# 6 Externalities

*"So ye shall not pollute the land wherein ye are: for blood it defileth the land: and the land cannot be cleansed of the blood that is shed therein, but by the blood of him that shed it."*

*—Numbers 35:33*

"Pittsburgh from the Salt Works at Saw Mill" by William T. Russell (1843)

Is Pittsburgh still this scenic?

*August 28, 2016*

http://rasmusen.org/g406/reg-rasmusen.htm, erasmuse@indiana.edu

**6.1: Externalities**

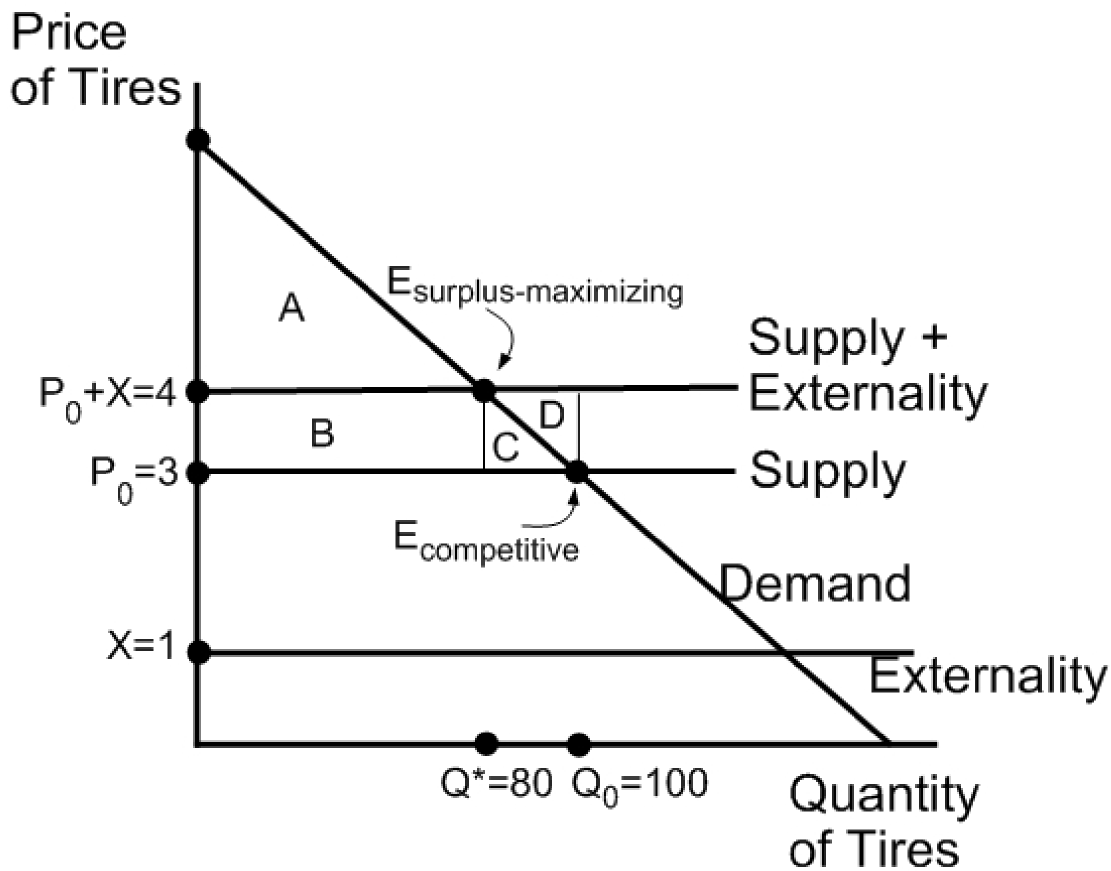
Recall from Chapter 2 that an externality is a spillover effect, any effect on someone else's surplus caused by the involuntary actions of someone else. Our example in Chapter 2 was manufacturing newsprint paper, which, if no precautions are taken, generates considerable water pollution. Neither the buyer nor the seller bears the cost of the pollution that results from newsprint production unless law or regulation requires them. As a result, even if the marginal benefit of the newsprint to the buyer equals the marginal cost to the seller it will still be less than the marginal social cost, which includes the cost to the third parties who lose from the pollution.

Similarly, positive externalities, where someone get a beneficial spillover without having to pay for it, also create market failure. It is not that beneficial spillovers are bad in themselves, but that whoever is doing the action that creates the externality is ignoring that benefit, and so will not be doing enough of the action. Shovelling snow off of the sidewalk in front of your house creates positive externalities, but since those benefits go to pedestrians instead of yourself, we would expect insufficient show shovelling to happy without laws, regulations, or social customs to encourage it.

On the other hand, in contrast to these "real" externalities, Chapter 2 explained that some externalities are "pecuniary" and do not cause market failure. Pecuniary externalities are spillovers that result from someone's actions changing prices. If more people move into town, that causes rents to rise, which hurts existing renters. Thus, immigration into the city has negative externalities for renters. At the same time, though, it has positive externalities for landlords and the new inhabitants, and the gain to them is greater than the loss to the old renters. Changes in prices are necessary to achieve the efficient market equilibrium, so although some people are helped and some are hurt by them, they do not change surplus in the same direct way as pollution or snow shovelling.

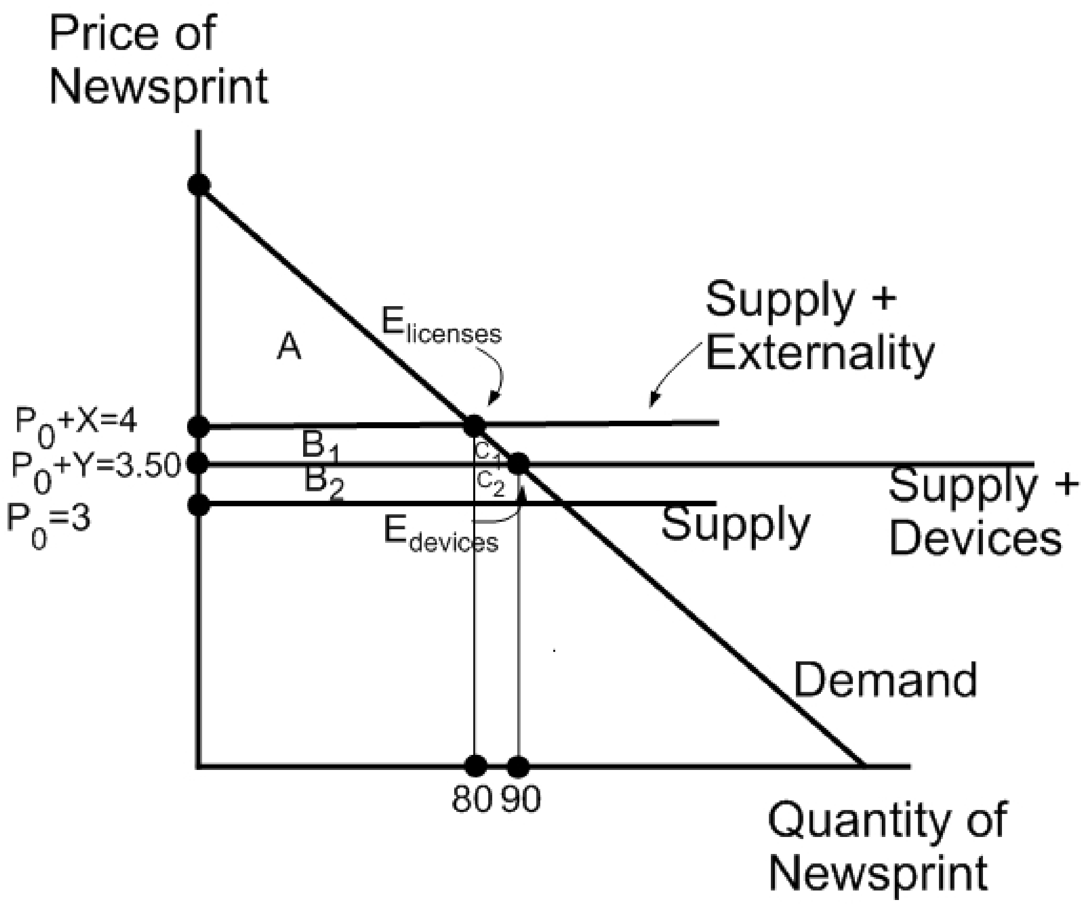
Figure 6.1 is a repeat from Chapter 2. The competitive equilibrium results in $Q_0 = 100$ and $P_0 = 3$ from the intersection of supply and demand. This, however, inflicts a total externality cost of $Q_0 * X = 100$ on the rest of the economy. At $Q_0$, the marginal cost of the newsprint, which includes the externality cost to third parties, is greater than the marginal social benefit, the benefit to the consumer precisely at the margin of buying versus not buying. Total surplus is (A+B+C) for the buyers, but the total externality of $Q_0 * X = 100$ must be subtracted from that. That quantity is shown on the diagram as B+C+D. Total surplus is $A + B + C - (B + C + D) = A - D$.

FIGURE 6.1
A NEGATIVE EXTERNALITY




As Chapter 2 said, total surplus could be increased by the government giving out production limits to each firm that which keep industry output down to $Q^* = 80$. The price would then rise to $P_0 + X$ because consumers would bid up the price at that quantity to the height of the demand curve. This would increase surplus because now consumer surplus would fall to A, producer surplus would rise to B, and the total externality would fall to B, for a total social surplus of A. The problem with higher output was that it increased the externality to C+D while only increasing consumer surplus by C.

FIGURE 6.2
PRODUCTION LIMITS VERSUS ANTI-POLLUTION DEVICES




Let's now add another twist. Suppose pollution control devices could be installed to completely eliminate the pollution at a cost of $Y$ per unit of newsprint, where $Y = 0.50 < X$. A government requirement that the companies limit their pollution to that amount will be even better than using production limits. Figure 62, a continuation of Figure 6.1, shows how limiting output to 80 has social surplus of $A$. If the government switched its policy to have no limit on output but required every company to install anti-pollution devices, output would rise to 90 and price would rise to $P_0 + Y = 3.50$. Consumer surplus would rise to $A + B_1 + C_1$ because the price has fallen and the quantity has risen. Producer surplus is zero, falling by $B_1 + B_2$ because the new price exactly equals the cost of production plus pollution control. The rest of the economy's negative externality cost has fallen to zero from $B_1 + B_2$, however, because there is no longer any pollution. Total surplus is $A + B_1 + C_1$, better than $A$.

One theme of this chapter will be that regulators should keep track of their ultimate objective, but on the way to that objective they should allow the economy as much flexibility as possible. Assigning companies production limits and requiring them to use a particular control technology is an extreme example of inflexible **command and control regulation**: telling people and companies what to do. Restricting output is not the objective, nor getting companies to install a certain pollution-control technology; reducing pollution is. If all firms are identical and the government has perfect information, then output restrictions can help, but the government doesn't know how much each firm should produce to maximize surplus, and in any case output restriction gives no incentive to companies to reduce their pollution per unit of output, and no incentive to anyone to develop pollution control technology. Pollution is actually much higher with production limits than it is with the second policy we looked at, requiring the pollution control devices. Requiring specific devices is another form of command and control, but more flexible because it doesn't say which firms produce how much. If some firms have higher costs of production, or cannot so easily install the pollution devices, this allows market forces to make those firms reduce their output most. Even better would be to not require a specific technology, but rather to command firms to limit their pollution emissions to an efficient level (zero in this example, but usually positive) by the cheapest means the firms can find. This is the difference between **design-based standards** and **performance-based standards** that OSHA chooses between in making ladders safer. As we will see, in the case of pollution there are even more flexible policy alternatives: pollution taxes and cap-and-trade.

**The Optimal Level of Pollution**

Before we come to policies dealing with externalities, it is worth observing that the surplus- maximizing level of externalities usually is not zero. Take air pollution as an example. It is extremely expensive to reduce the amount of smoke from a tire factory to zero, either by using special technology or by shutting down the factory completely and sacrificing all the producer and consumer surplus from the tire market. As with all economic goods and bads, surplus is maximized by comparing the marginal cost with the marginal benefit.

FIGURE 6.3
THE OPTIMAL STRICTNESS OF AIR POLLUTION REGULATION

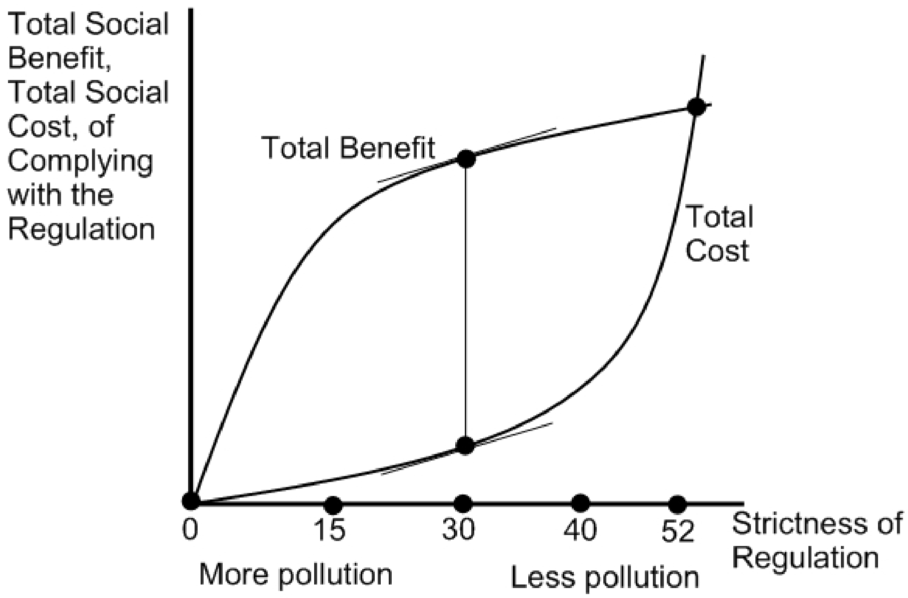



Figure 6.3 shows the *total* cost and benefit of stricter air pollution regulations. The horizontal axis shows the strictness of regulation, where 0 means no limits at all and 52 means that firms are required to reduce their air pollution substantially. The vertical axis shows the social benefit from stricter regulation and less pollution, and the social cost from pollution controls that production more expensive and drive up consumer prices. The optimal level of strictness is 30, which has the greatest net benefit—the biggest difference between total benefit and total cost. This is where the slopes of the two curves are identical, as shown by the slanting lines. Since the slope of total benefit is marginal benefit and the slope of total cost is marginal cost, this is where the marginal benefit equals the marginal cost. Having no pollution control would be bad because starting at 0 the marginal benefit is much greater than marginal cost—the total benefit curve has a much steeper slope than the total cost curve, so the net benefit is increasing rapidly. A level of 52 would be just as bad, with a net benefit of zero, because there the marginal benefit is much less than the marginal cost.

Table 6.1 shows some real-world estimates of the marginal cost of air pollution. The first line shows the percentile nationally of the marginal damages of emissions. In the 1st percentile is Klamath, Oregon, a rural area with very little pollution, so that there the marginal cost per ton of fine particulate matter is only $250. In the 99th percentile is heavily polluted Cuyahoga, Ohio, where the cost of that same one of pollution would be $12,400, and in the 99.9th is Hudson, New Jersey where the cost is $41,700. The marginal cost of each kind of pollution in the table increases drastically with its level. Having one standard for automobile emissions for the entire country will either result in air too dirty in Cuyahoga or too clean in Klamath or both. It would be interesting to calculate the transfer of wealth from towns and suburbs to cities that has resulted from our one-limit-for-all policy. Public discourse has focussed on the most polluted areas— Los Angeles, in particular— while ignoring the cost of limiting emissions on people in Montana and Maine.

TABLE 6.1
MARGINAL DAMAGES OF EMISSIONS BY QUANTILE (DOLLARS PER TON)

| Percentile:<br><br><br>Pollutant | 1st<br>Klamath<br>Oregon | 25th<br>Tyler<br>Texas | 50th<br>Bradley<br>Arizona | 75th<br>Florence<br>Texas | 99th<br>Cuyahoga<br>Ohio | 99.9th<br>Hudson<br>N.J. |
|---|---|---|---|---|---|---|
| Fine Particulate Matter | 250 | 700 | 1,170 | 1,970 | 12,400 | 41,770 |
| Coarse Particulate Matter | 60 | 120 | 170 | 280 | 1,960 | 6,550 |
| Nitrogen Oxides | 20 | 180 | 250 | 370 | 1,100 | 1,780 |
| Ammonia | 100 | 300 | 900 | 2,000 | 20,620 | 59,450 |
| Volatile Organic Compounds | 40 | 120 | 180 | 280 | 1,370 | 4,540 |
| Sulfur Dioxide | 220 | 550 | 970 | 1,300 | 4,130 | 10,860 |

An extreme example of neglect of cost-benefit analysis is the government's **Superfund program** , which cleans up toxic waste sites. The program was begun in order to identify and clean up old toxic waste sites that did not meet current standards. Current producers of toxic waste are taxed for the clean-up of past sites, since often the original producer cannot be determined or has gone out of business. A major fear is that chemicals abandoned in the sites might cause cancer in people living nearby. Table 62 shows how fast diminishing returns set in. Five percent of the expenditures would prevent 99.47% of the cancers, though with a very high marginal cost of $145 million per life saved– far above the estimates of the value of human life we have studied. Going up to 99.86% would raise the cost to $1.107 billion, and increasing it still further to 99.98% would raise the cost to an astonishing $241 billion dollars per cancer case.

TABLE 6.2
SUPERFUND COSTS

Summary of Superfund Cost-Effectiveness*

| Percentage of Remediation Expenditures, Ranked by Cancer Cost Effectiveness | Cumulative Percentage of Total Expected Cancer Cases Averted | Marginal Cost per Cancer Case Averted ($ millions) |
|---|---|---|
| 5 | 99.47 | 145 |
| 25 | 99.86 | 1,107 |
| 50 | 99.96 | 6,442 |
| 75 | 99.97 | 28,257 |
| 95 | 99.98 | 241,058 |

* Using the following assumptions: average exposure concentrations and intake parameters, 3 percent discount rate and no growth factors for cost, 3 percent discount rate for cancers, and a ten-year latency period for the development of cancer.

*Source:* James T. Hamilton and W. Kip Viscusi, *Calculating Risks?: The Spatial and Political Dimensions of Hazardous Waste Policy* (Cambridge, Mass.: MIT Press, 1999), Table 5.6.

Marginalist thinking is important for looking at externalities for two reasons. First, it is important to determining the surplus-maximizing level of the externality. Starting with no pollution control at all, pollution would be so high that the the marginal benefit of reduction would be even greater than in Table 6.1's Hudson, New Jersey. Requiring the entire country to reach the low pollution level of Klamath, Oregon, on the other hand, would cause the marginal cost of pollution reduction to rise to a level far beyond its marginal benefit. Superfund should not try to prevent every death that might result from toxic waste cancer; the marginal cost per life saved rises too far once we go much beyond 99% cleanup.

Second, the concept of marginalism is helpful in determining where pollution should be located after we have determined which overall level is efficient. When pollution marginal costs are high in Hudson and low in Klamath, that suggests we might be able to increase surplus by reducing the amount of pollution in Hudson and increasing it in Klamath. Rather than imposing regulations that require equal percentage or absolute reduction of pollution in different counties, it makes more sense to require less reduction in counties where the marginal benefit of pollution reduction is less.

That is the idea behind the **Larry Summers memo** of box 6.1. Lawrence Summers was a prominent economist employed the World Bank. In the memo, he notes that the marginal cost of pollution and the marginal benefit of pollution control are much lower for poor countries. Being poorer, people there put a higher value on material wealth than on reducing the health costs of pollution or improving the beauty of the environment. Indeed, the material wealth itself could be used to save more lives than extra pollution would cost. Total world surplus would rise if profitable but polluting industries were to move their operations from rich countries to poor countries. This, in fact, is what the free market itself moves toward, if we include supply and demand for government policy as part of the market. Rich countries demand more pollution regulation, increasing the cost to manufacturing plants, some of which find that this extra regulatory cost makes it worthwhile to move operations to a poor country, which welcomes the employment and taxes. Although the poor country still dislikes the pollution, it dislikes it less, relative to the employment and tax revenue.

Contrary to what many people think, pollution has declined substantially over time in the United States.[1]

[1] See"Clearing the Air," Joel Schwartz, *Regulation*, 26, (Summer 2003).

BOX 6.1: POLLUTION EXPORTS?

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DATE: December 12, 1991
TO: Distribution
FROM: Lawrence H. Summers
EXTENSION: 33774
SUBJECT: GEP

...[page 5 of 7]

3.  'Dirty' Industries Just between you and me, shouldn't the World
Bank be encouraging more migration of the dirty industries to the
LDCs [Less Developed Countries]?  I can think of three reasons:

1) The measurements of the costs of health impairing pollution
depends on the foregone earnings from increased morbidity and
mortality.  From this point of view a given amount of health
impairing pollution should be done in the country with the lowest
cost, which will be the country with the lowest wages.  I think the
economic logic behind dumping a load of toxic waste in the lowest
wage country is impeccable and we should face up to that.

2) The costs of pollution are likely to be non-linear as the
initial increments of pollution probably have very low cost.
I've always thought that under-populated countries in Africa
are vastly under-polluted, their air quality is probably vastly
inefficiently low compared to Los Angeles or Mexico City.  Only
the lamentable facts that so much pollution is generated by non-
tradable industries (transport, electrical generation) and that
the unit transport costs of solid waste are so high prevent world
welfare enhancing trade in air pollution and waste.

3) The demand for a clean environment for aesthetic and health
reasons is likely to have very high income elasticity.  The concern
over an agent that causes a one in a million change in the odds of
prostrate cancer is obviously going to be much higher in a country
where people survive to get prostrate cancer than in a country
where under 5 mortality is 200 per thousand.  Also, much of the
concern over industrial atmosphere discharge is about visibility
impairing particulates.  These discharges may have very little
direct health impact.  Clearly trade in goods that embody aesthetic
pollution concerns could be welfare enhancing.  While production is
mobile the consumption of pretty air is a non-tradable.

The problem with the arguments against all of these proposals for
more pollution in LDCs (intrinsic rights to certain goods, moral
reasons, social concerns, lack of adequate markets, etc.)  could be
turned around and used more or less effectively against every Bank
proposal for liberalization.
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Let's focus on air pollution, because it is one of the most heavily regulated and one of the easiest to measure. Table 63 shows what has happened in the United States. Carbon monoxide emissions have fallen from 178 million tons per year in 1980 to 78 in 2008. Lead emissions have fallen from 74,000 tons per year to 2,000. The extent of the decline should not really be surprising, since the country spends perhaps $79 billion/year on pollution control,[2] and the **Environmental Protection Agency (EPA)** itself had a budget of $10.3 billion in 2010.[3] If air pollution had not declined, we would have to wonder whether all that spending was really making any difference.

TABLE 6.3
NATIONAL EMISSIONS ESTIMATES
(millions of tons per year)

| | 1980 | 1985 | 1990 | 1995 | 2000 | 2005 | 2008 | 2017 |
|---|---|---|---|---|---|---|---|---|
| Lead (1,000's tons) | 74 | 23 | 5 | 4 | 3 | 2 | 2 | 1 |
| Nitrogen Oxides | 27 | 26 | 25 | 25 | 22 | 19 | 16 | 11 |
| Sulfur Dioxide | 26 | 23 | 23 | 19 | 16 | 15 | 11 | 3 |
| Carbon Monoxide | 178 | 170 | 144 | 120 | 102 | 93 | 78 | 60 |
| Volatile Org. Comp. | 30 | 27 | 23 | 22 | 17 | 18 | 16 | 16 |
| Particulate Matter (PM10) | | | 8 | 7 | 7 | 6 | 6 | 5 |

Source: 2017: EPA: https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data. Lead in 2014:National Emissions Inventory https://www.epa.gov/sites/production/files/2017-04/documents/2014neiv1_profile_final_april182017.pdf

In the Third World, pollution has been increasing along with industrialization. This is in line with the Larry Summers memo. Compared to rich people, poor people value goods more than clean air. Economic reasoning predicts that at a certain point a country becomes wealthy enough that people start to prefer clean air more and the government starts regulating pollution more heavily, so income growth slows down, but air quality improves.

**6.2: Command-and-Control versus Pollution Taxes**

The obvious way to control any externality is to ban it. Cigarette smoking creates the negative externality of smelly smoke that bothers people near the smoker. Many organizations therefore ban smoking, having calculated that the marginal cost to the non-smoker exceeds the marginal benefit to the smoker. Other organizations allow smoking, having come to the opposite conclusion for the people they serve.[4]

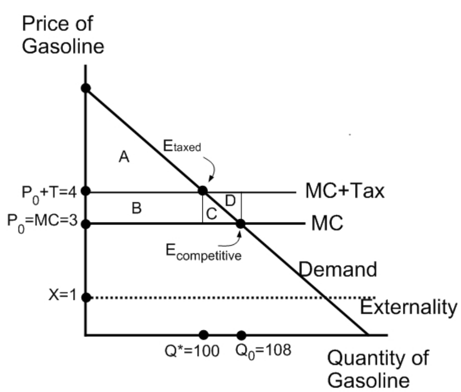
[2] "Assessment of the Obama Administration's Cost-Benefit Analysis of Clean Air Act Regulations,"NERA, June 15, 2011, p. 4. This is a politically sensitive number and may not be accurate. The EPA has tried to hide costs and inflate benefits of pollution control in its recent report.

[3] "Funding Highlights," Whitehouse.gov, p. 149.

[4] Often dislike of the smell is masked as concern about health, since that is a more socially acceptable motivation, but the evidence that second-hand smoke causes lung cancer is only epidemiological (correlations between lung cancer and being in places with smokers and cancer, a correlation which could

In other situations, notably those of industrial pollution, the producers of the externality are fixed in place and we neither want them to pollute freely nor to shut down altogether. Rather, marginalism tells us that to maximize surplus we wish for the producer to limit the externality's magnitude to where the good's social marginal cost (the private marginal cost plus the externality) starts to exceed its marginal benefit. Like banning the externality altogether, this could be done simply by command— "Produce no more than 14 tons of sulfur dioxide per month," or by mandating that particular technologies be used "Every coal-using electrical generating plant must install Type G scrubbers on its smokestacks." One defect of command-and-control regulation is its inflexibility. Type G scrubbers might not be the cheapest way to reduce emissions, for example, or a plant might have a particularly high benefit for producing more sulfur dioxide this month. Also, command-and-control regulation is in a sense too lax, because it gives no incentive to polluters to reduce pollution down beyond the commanded level, and it does not allow customization to fit the cost-benefit situation of particular individual polluters. The Environmental Protection Agency has long used command-and-control regulation as its main tool, though in the milder form of emissions restrictions rather than technology requirements.

FIGURE 6.4
A POLLUTION TAX




An alternative to command-and-control is a **pollution tax.** Cigarette taxes might be considered a pollution tax, though they tax the smoker whether he smokes in a low-externality place (at home) or a high-externality place (a restaurant). Figure 64 shows how a pollution tax on gasoline could work. Suppose the marginal production cost of producing gasoline is constant at 3 dollars per unit. If each unit of pollution causes 1 dollar of damage, then a tax of 1 dollars per unit of pollution gives producers the right incentive to decide how much to pollute. It **internalizes the externality** by making the private cost to the polluter equal to the social cost. Once the tax is imposed, sellers reduce the quantity of gasoline they supply, and the new equilibrium equates the marginal social cost and the marginal social benefit.

We can also calculate the gain in social surplus. Producer surplus is zero both with and without the tax (since marginal cost is constant and the supply curve is perfectly

have many causes) and far weaker than is usually required for such studies. Think about the relative quantities of smoke that the smoker and the bystander inhales, and you will realize how implausible is the link. See "The Evidence for the Passive Smoking Theory," from *Velvet Glove, Iron Fist: A History of Anti-Smoking*, Christopher Snowdon (2009).

elastic). Imposing the tax has three effects. First, it reduces consumer surplus by the rectangle (4-3)(100-0)= 100 plus the triangle 0.5(4-3)(108-100)= 4, a total of 104. Second, the tax raises tax revenue of 100— the same rectangle that consumers lost. That 100 represents merely a shift of surplus from consumers to taxpayers. Third, the tax benefits anyone hurt by the externality. We have assumed a cost of 1 per unit of externality, so this would be a gain of 8. This gain of 8 to third parties outweighs the loss of the triangle of size 4 to consumers, so total surplus rises by 4 as a result of the tax and the reduced consumption.

Negative externalities are a different kind of market failure than we have seen so far, because the market failure is overproduction rather than underproduction. In the case of market power or overestimates of product quality, the amount of traded goods ends up being too large, but with negative externalities it is too small, since the buyer and seller don't care about the costs to third parties.

Gasoline taxes are useful for dealings with other negative externalities too, not just pollution. Professors Parry and Small found that the negative externality of each car on the road slowing down the others was even more important than the pollution externality. They compared the United States with Great Britain, which has a much higher gasoline tax, and concluded that the tax was inefficiently small in the U.S. and inefficiently great in the U.K. as far as internalizing externalities.[5]

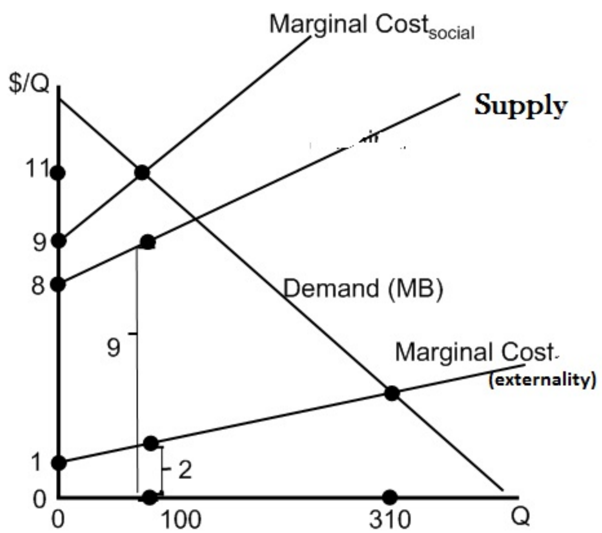
> BOX 6.2: COMMAND-AND-CONTROL AND NUCLEAR ARMAGEDDON
>
> "The U.S. Air Force has completed upgrading the guidance systems of its 450 LGM-30 Minuteman III ICBMs.... The air force has also replaced decades old solid fuel rockets in its missiles. ...The last of the Minuteman III missiles will receive their new motors this year. ...The first six test flights have shown that the new and improved missiles are less accurate and had shorter range than the missiles they replaced.... The shorter range can be attributed to Environmental Protection Agency (EPA) regulations. The old motors did not have to comply with EPA rules, the replacement ones do. This meant the new rocket motors were heavier, which resulted in shorter range." But as one commentator pointed out,
>
> "If nuclear missiles have to comply with EPA regulations, what about the warheads?"

Pollution taxes are a more flexible policy than simply telling companies how much to pollute, and in some cases, like this one, they don't even require the government to know the demand or supply curves in the industry, just the cost of the externality. Telling companies how much to pollute requires the government to know not only the marginal cost of pollution, but the marginal cost to each company of preventing pollution. In addition, telling each company how much it can pollute via command and control regulation gives ample scope for government favoritism and raises no rev-

[5] Parry, Ian W. H. and Kenneth A., Small"Does Britain or the United States Have the Right Gasoline Tax?" *American Economic Review,* 95 (September 2005).

enue. Pollution taxes, in contrast, apply equally to everyone and raise revenue without the deadweight loss created by sales or income taxes. Although criticized as a policy which allows rich companies to just pay and then get away with polluting as much as they want, pollution taxes can also be framed as a policy which makes companies pay whenever they pollute. Command and control, on the other hand, lets companies pollute for free. As one might expect, command-and- control is usually more popular with businesses, especially those that are well connected politically, since they can pollute without cost up to the limit. Pollution regulation can even be a competitive tool, if incumbent companies are **grandfathered**, meaning they can pollute at existing levels, whereas entrants must build new plants that pollute much less.

FIGURE 6.5
A POLLUTION TAX WITH UPWARD-SLOPING SUPPLY




The example in Figure 6.5 is the simplest situation of a pollution tax, the situation where the marginal cost of production and the marginal externality cost of pollution to third parties is constant. Once you understand it, you can advance to Figure 6.5, in which both the marginal private cost of production and the marginal cost of the externality are increasing. Here, as in the earlier figure, the marginal social cost is the sum of the marginal private production cost (from the supply curve) and the marginal externality. At an output of 0, the marginal private cost is 8 and the marginal externality cost is 1, for a social marginal cost of 9. At an output of 100, the marginal private production cost is 9 and the marginal externality cost is 2, for a social marginal cost of 11. Since both the marginal private cost and the marginal externality cost are increasing the marginal social cost too will be increasing, but it is increasing with a steeper slope than either, since it adds up their rates of increase.

Surplus is maximized at an output of 100, where the demand curve crosses the marginal social cost curve. The free market would result in output of 310, inefficiently high. To get output down to 100, a tax of 2 per unit could be imposed. That is more than the externality's marginal cost at the output of 0, and less than at 310, but it exactly equals it at the output of 100. At any market price less than 11, producers would be eager to increase the supply, but at that price, they would be willing to supply exactly 100, since the marginal production cost is 9 and the tax is 2.

**Cap and Trade**

Another way to achieve optimal pollution levels is to regulate how much each firm can pollute, but allow firms to sell their rights to pollute. In effect, this caps the total quantity of pollution rather than charging companies a price to pollute. Thus, this is called **cap and trade**. If it is very important to avoid letting total pollution cross some particular threshold where its marginal cost rises sharply, regulating quantity this way is better than imposing a tax, because if the tax level is picked to be just a little too low, pollution may cross the threshold for sharply higher marginal costs of damage.[6] If companies must buy their initial pollution permits, the quantity policy can, like the tax policy, raise revenue for the government that can use to replace distortionary taxes. This is like the spectrum auctions used in telecommunications. While not using property rights as much as for telecom, some countries have indeed tried using emissions trading, both for pollution and for carbon dioxide.[7]

FIGURE 6.6
CAP AND TRADE

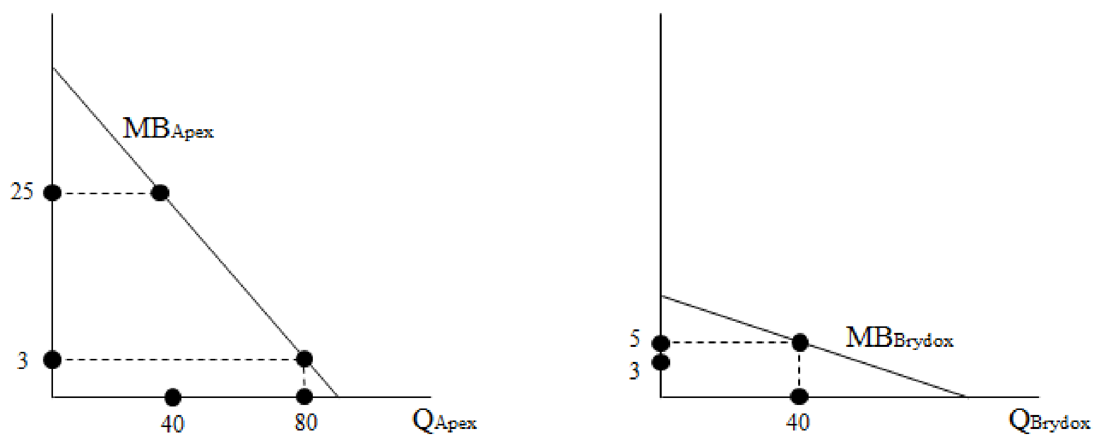



Figure 6.6 illustrates how emissions trading can raise total surplus compared to command-and-control. A firm with a high cost of reducing pollution can buy permits from a firm that has a lower cost of reducing pollution.

[6]Weitzman, Martin, "Prices vs. Quantities," *Review of Economic Studies*, 41: 477–491, October 1974.
[7]"2010 EPA Allowance Auction Results."

The government begins by allocating 40 units of pollution licenses to Apex and 40 to Brydox. The two companies differ in their marginal benefits from polluting. At the initial allocation, Apex's marginal benefit of pollution is $25/unit, while Brydox's is $5/unit. This could be because Brydox gets less profit from selling extra output (which requires extra pollution) or because Brydox could have bought pollution-reducing equipment at a lower cost.

> BOX 6.3: SELLING ALLOWANCES PAYS BETTER THAN STEELMAKING
>
> The Kyoto Protocol of 1997 required signatories to reduce carbon emissions. In 2005, the European Union started a cap-and-trade system. Companies were issued free carbon permits that they could sell.
>
> In 2009, Corus, the EU's second-largest steel producer closed a plant in the United Kingdom, cutting 1,700 jobs. The closed plant's capacity was three million tons of steel, which would also produce six million tons of $CO_2$.
>
> The market price of a permit had ranged from $21 to $50. At the high price, Corus could make $300 million a year. Corus was essentially being paid to lay off British workers. But that's the whole point of cap-and-trade: restrict carbon emission to the companies that value it most. (*The Wall Street Journal Asia*, "Cap and Trade in Practice," (December 18 2009).)

The initial allocation does not maximize surplus. If the licenses are tradable, then Brydox could sell one license to Apex for $10 and Apex would gain $15 while Brydox gained $5, a gain in total surplus of $15. We would expect the two companies to keep trading licenses until their marginal benefits are equal— perhaps at Apex using 70 of them and Brydox using 10, with each company's marginal benefit of pollution being $6/unit.

One problem with tradable permits, though, is that the government will be tempted to violate the property rights it established earlier. Seeing that Brydox is making more money from selling pollution licenses than it is from selling goods, the electorate may be offended and tell its leaders to confiscate Brydox's licenses. Foreseeing this, Brydox may be reluctant to sell licenses to Apex in the first place.

## 6.3: The Coase Theorem

I said earlier that clear allocation of property rights can obviate the need for regulation.[8] This is most clearly expressed in the **Coase Theorem**. This idea was never stated as a theorem or called one in Coase's 1960 article, which was non-mathematical, but the name caught on. Here is one statement of it.[9]

[8] "To obviate": to make unnecessary.

[9] "The Problem of Social Cost," Ronald H. Coase,, *Journal of Law and Economics*, 3: 1–44 (1960). The Coase Theorem was stated and named by *The Theory of Price*, George J. Stigler, 3rd edition, p. 133 (1966; 1st edition 1942). On the link, see "A Case of Mistaken Identity: George Stigler, 'The Problem

THE COASE THEOREM: If information is symmetric, negotiation is costless, and contracts are costlessly enforceable, then people will choose surplus-maximizing actions regardless of whether there are externalities and regardless of who has the property rights.

Coase used the example of a cattle rancher who lives next to a wheat farmer. Occasionally, the cattle get through the fences and trample down wheat. The Coase Theorem claims that the amounts of wheat grown and cattle raised do not depend on whether the law requires the rancher to pay compensation to the farmer.

The reason for the paradox is that even though the rancher would not ordinarily have the efficient incentive to make sure his cattle don't break through the fence if he doesn't have to pay for the damage they cause, the farmer will pay him to take the efficient level of care. One way to do this would be for the farmer to pay the rancher a large lump sum on the condition that the rancher pay for any cattle damage. If that efficient level of care is zero, then the farmer won't pay the rancher, and the cattle will break in once in a while.

BOX 6.4: THE TOWN OF CHESHIRE BUYOUT

"Two years after the Environmental Protection Agency accused the plant's owner, American Electric Power, of violating the Clean Air Act in this southeast Ohio hamlet, the company, which is contesting that accusation, is solving at least some of its problems by buying the town, for $20 million.

Over the next few months, all 221 residents of Cheshire will pack up and leave. The 90 homeowners here will get checks for about three times the value of houses they probably could not have sold anyway. In return, they have signed pledges never to sue the power company for property damage or health problems." (Katharine Q. Seelye,"Utility Buys Town It Choked, Lock, Stock and Blue Plume," *The New York Times*, (May 13, 2002).)

A numerical example will help. Suppose a paper mill is polluting a river. The farmer downstream had been selling trout fishing rights to rich tourists for $20,000. Now the trout have fled, and he gets zero. The factory could install filtering machinery that would eliminate the pollution, at a cost of $4,000. What happens?

The Coase Theorem starts off with rights being well-defined. Here, the right in question is the right to control the river's water quality. One way to define it for the law to say that the factory has the right to dump its waste water into the river. Another way is for the law to say that the farmer has the right to a clean river. We have to see what happen under each system.

First, suppose the farmer has the right to a clean river. He will tell the factory to stop polluting. If the factory refuses, the farmer will go to court and tell the judge that the factory is infringing on his right. The judge will then tell the factory to stop polluting. If the factory does not stop, the judge will fine the factory or order its president to

of Social Cost,' and the Coase Theorem," Steven G. Medema, *European Journal of Law and Economics*, forthcoming, (July 29, 2010). There is no standard statement of the Theorem; what I give here would not be controversial as a version of it. See also the interview: "Looking For Results Nobel Laureate Ronald Coase on Rights, Resources, and Regulation," Thomas W. Hazlett, *Reason*, ( January 1997) .

go to jail for contempt of court. The factory (or, rather, its president) will decide to pay the $4,000 for new machinery to stop the pollution. That is the surplus-maximizing result, since it will save the farmer $20,000 in lost income.

FIGURE 6.7
RONALD COASE AND GEORGE STIGLER

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Second, suppose the factory has the right to dump its waste water into the river. Now the farmer can't go to court to stop it. Coase's insight is to see that this inability isn't the end of the story. What the farmer will do is go to the factory and offer to buy the factory's right. The farmer will say, "Factory, I wish the law didn't let you pollute, but since it does, how about if I give you $5,000 and you stop polluting?" The factory will agree, and pay the $4,000 for new machinery to stop the pollution. That is the surplus-maximizing result, since it will save the farmer $20,000 in lost income.

Thus, either way, we get the surplus-maximizing result. The only difference is that if the factory has the right to pollute, the farmer has to buy that right, so the farmer is worse off by $5,000. But we do get allocative efficiency.

Think back to cap-and-trade. The important thing is to allow the emissions to be tradable.

The Coase Theorem does not always apply, because it has premises which are sometimes invalid, depending on the particular situation. Professor Coase spent most of his career thinking about situations in which his theorem fails— reasonably enough since that is when government policy is important and interesting. Here are how some of the premises of the Theorem enter in the trout example.

**If information is symmetric . . .**

Suppose the farmer doesn't know that the factory's cost of pollution control equipment would be $4,000. Instead, he thinks it's probably around $1,000. In that case, he wouldn't offer the factory $5,000 to stop polluting. Instead, he might offer $1,500, and the factory would turn him down. The result would be inefficient pollution.

**If negotiation is costless . . .**

If it cost $25,000 in lawyer fees and management time for the farmer and the factory to work out a deal, then the factory would end up polluting even though it would prefer to have a deal with the farmer and be paid $5,000 not to pollute. Or, if the two parties are afraid they will end up spending too much of their time on haggling and working out the details of an enforceable contract, they won't try.

BOX 6.5: COASE CONVERTS CHICAGO

"When, in 1960, Ronald Coase criticized Pigou's theory rather casually, in the course of a masterly analysis of the regulatory philosophy underlying the Federal Communications Commission's work, Chicago economists could not understand how so fine an economist as Coase could make so obvious a mistake. Since he persisted, we invited Coase (he was then at the University of Virginia) to come and give a talk on it. Some twenty economists from the University of Chicago and Ronald Coase assembled one evening at the home of Aaron Director. . . .

Coase then asked us to infer that in this abstract world there would be no external economies or diseconomies . . .

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."

**If contracts are costlessly enforceable . . .**

Suppose the farmer and the factory do make a deal to curb the pollution, but the factory violates it. The farmer must then go to court to force the factory to keep the contract. If it would cost the farmer $30,000 in legal fees, time, and bother to go to court, he won't. But if he foresees that, he won't make the deal with the factory in the first place. The factory will keep on polluting because it can't make a credible commitment to stop. The factory would like to be cheaply suable, because then the farmer would believe it when it said it would stop polluting in exchange for money. (Note: Would it be better for the farmer to delay payment till after he sees the factory has stopped pollution?)[10]

So far we have been staying with the original example in which the surplus-maximizing outcome was for pollution not to occur. The outcome would change if the trout fishing income was only $3,000, not $20,000. Then if the farmer owned the property right he could still stop the factory from polluting, but he wouldn't. Instead, he would say, "Factory, if you give me $3,500, I'll agree that that's fair compensation, and I'll let you kill my fish." The factory will agree— which is, with the new numbers, the surplus-maximizing result. If the factory has the right to pollute, the

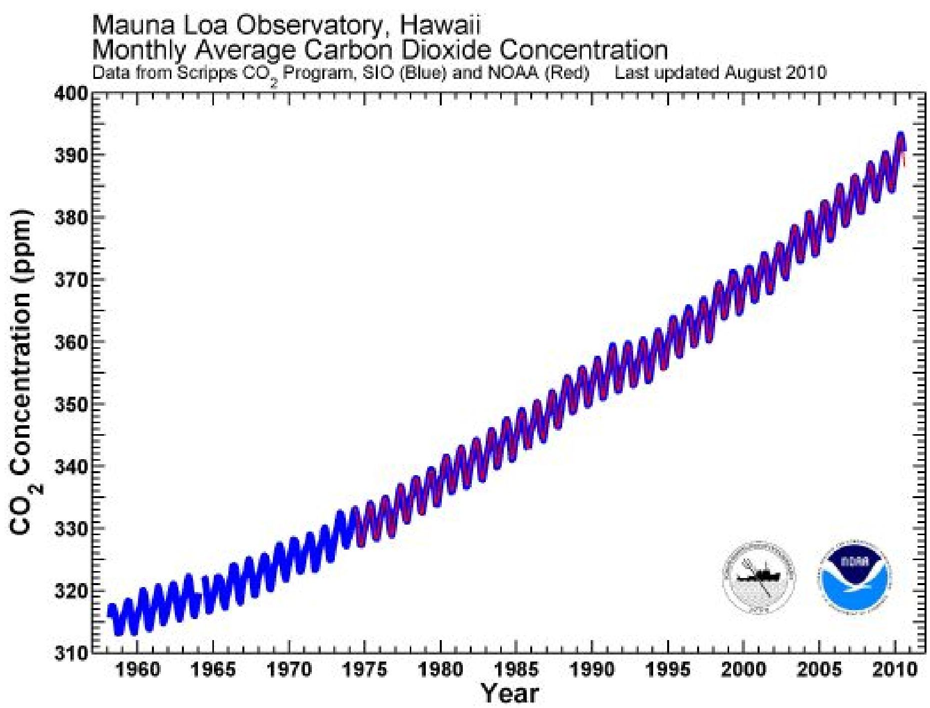
[10]There can be other problems too. One is extortion: maybe the factory locates there just to extract payments from the farmer. See "Donate Now!" http://rasmusen.org/g406/readings/Savetoby2005.htm and "Toby Has Finally Been Saved!!!!!" http://www.savetoby.com/.

farmer will only offer $3,000 to the factory to stop polluting, and the factory will refuse his offer— again the surplus-maximizing result.

**6.4: Global Warming**

There is wide disagreement as to whether we control air and water pollution too strictly or too laxly, but pollution is not one of the main political issues of the year 2011 in the United States and Europe. Global warming, on the other hand, is frequently in the news. The controversy is over whether the world is getting warmer because of increased levels of carbon dioxide and how much harm higher temperatures would cause compared to the cost of reducing carbon dioxide somehow.

FIGURE 6.8
The Rise in $CO_2$ from 1960 to 2010




Carbon dioxide is breathed out by animals, and absorbed by plants. Carbon dioxide is also generated when people burn coal, oil, or wood, or when they make cement from calcium carbonate (the main mineral in limestone). This man-made carbon dioxide is the source of the current concern, because carbon dioxide in the atmosphere increased over the 20th century from about 300 parts per million to 395, as shown in Figure 68.[11]

Carbon dioxide matters because scientists do not not understand what has caused the earth's climate to change over its history, including why the Ice Ages came and went or why the temperature fluctuated between 1850 and 1970, but they do know that carbon dioxide could warm the earth due to **the greenhouse effect.** Greenhouses stay warmer than the air outside. Since glass is transparent, the rays of the sun go through it into the greenhouse, including the warm infrared rays at the low-frequency end of the spectrum. The rays lose energy in going through the glass and hitting what is inside, and when they reflect or when the earth gives off infrared heat at night many rays are too weak to go back through the glass. Thus, heat is trapped inside.[12] Carbon dioxide, along with other less important gases such as methane, are called **greenhouse gases** because they too can create a greenhouse effect. The sun's radiation can get through greenhouse gases to the earth's surface but cannot radiate back so easily into space. Much of this is desirable, of course, but the burning of fossil fuels has increased the size of the effect, and can be expected to warm the earth.

Where the theory becomes speculative is in the feedback effects of carbon dioxide on water vapor. Not enough carbon dioxide is being generated by burning to cause important climate change by itself. The real danger is from water vapor, which is also a greenhouse gas. When carbon dioxide warms the earth a little, that results in evaporation of water, and the water vapor will warm the earth more, a multiplier effect. The interactions become quite intricate, because the extra water vapor can also result in clouds, which can block radiation from the sun and partially reverse the warming. A key element of models of global climate is the size of the positive and negative feedback effects that they assume. The theory that carbon dioxide emissions are big enough to increase world temperatures significantly depends on knowledge about feedbacks that we do not yet have. It is natural, then to turn to look at what has happened to world temperatures.

**What Has Happened to Temperatures around the World?**

Figure 69 shows what has happened to the average temperature at weather stations around the world. It shows the temperature "anomaly," putting 0 on the axis as the temperature in the middle part of the period and measuring changes relative to that period. It shows the periods from 1880 to 2010. Temperatures vary considerably from year to year, but they tended to rise from 1890 to 1940, by a total of about 0.4°F (0.2° C), showed little pattern of change from 1940 to 1970, and then rose by 1.1°F (0.6° C) more up to 2000. Figure 610 shows just the period from 1996 to 2010. Over

[11] Intergovernmental Panel on Climate Change (IPCC), "Climate Change 2007: Synthesis Report; Summary for Policymakers," (November 2007), p. 38.

[12] Another important effect is that the greenhouse traps a layer of air that cannot mix with the outside air and dissipate heat. That is important for glass greenhouses, but not for the earth's greenhouse gases.

that period there has been no clear trend, though temperatures have stayed well above where they were in 1970.[13]

FIGURE 6.9
AVERAGE SURFACE STATION TEMPERATURES AFTER 1880

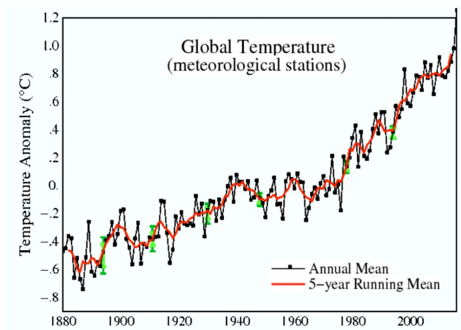
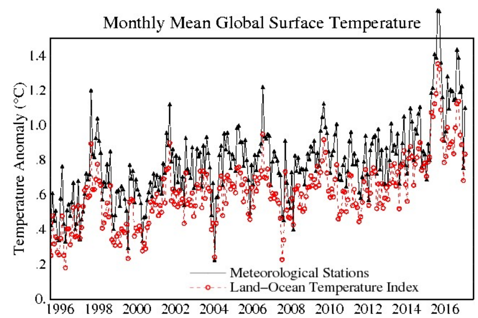



FIGURE 6.10
AVERAGE SURFACE STATION TEMPERATURES AFTER 1996




Climatologists try to correct for something called the **urban heat island problem**. This is the increase in the average temperature of cities as they grow. Cities have roads, buildings, and parking lots that can make night-time temperatures, especially, warmer than they would be in a natural setting. Cities also release heat in innumerable ways, from industrial machinery to home heating. A weather station in a city would experience a gradual increase in temperature over time even if there were no trend in the region's temperature outside of the city.[14]

For the past thirty years, there is a more uniform source of temperature data: satellite measurements. Satellites carry instruments that can measure temperatures by measuring the microwave emissions of oxygen molecules at different depths in the atmosphere. This kind of measurement is no harder over the sea than over land, and does not have to correct for the urban heat island effect. As Figure 611 shows, however, there is a different warming pattern with satellite measurements, though 2000–2010 is a little warmer than 1979–2000.

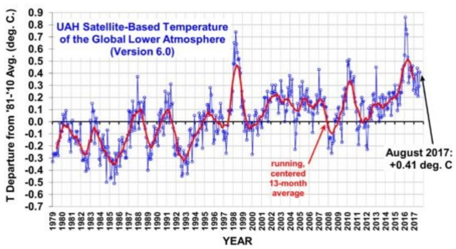
Thus, it seems that global warming has indeed occurred, but in a puzzling pattern where temperatures increased during the 1980's and 90's and levelled off after 2000. The puzzle is made even more difficult by the scandal known as **Climategate**. One of the sources of global temperature data is the Climate Research Unit in the United Kingdom. Weather stations all over the world collect data, but that mass of data

[13]For surface station temperature data, go to the NASA site at http://data.giss.nasa.gov/gistemp/tabledata/ZonAnn.Ts+dSST.txt.

[14]The placement of temperature stations can be seen at: http://www.surfacestations.org/ and by state at http://gallery.surfacestations.org/main.php?g2_itemId=20.

needs to be organized, averaged across regions, corrected for the appearance and disappearance of stations, and adjusted for the urban heat island effect. Someone whose identity is still unknown leaked a large amount of emails and computer code from the Climate Research Unit in 2009. The emails revealed a strong bias towards finding global warming in the data and personal hostility towards scholars who were skeptical of global warming. The computer code was messy enough to raise doubts about the accuracy of the data. Nonscientists were left wondering who could be trusted. More recent analysis at Berkeley seems, however, to have confirmed the general picture of temperature rising in the 80's and 90's and flattening out after 2000.[15]

FIGURE 6.11
SATELLITE-MEASURED TEMPERATURES




What will happen to the temperature in the future if $CO_2$ rises? The IPCC, a U.N. organization that summarizes climate science, estimated that if nothing were done then by 2099 the average temperature would rise 7.2°F (4°C).[16]

A survey in the *Journal of Economic Literature* says that limiting atmospheric $CO_2$ to 450 parts per million (ppm) would limit the temperature rise to 4.9°F (2.7° C). This would require emission prices of \$40-\$90 per ton of $CO_2$ by 2025 (\$140–\$330 per ton of carbon), a present value cost of \$8-\$40 trillion dollars if we cut off the costs at 2050.[17]

What is the cost or benefit of global warming? It is hard to estimate costs as far out as the year 2100. The IPCC says the effects of a 7.2°F increase would be increased water supply in the moist tropics and high latitudes, water stress for many people, significant species extinctions, widespread coral mortality, coastal wetland loss, increased damage from floods and storms, and both good and bad changes in farm productivity. It also lists increased mortality from heat waves, though, oddly, it doesn't mention the much greater diminution in mortality from cold.[18] The effects would be unevenly distributed, even if the temperature increases were equal worldwide. Siberia and Canada would enjoy milder winters, and rainfall would on average increase, but the tropics would be even hotter than today, and some places (such as the Mediterranean) would have more frequent droughts.

[15] "Scientist who said climate change sceptics had been proved wrong accused of hiding truth by colleague," *Mail Online*, David Rose, (October 30, 2011).

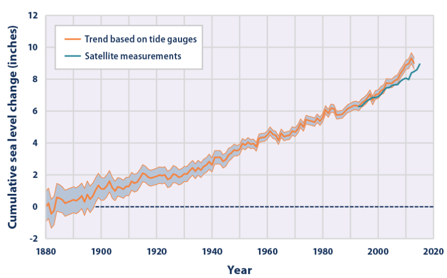
[16] "The IPCC Fourth Assessment Report: Climate Change 2007:Synthesis Report," , "A1F1 scenario," worst-case, Table SPM-1.

[17] "Designing Climate Mitigation Policy," J. E. Aldy,, A. J. Krupnick, , R. G. Newell, & I. W. H. Parry, *Journal of Economic Literature*, Vol. 48, p. 910 (December 2010).

[18] "The IPCC Fourth Assessment Report: Climate Change 2007: Synthesis Report."

One of the main concerns is that the sea level will rise, because (a) water expands when heated, and (b) if non-floating ice melts— and in particular Greenland's ice, since Antarctica isn't getting warmer— that raises sea level. Note that melting of the Arctic Ice doesn't do this, because that ice floats on the water. Figure 612 shows that the sea level has increased by almost 4 inches from roughly 1980 to 2020. Oddly, though, it had already increased 6 inches from 1880 to 1980, so there is something else unknown besides global warming going on that is increasing sea levels.

FIGURE 6.12
SEA LEVEL OVER TIME




**What Should Be Done about Carbon Dioxide?**

Suppose carbon dioxide is indeed contributing to global warming, and that global warming is bad for the world. What should we do? We could try to limit output of carbon dioxide, we could try to limit the effect of carbon dioxide, or we could try to soften the effects of the warming.

Most attention has been focused on international efforts to limit output of carbon dioxide. This could be regulated in the same way as pollution such as sulfur dioxide by command-and-control, pollution taxes, pollution taxes, or cap-and-trade. Both the costs of limiting carbon and the potential benefits are vast. A survey in the *Journal of Economic Literature* says that keeping atmospheric $CO_2$ down to 450 parts per million (ppm) would limit the temperature rise to 4.9°F (2.7° C) and require emission prices of \$40-\$90 per ton of $CO_2$ by 2025 (\$140–\$330 per ton of carbon).[19] The cost- side surplus loss from that policy would have a present value cost of \$8-\$40 trillion dollars (if we cut off the costs at 2050). At a discount rate of 5%, that comes to \$400 billion to \$2 trillion per year, compared to a world GDP of \$66 trillion in 2007.[20]

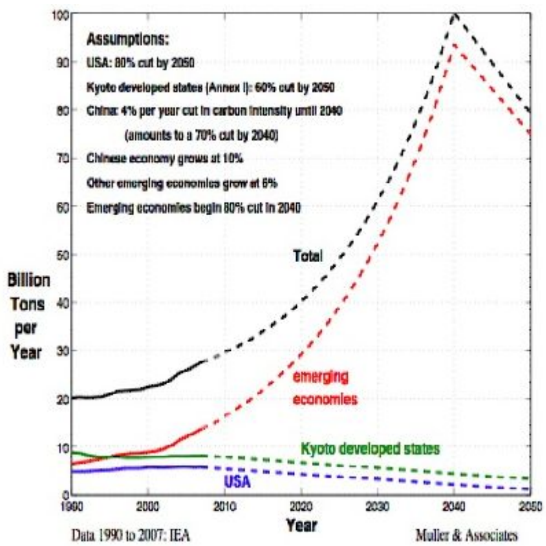
In estimating the costs of temperature rises and and carbon reduction policies, much depends on the discount rate used to calculate the present value of a dollar of benefits 100 years into the future. At a discount rate of 7%, the present value of that dollar is a penny. At a discount rate of 1% it is 37 cents. William Nordhaus found \$8/ton using market interest rates as the discount rate, and Richard Toll gave a range of \$4–\$20/ton in his 2009 analysis. Lord Nicholas Stern came up with an optimal emission price of \$85/ton of $CO_2$, using a discount rate much lower than the market interest rate because he viewed people and markets as short-sighted, perhaps in the

[19]The price per ton of carbon is 3.5 times more than for C02 because each molecule of $CO_2$ has two oxygen atoms as well as one carbon atom.

[20]"World GDP, World Gross Domestic Product, GWP, Gross World Product," *EconomyWatch* (2010).

tradition of Ramsey.[21] Thus, Lord Stern believes that all kinds of investment should be drastically increased, not just investment in preventing global warming.[22]

FIGURE 6.13
A NEGATIVE EXTERNALITY




The **Kyoto Protocol** of 1997 is an international agreement that has tried to limit carbon dioxide emissions, an agreement signed by many countries but not by the United States, where the Senate unanimously passed a resolution opposing it. Under it, OECD countries were to reduce their emissions by 28% by 2012 over what they would have been with ordinary growth, but Kyoto was only claimed to be a first step. since its effect by 2100 would only be a lowering of 0.12° C at a cost (if the US were included) of $180 billion per year.[23] The biggest growth in emissions is expected in developing countries like China and India, where rising standards of living will cause rising use of energy. The European Union has implemented a cap-and-trade system, with uneven success. How to allocate the initial carbon allowances has been politically controversial. Transportation is not covered at all; only industrial uses. There was much complaint because utility companies that generated electricity from coal were given large initial allowances, but not quite large enough to cover all the carbon they needed to burn. As a result, they bought carbon allowances on the open market, at a price, and since this was part of their marginal cost, they were able, under the countries' regulatory systems to pass on the cost to consumers via higher prices. This, of course, is how cap-and-trade is supposed to limit carbon use— by making carbon products such as electricity more expensive— so the complaints were inevitable.

A different problem is that regulating carbon emissions in just Europe raised costs

[21] "Designing Climate Mitigation Policy," J. E. Aldy,, A. J. Krupnick, , R. G. Newell, & I. W. H. Parry, *Journal of Economic Literature*, Vol. 48, p. 910 (December 2010).

[22] "A Mathematical Theory of Saving," Frank P. Ramsey, *The Economic Journal*, 38: 543–549 (1928). For a history of the issue from then till 2003 see "Should We Discount Future Generations' Welfare? A Survey on the 'Pure' Discount Rate Debate," Gregory Ponthiere, University of Liege (2003).

[23] Lomborg, pp. 24–29. I find this number puzzling given the $400-$2,000 billion figure I cited earlier (though for a much bigger $CO_2$ reduction). Probably it reflects how uncertain we are of the potential costs.

for carbon-burning European companies but not for companies in other parts of the world such as China. One manager of a French cement plant said, "I've been yelling about this. What do you want me to do? Put a plant in Mauritania or Morocco and close this one?". Unlike in the case of ordinary pollution, carbon dioxide causes the same problem wherever in the world it is emitted— the problem is *global* warming— and so shifting output overseas has no overall benefit.[24] This unintended policy effect of shifting of where or when carbon dioxide is generated is known as **emission leakage**.[25] Emissions leakage appears in other ways too. If less oil is used in Europe because of cap-and-trade, then the world price of oil falls and more will be demanded on other continents. If coal producers expect oil demand to fall in the future because more countries will adopt anti-carbon policies or work hard on carbon-free substitutes for coal, they will produce more coal now, while they can still sell it. Thus, green policies can actually accelerate carbon emissions.

An alternative to cap-and-trade (though one with an equal problem of emissions leakge) is the **carbon tax**. Instead of auctioning off permits or giving them away, the government would charge a tax on emissions, collecting revenue without constraining the total amount of carbon output. Five Scandinavian countries, the United Kingdom, and the province of British Columbia in Canada impose carbon taxes, which they use to attain the national carbon emission goals negotiated in the European Union. About 80% of U.S. carbon output could be covered by a system that taxed only 3,000 companies and government units. There are about 247 million registered motor vehicles in the United States, but only 146 petroleum refineries— and many other industries use petroleum products.[26] Carbon tax revenue could be used to reduce income taxes, and though the impact of carbon taxes would be particularly hard on the poor (via the rise in the prices of such things as electricity and gasoline) their taxes could be particularly reduced, or, if they were already below the tax threshold, they could be provided tax credits. Since carbon is used in so much of the economy, a carbon tax would have an effect similar to that of a sales tax on goods that exempted services. A $1/ton tax on carbon, which would amount to about a 1 cent per gallon tax on gasoline, would reduce emissions by 2%. Economist William Nordhaus has argued that a carbon tax would be superior to cap-and-trade because it would be easier to implement one country at a time, because of our uncertainty over the appropriate year-to-year cap to put on emissions, and because it avoids the political problem of how to assign permits. As mentioned earlier, he estimates $8/ton of $CO_2$ ($28/ton of carbon) as the optimal tax

[24] "Europe's Problems Color U.S. Plans to Curb Carbon Gases," *Washington Post*, p. A01 (April 9, 2007).

[25] See "On Hotelling, Emissions Leakage, and Climate Policy Alternatives," Carolyn Fischer and Stephen Salant, Resources for the Future (2010).

[26] "The Design of a Carbon Tax," Gilbert E. Metcalf, and David Weisbach, *Harvard Environmental Law Review* 33(2): 499–556 (2009).

level,[27]

**Carbon sequestration** refers to the capturing of carbon dioxide that is in the air or would be emitted there and immobilizing it in some other chemical form. This is the reverse of burning carbon to produce carbon dioxide; instead, one starts with the carbon dioxide and turns it into some chemical form that does not cause global warming. Trees and other plants do this, so reforestation is one tool for reducing global warming. Or, carbon dioxide can be reacted with magnesium- and calcium-based rocks. To do that, the gas is captured at the site of emission, compressed, and transported to some site where it can be injected into underground rocks. Using current technology, that would add 75 percent to the cost of electricity for a new pulverized coal plant and around 35 percent for a new gasification coal plant.[28]

Carbon sequestration could be implemented by command-and-control as a requirement for new power plants, but it could also be part of a cap-and-trade or carbon tax scheme. In that case, power plants would consider the costs of sequestration via chemical reaction and could use that instead of purchasing extra carbon allowances or paying extra carbon tax if sequestration were more cost-effective. Sequestration by means of tree planting would not be so automatic, but it could be achieved by giving out extra carbon allowances to anyone planting trees or by allowing that to substitute for paying the carbon tax for emissions.

A quite different approach is to use **geoengineering solutions**, which try to change the relationship between emissions and climate change. Under one approach, tons of iron would be dumped into the Antarctic Ocean, a part of the world's oceans having enough other nutrients that with the addition of iron, green algae would bloom and absorb more carbon dioxide. When the algae died, it would sink to the ocean floor, permanently removing the carbon. Under another approach, aerosols such as sulfur dioxide would be inserted into the upper atmospheres using converted jetliners, simulating the effects of volcanic eruptions, which are known to cause enough blockage of the sun's rays to reduce world temperatures. In 1991 the eruption of Mount Pinatubo in the Philippines poured such a large amount of sulfur dioxide into the atmosphere that the average global temperature dropped 0.5 degree Centigrade for almost two years, which is about the same as the amount of global warming we have experienced.[29] Or, geoengineering could proceed on a small scale. One reason cities are warmer is because they have a lot of black surface that absorbs heat from the sun. Planting 11 million trees, and reroofing 5 million homes and painting a quarter of the roads with

[27] "The Architecture of Climate Economics: Designing a Global Agreement on Global Warming," William D. Nordhaus, *Bulletin of the Atomic Scientists*, 67: 9–18 (2011).

[28] "Carbon Capture and Storage R&D Overview," U.S. Department of Energy.

[29] "Geoengineering: A Global Warming Fix?" Pete Geddes, National Center for Policy Analysis (January 30, 2008) .

more reflective surfaces might reduce Los Angeles temperatures by 5.2° F (3° C).[30]

The main disadvantage of geoengineering solutions is the fear of unanticipated consequences from large interventions. Geoengineering would seem to be much cheaper than emission control, however. William Nordhaus has estimated the present value of the cost of implementing the Kyoto Protocol with U.S. participation as $0.54 trillion, with a benefit of $1.17 trillion. He estimates that the more drastic policies advocated by the United Kingdom's Stern Review would cost $27.70 trillion and have a benefit of $13.53 trillion, while the carbon tax Nordhaus himself finds optimal would cost $2.16 trillion and have a benefit of $5.23 trillion.[31] All these estimates are uncertain, but estimates of the cost of geoengineering solutions are in the billions rather than trillions of dollars. In addition, the cost of geoengineering solutions can be delayed until the amount and cost of warming becomes clearer, and geoengineering would work faster as an emergency policy if we have underestimated the speed with which warming could proceed and the severity of its consequences.

To be sure, government failure is a danger when large sums of money are invested. The solar panel company Solyndra received half a billion dollars in loan guarantees soon before it filed for bankruptcy in 2011. From 1961 to 2008 the federal government spent $172 billion (in 2005 dollars) on energy projects, a quarter of it from 1974 to 1980.[32] Much of that was on basic research, the payoff from which is hard to measure. The projects included notorious failures in trying to develop new technology on a commercial scale when private companies were unwilling to take the risk without government support. In 1971, the Clinch River Breeder Reactor project was started to provide a cheaper source of nuclear fuel. In 1983 the program terminated after billions of dollars in spending but without producing any new fuel. In the late 1970's, President Carter called the Synthetic Fuels Corporation, which was to turn coal into oil as the Germans did in World War II, the "keystone" of U.S. energy policy. In 1986 it closed down, a failure. President George W. Bush called in 2003 for hydrogen-powered car subsidies to "overcome obstacles to taking these cars from laboratory to showroom," but they never did make it to the showroom. The Congressional Budget Office estimated that a quarter of the funds were diverted to congressmen-favored projects outside the scope of the main effort. Currently, carbon sequestration projects are looking increasingly dubious.[33] There are no matching successes, except perhaps for the government- subsidized development of nuclear power in the 1960's.

[30] *Cool It*, Bjorn Lomborg (2007), p. 24.

[31] *The Challenge of Global Warming: Economic Models and Environmental Policy*, William Nordhaus, Table V-3, p. 218, (July 24, 2007).

[32] "U.S. Federal Investments in Energy R&D: 1961–2008" J.J. Dooley, U.S. Dept. of Energy (October 2008).

[33] "Before Solyndra, a Long History of Failed Government Energy Projects," *The Washington Post* (November 12, 2011).

Geoengineering for climate change is like basic research in that lack of interest by private companies does not indicate lack of potential benefit. There is no profit potential from changing the world's temperature, unless it be from extortion, which the government could easily shut down. Thus, it requires government funding, though on such a small scale relative to alternative energy or reduction in energy use that a single country might find the benefit worth the cost. Besides its relative cheapness, moreover, geoengineering has **option value**, meaning that its implementation can be delayed until the true scope of temperature change becomes apparent. Efforts to control carbon dioxide need to begin now, before the temperature has risen significantly, and would be wasted if it turns out that temperatures are not going to rise much more. Mankind has survived experts' predictions of disaster ranging from DDT (1970's), the ozone hole (1990's), acid rain (1980's), bird flu (2005), swine flu (1976), Ebola virus (1970's, mad cow disease (1980's), SARS (2003), and the Y2K computer collapse (1999).[34] Policymakers should listen to experts such as scientists, lawyers, and economists, but they should listen critically and make sure that claims are backed up by evidence and reasoning rather than just expert authority. In addition, even if we manage to halt the growth in carbon dioxide emissions, unless we halt emissions completely the atmospheric level will increase, so reducing growth merely delays the problem of high temperature rather than solving it. Geoengineering, on the other hand, could be implemented relative quickly, or on a bigger or smaller scale depending on what happens to the climate. As President Eisenhower said about what he learned in the army: "Plans are worthless, but planning is everything. There is a very great distinction because when you are planning for an emergency you must start with this one thing: the very definition of "emergency" is that it is unexpected, therefore it is not going to happen the way you are planning."[35] Plans that can be changed are especially valuable when the situation is one that we have not encountered before.

Still another solution to global warming is to not try to control the temperature at all, but to control its effects instead. In the summer, you do not try to change the weather; you install air conditioning. Similarly, if the problem is poor crop yields because of a permanent drop in rainfall, one solution is to try to lower the temperature to try to increase rainfall, but a more straightfoward solution is irrigation and the use of different crop varieties. With fifty years and 27 trillion dollars saved from not trying to adjust carbon dioxide levels, it would be possible to make a lot of adaptions to the increase of 7.2 degrees Farenheit expected by the IPCC.[36] This policy of adjustment to

[34]"Apocalypse Not: Here's Why You Shouldn't Worry about End Times," Matt Ridley, (August 17, 2012 ).

[35]From a speech to the National Defense Executive Reserve Conference in Washington, D.C. (November 14, 1957) ; in *Public Papers of the Presidents of the United States, Dwight D. Eisenhower, 1957,* National Archives and Records Service, Government Printing Office, p. 818.

[36]"Global Temperature," GlobalGreenhouseWarming.com (January 21, 2011).

temperature change is called **amelioration**.

On the other hand, many countries might prefer not even to engage in amelioration, but instead to spend the emissions restriction or amelioration budget to raise their standard of living. In poor countries, clean water supplies, malaria, medical facilities, and literacy are higher priority than temperature change. Climate scientist Roy Spencer notes that "22,000 children die each day in the world due to poverty; in contrast, we arent even sure if anyone has ever died due to human-caused global warming.[37]

This suggestion, however, takes us into the difficult question of countries' differing objectives. Spending a trillion dollars on poverty aid in Africa has no direct benefit to the United States. Even spending a trillion dollars on reducing the growth rate of $CO_2$ output has more benefit to the rest of the world than on the United States. The free rider problem is severe. Ideally, most countries (except for the few that would actually benefit from warmer temperatures) would like other countries to restrict carbon dioxide but not to bear any costs themselves. Since each country is independently governed, it is hard to force cooperation. Moral suasion— that is, shame— has diminishing returns when it comes to inducing countries to give up significant chunks of GDP. Thus, even if there were unanimous agreement as to the ill effects of global warming, some solution to free riding would need to be found.

Indeed, Figure 6.14 suggests that at first cut, we can simplify the problem to just that of keeping China's carbon dioxide from growing. China is so big, and growing so fast, that the rest of the world is trivial by comparison. China is also militarily powerful, and cannot be intimidated. It could be paid— but the Coase Theorem does not apply here, because of free riding in the bargaining over who would pay. How would you address this?

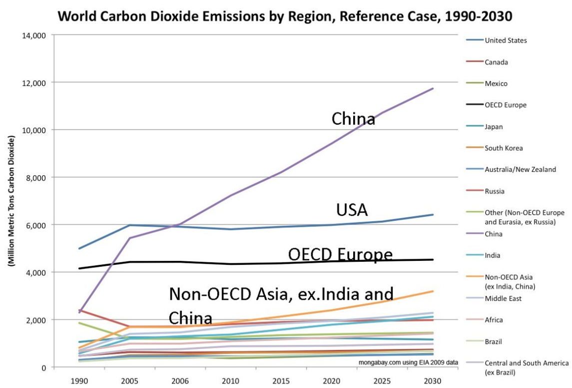
**EPA vs. Massachusetts**

The United States President and Congress have not been able to come to agreement on a policy to deal with global warming, so in effect American policy has been to wait and see. The Environmental Protection Agency, however, is granted broad and indefinite authority to deal with pollution. Is $CO_2$ pollution? Part of the Clean Air Act is U.S. Code Title 42. §7521, "Emission standards for new motor vehicles or new motor vehicle engines," which says:

> (a)(1) The Administrator shall by regulation prescribe (and from time to time revise) in accordance with the provisions of this section, standards applicable to the emission of any air pollutant from any class or classes of new motor vehicles or new motor vehicle engines, which in his judgment cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare.

[37] "Science under President Trump: End the Bias in Government-Funded Research," Roy Spencer, *Climate Change* blog (2016).

FIGURE 6.14
ONLY CHINA MATTERS




Title 42 §7602 "Definitions" says:

> (g) The term "air pollutant" means any air pollution agent or combination of such agents, including any physical chemical biological radioactive physical, chemical, biological, (including source material, special nuclear material, and byproduct material) substance or matter which is emitted into or otherwise enters the ambient air.

In 1999, 19 private organizations filed a rulemaking petition asking the EPA to regulate greenhouse gas emissions from new motor vehicles under the Clean Air Act. Fifteen months later, the EPA requested public comment. The EPA received more than 50,000 comments over the next five months. In September, 2003 the EPA entered an order denying the rulemaking petition, saying:

> (1) that contrary to the opinions of its former general counsels, the Clean Air Act does not authorize EPA to issue mandatory regulations to address global climate change; and
> (2) that even if the agency had the authority to set greenhouse gas emission standards, it would be unwise to do so at this time.

The EPA's denial was challenged in court by the state of Massachusetts on the grounds that the EPA's refusal to regulate was contrary to the Clean Air Act. In *Massachusetts v. Environmental Protection Agency*, 549 U.S. 497 (2007), the Supreme Court ruled that the EPA did have authority to regulate greenhouse gases and must do so. Since then, the EPA has slowly been moving to do just that. In 2009 it issued a finding that six major greenhouse gases were a threat to public safety, and in 2010 it issued rules establishing a program to require permits and carbon dioxide control efforts for major new industrial sources and, with the National Highway Traffic Safety Administration, for cars and trucks. These will be phased in over several years starting in 2011.[38]

## 6.5: Concluding Remarks

Externalities are a major source of market failure and pollution regulation is the prime example of government response to them. The three main ways to regulate are command-and-control, tradable emissions permits, and pollution taxes. Command and control is the most direct way to regulate, but is inflexible and costly. tradable permits

[38] "Climate Change— Regulatory Initiatives," EPA.

allow the total quantity to be controlled, and if the permits are auctioned off they can also raise revenue for the government. Pollution taxes always raise revenue, and they avoid the problem of unduly constraining the economy's growth by limiting emissions, but they don't allow for fine control of the emissions quantity. In recent years, concerns over carbon dioxide have taken center stage in the regulation of externalities. Carbon dioxide is the opposite of other pollutants in the sense that each ton emitted is harmless in isolation to the place where it is emitted, but in conjunction with emissions around the world it may well be causing the world's temperature to warm with unpredictable consequences. This makes effective regulation difficult, since each country would like to behave as a free rider. The science remains uncertain, and the political future of global warming even more so.

## Review Questions

1. When is pollution a sign of market failure?
2. How are command-and-control regulation, pollution taxes, and cap-and- trade policies similar to each other and how are they different?
3. What is the effect of different kinds of pollution regulation on market prices and quantities?
4. What determines the optimal amount of regulation of an externality?
5. What does the Coase Theorem say about when regulation of externalities is useful?
6. Why is determining the optimal response to global warming especially difficult compared to pollution regulation?

## Readings

1. "The SuperFreakonomics Global-Warming Facts Quiz," Stephen Leavitt.
2. "Abolish Drunk Driving Laws: If Lawmakers Are Serious about Saving Lives, They Should Focus on Impairment, Not Alcohol," Randy Balko.
3. "Poor Countries Shouldnt Sacrifice Growth to Fight Climate Change," Charles Kenny, *Bloomberg BusinessWeek*.

4. *“Lawn Wars: Leaf Blower Opponents Seek Peaceful Resolution to Neighborly Feud,” The Guardian*.

5. “Giant Pipe and Balloon To Pump Water into the Sky in Climate Experiment,” *The Guardian*.