere other than point A, you will end up at a different efficient allocation. For example, starting with an initial allocation of Jack has everything, will result in an efficient market equilibrium where Jack continues to have everything.

Assumptions of welfare theorems:

1. COMPLETE MARKETS AND PROPERTY RIGHTS. A well-defined, transferable, and secure property right exists for each good. A market exists to trade the rights to each good. The benefits of each good accrues to the owner of the property right.

2. ATOMISTIC PARTICIPANTS. Producers and consumers are small relative to the market and thus cannot influence prices.

3. COMPLETE INFORMATION. Consumers and producers have equal knowledge of current and future prices.

4. NO TRANSACTION COSTS. It must be costless to price and trade each good.

Consider the market for wheat or most any agricultural commodity. The owner of the wheat can sell it in the spot markets in Chicago. As owner of the wheat, she (and only she) gets all the benefits of eating the wheat if she desires. An individual farmer is very small and has no influence over prices, regardless of how much she sells. The quality of the wheat is known to all potential buyers. Transaction costs are low in the highly liquid spot markets in Chicago.

Now consider the environmental good clean air, which can be consumed by consumers enjoying a view, or by polluters emitting smoke. Clearly no market exists for this good. No price exists that polluters or households must pay. When a polluter uses clean air, all benefits accrue to the polluter, but multiple households can enjoy the clean air without reducing the benefits to others.

The above two examples and the welfare theorems tell us three things:

1. A motivation for government regulation exists for clean air, it does not exist for wheat production (despite the demand for government wheat subsidies).

2. The welfare theorems identify the problem with clean air: it is not priced. Thus, pollution occurs because polluters do not pay enough for, and thus tend to over-use, clean air. Polluters do not pollute because they are immoral.

3. The solution looks relatively simple: just raise the price of clean air somehow until efficiency is achieved.

F Bads

The welfare theorems and results are unchanged for bads, as long as the assumptions of the welfare theorems are not violated. Two differences are that bads have a negative price, since you have to pay someone to accept a bad. In addition, indifference curves and isoquants look different.

Suppose coal fired electricity production is tied to SO_2 emissions. The plants may be located near Jack or April's house, or perhaps some near each. Figure 16 shows that Jack and April's utility are increasing in electricity, but decreasing in SO_2. The MRS is positive: increasing Jack's SO_2 means that electricity must also increase to keep utility from falling.

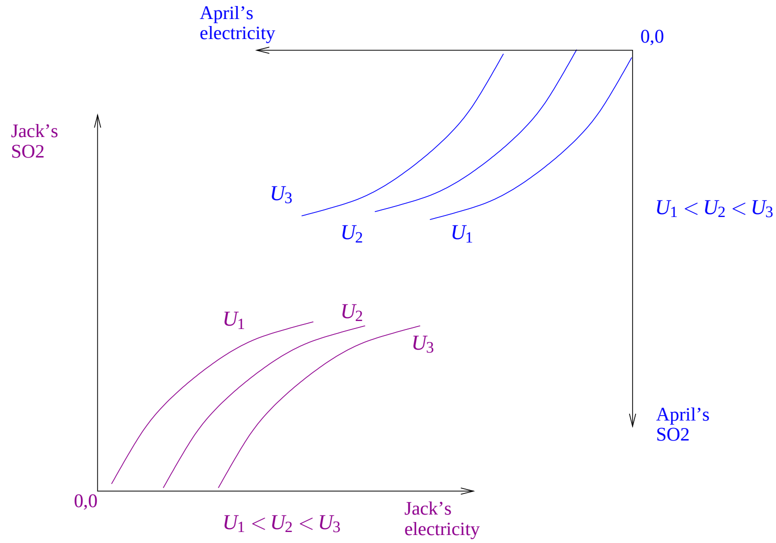

Figure 16: Edgeworth Box with a bad.

Efficiency of exchange still results with the MRS equal to the price ratio:

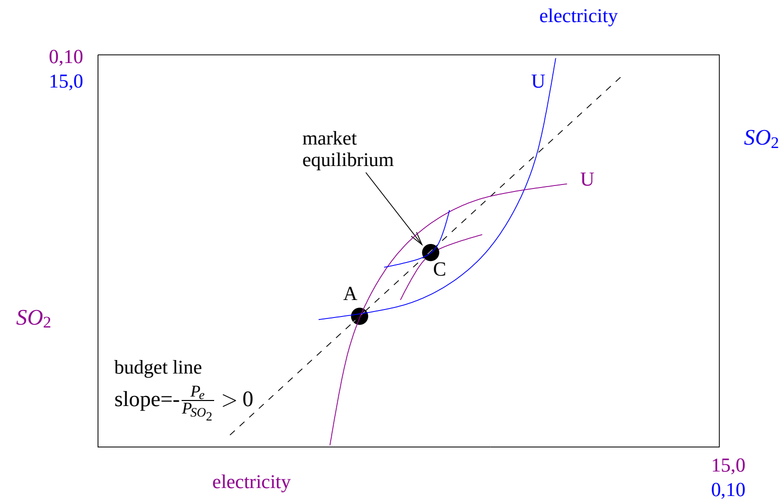

Figure 17: Edgeworth Box with a bad.

Notice the price ratio is now positive since the price of SO_2 is negative.

Figure 18 shows the production possibilities set for electricity and SO_2. We see that more SO_2 emissions expands the amount of electricity that may be produced. The MRT is positive, and is again equal to the price ratio.

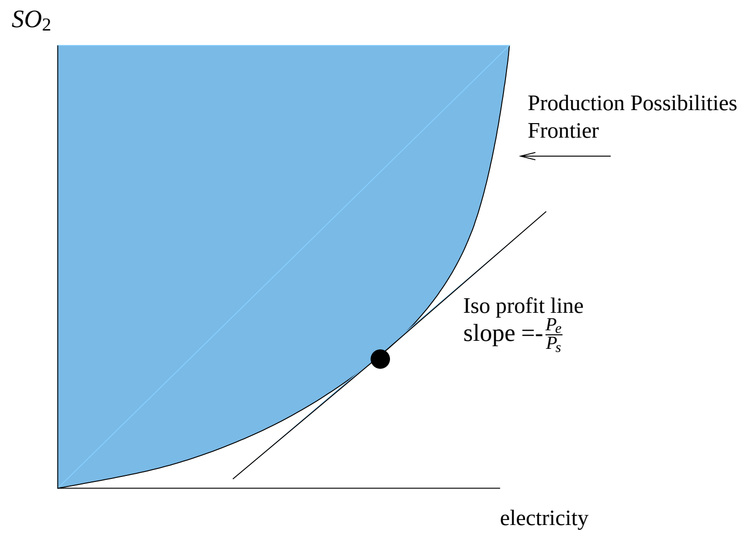

Figure 18: Production possibilities when one good is a bad.

Overall we see that it does not matter whether or not we have a good or bad. What matters is whether the good or bad can be priced and sold, and whether or not benefits accrue only to those who hold the good or bad.

III Surplus

A Goods

We can take a look at the markets for individual goods and see that the market equilibrium is efficient. Figure 19 gives the supply and demand for electricity, along with the market price p^*.

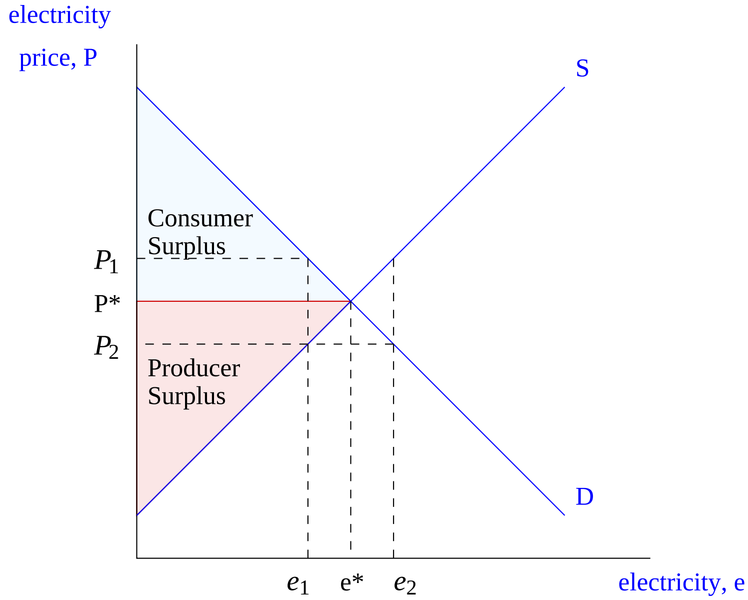

Figure 19: Consumer and Producer Surplus.

By demand, we mean marginal willingness to pay (MWTP). At e_1, households are willing to pay p_1 for a little bit more electricity. By supply, we mean the marginal opportunity cost (MC) of supplying electricity. At e_1, households value additional electricity more than it costs to produce, hence producing more electricity is Pareto preferred. Similarly, at e_2 the last bit of electricity is worth less to the household than it costs to produce. By reducing production, we free up resources that are more valuable elsewhere. Therefore, efficiency requires e^*.

Definition 10 *The CONSUMER SURPLUS associated with consumption q is the area between the demand curve and the horizontal axis over the region zero to q, less the price paid.*

The consumer surplus is the the difference between what consumers are willing to pay and what consumers have to pay, for all goods sold.

Definition 11 *The PRODUCER SURPLUS for q units is the difference between revenue and cost of providing q units. It equals the area between the supply curve and the horizontal line through the price, over the region zero to q.*

From the graph, market equilibrium, and thus efficiency, is equivalent to maximizing surplus. At e_1 or e_2, surplus increases by moving to e^*. EFFICIENCY=MAXIMUM SURPLUS.

B Bads

The analysis of goods carries over when we consider the environmental good, such as clean water. Here the supply curve would be the cost of filtering out the pollutants. If we consider a bad like pollution, we flip the axes, as in Figure 20.

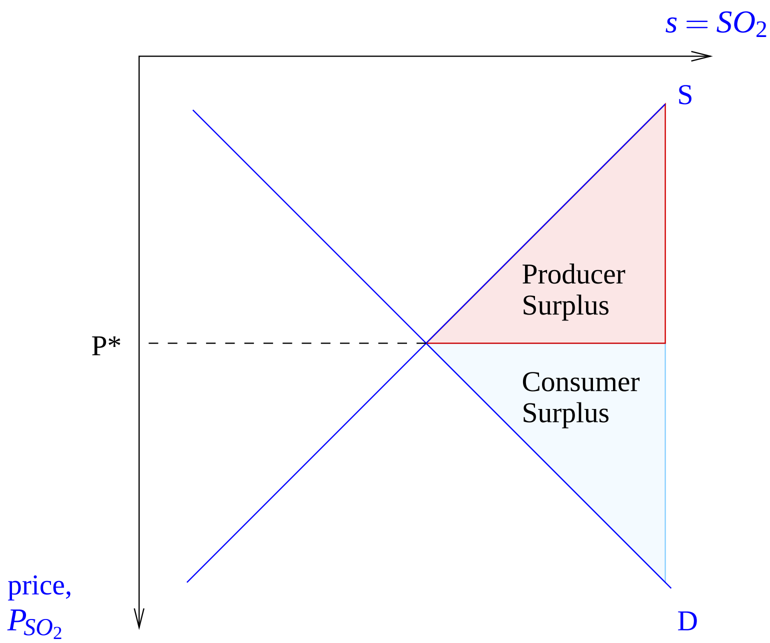

Figure 20: Surplus for bads.

As SO_2 increases, the utility damage increases as well, thus increasing the amount households are willing to pay to get rid of it. For producers, as SO_2 decreases, the opportunity cost of reducing emissions increases, as it becomes more and more difficult to reduce pollution. The consumer surplus is the difference between what households have to pay to get rid of SO_2, and the amount they actually pay, P^*. The producer surplus is the difference between what they are paid to reduce pollution and the cost of reducing it.

IV Market Failure I: Public Goods

A MARKET FAILURE is a good or bad for which we have a violation of one or more of the assumptions of the welfare theorems.

For example, in an oligopoly or monopoly, firms have market power and can thus influence prices. This violates assumption two, and is a justification for the government's antitrust regulation.

A Public Goods

Definition 12 *A good (bad) is EXCLUDABLE if it is practical to selectively allow consumers to consume (avoid consuming) the good.*

Electricity is excludable: FPL allows only those consumers who pay for electricity to use it. A beach is not excludable. Even for private beaches, it is difficult (but not impossible) to prevent others from using it, especially if they are simply checking out the view from the street. Urban air pollution is a bad which is not excludable.

Definition 13 *A good (bad) is RIVAL if consumption of a unit of the good (bad) by one person diminishes the amount of the good (bad) available to others to consume.*

Electricity is rival. The juice supplied by FPL that powers my Ipod cannot be used to power something else. The electricity is used up. A beach is is non-rival up to a certain point. My being on the beach does not prohibit others from using the beach, unless it is packed to capacity.

So rival and excludable should be viewed on a continuum. The degree of non-excludability depends on the cost of exclusion. The degree of non-rivalry depends on the number of people who can use the good before capacity is reached.

Definition 14 *A PURE PUBLIC GOOD/BAD is non-rival and non-excludable*

Non-rival goods violate assumption 1: the benefits of the good do not accrue solely to the owner. Excludable goods also violate assumption 1: the property right is not secure. Public goods will be under-provided in a market economy, since people besides the owner can use the good without paying for it. Therefore, the price does not reflect what people are willing to pay.

B Optimal Provision of Public Goods

Supply of a public good is the same as supply of any other good. Demand for a non-rival good is different. If Jack is willing to pay $2.50 for the beach and April is willing to pay $3, then we should provide the beach as long as it costs less than $5.50 to produce, *because both Jack and April can consume the beach together*. If the beach were rival, we would need to provide two beaches. Thus if beaches are rival we should provide one beach if the first beach costs less than $3, and a second beach if the second costs less than $2.50.

With non-rival goods, we sum the demand curves vertically.

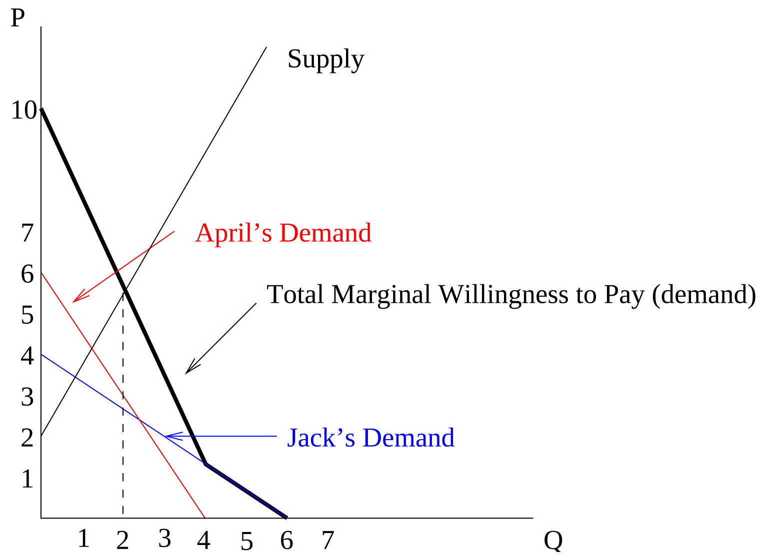

Figure 21: Optimal Provision of A Public Good.

The optimal provision occurs where total marginal willingness to pay (demand) intersects marginal cost (supply), here two units.

C Market Provision of a Public Good

If the good is non-excludable, then no public goods will be supplied. At any price above zero, consumers will use the good without paying, because the owner cannot prevent consumers from using the good. Assuming costs are greater than zero, any market provision of a non-excludable good results in negative profits, and so the good is not provided. A good example is Coral Gables mosquito eradication efforts. Efficient private provision is unlikely, since some households will free-ride.

Definition 15 *FREE RIDING: Getting the benefits of, but not paying for, a non-excludable good.*

Suppose now that the owner could put a fence around the beach and charge admission. Let us think of the good in Figure 21 as the number of visits to a single beach. If we charge \$5.50, as the graph seems to indicate, then April will not go (she is willing to pay \$5 for the first visit, but the cost is \$5.50). Similarly, Jack will not go either. Only by charging \$2.50 would both Jack and April go twice, which is efficient, but in that case the producer loses because the marginal cost is \$5.50. Since the firm loses money, it will not provide two units (the firm makes $\$2.50 \cdot 2 = \$5$ on the second unit, but the marginal cost is \$5.50). If we sum the demand curves horizontally, as in Figure 22, we see that the private provision is less than optimal, a little more than one unit.

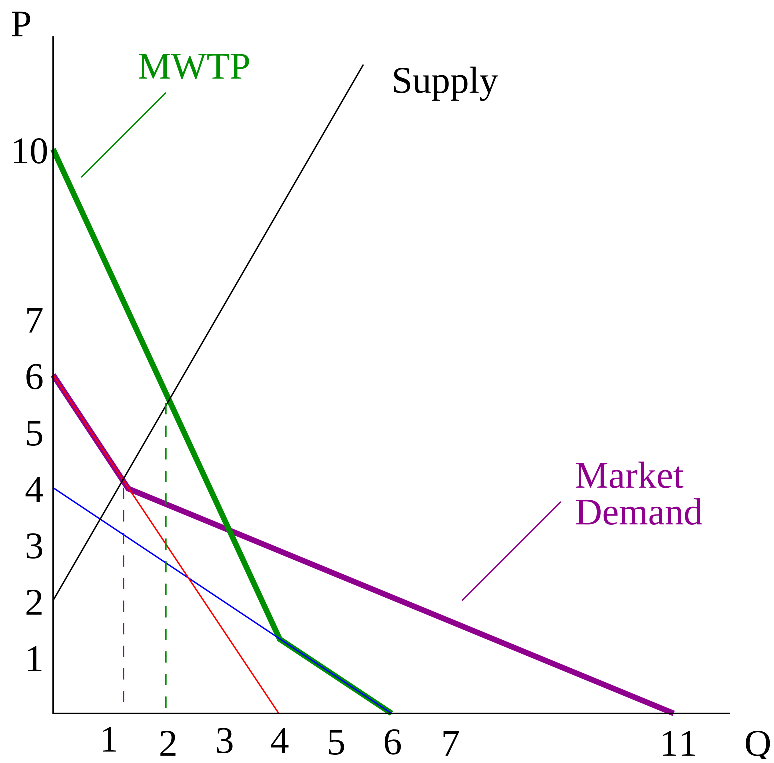

Figure 22: Market and optimal provision of a non-rival good.

The key is that the producer must charge the same price to both Jack and April. If Jack and April pooled their money and offered a total of $5.50 for their second trips, the producer would accept. But then Jack and April cannot easily bargain with each other. April may claim she is not willing to pay $3, to try to get Jack to pay more, for example.

V Market Failure II: Externalities

Definition 16 *An EXTERNALITY occurs when one person or firm's actions affect another's without compensation.*

Suppose a steel mill generates water pollution which drifts downstream to a nearby farm, which uses the water for irrigation. The toxins generated by the steel mill reduce crop output. Since the farmer is not compensated, we have an externality.

The farmer could force compensation if she owned the stream (a possibility we will discuss later). So we have a violation of assumption 1, the costs of the bad (pollution) do not accrue only to the steel mill. The property rights of the stream are unclear.

It is also possible to have a consumption externality: my driving generates pollution which may give a child asthma. The child has no way to extract compensation from me. Externalities can also be positive. My purchase of mosquito control benefits my neighbor, yet I receive no compensation.

- NEGATIVE EXTERNALITY: One person/firm's activities decrease another's utility or profits.
- POSITIVE EXTERNALITY: One person/firm's activities increase another's utility or profits.

The market economy will provide more goods with negative externalities than is efficient, and fewer goods with positive externalities. In Figure 23, let Q be steel production. The supply curve represents the marginal cost: if the price of the good exceeds the marginal cost, the firm will make profits and will therefore supply the good. But what is not included in the marginal cost is the cost of steel production on the farmer. For points between the efficient Q and the market Q, the combined marginal cost of the steel and the reduction in farm output outweighs how much society values steel. Thus it is efficient to produce Q marked by the green line. But since the steel producer does not pay the cost to the farmer, he has an incentive to produce anyway. So the market is not efficient and too much steel is produced.

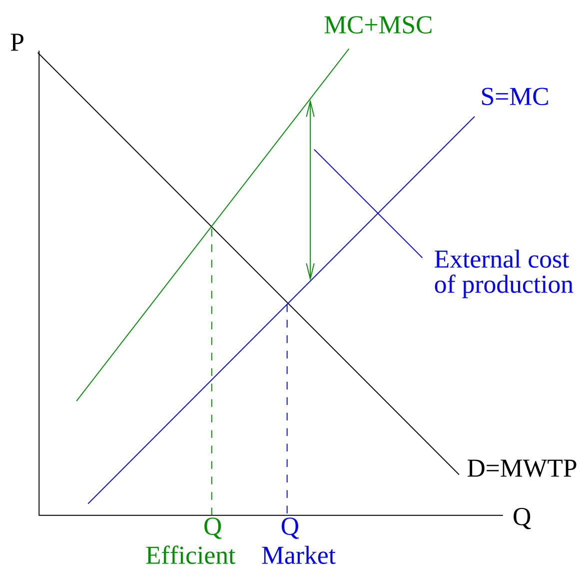

Figure 23: Market and optimal provision of a good with external costs.

Finally, note the actions of others often affect our utility in a way that is priced. When others buy houses in Miami, the price of houses rises, thus negatively affecting the utility of potential home buyers. But the market is acting efficiently here: it allocated the limited supply of houses to those willing to pay the most. Further houses were not produced because apparently the marginal cost was too high.

VI Conclusions

We now have a clear understanding of environmental problems:

- The market fails to produce enough environmental goods, and too many environmental bads, because the polluter does not pay for the cost of pollution.
- Optimal provision of public goods, bads, and goods with external costs is such that the marginal costs (including costs to people and firms hurt by pollution) equal the marginal willingness to pay.

We have identified what levels of pollution we would like. Next we will think about how to design regulation to achieve that goal.