Chapter #5: Issues in Externality Control

Contents:

Positive Externalities

A positive externality exists if the activities of one individual (or group) lead to increases in the utility or productive ability of some other individual (or group), when the benefits are not transmitted through a market.

For example, an apple farmer might receive unpaid benefits from a neighboring honey producer if the honey producer's bees pollinate the apple trees. Because the benefits associated with positive externalities are not paid for in market transactions, the activities producing these benefits are carried out at an inefficiently low level. In the first example above, unless the apple farmer pays the bee keeper for the marginal value of pollinating services, the bee keeper will not recognize this value in her objective function and thus keep an inefficiently low number of bees.

An Economic Model of Positive Externalities: Consider a fertilizer manufacturers who uses animal waste as an input and generates a positive externality by removing the waste from the environment. Let:

X = the amount of animal waste used by fertilizer manufacturers.
D(P) = the fertilizer manufacturers' demand for X
PB(X) = the fertilizer manufacturers' private benefit from output X (i.e., the area under the demand curve).
EB(X) = environmental benefit of removed waste X.
SB(X) = social benefit of X = PB(X) + EB(X).
C(X) = cost of obtaining X.
SW(X) = social welfare of using X = PB(X) + EB(X) - C(X)

Now Consider the Market for Animal Waste

Social optimization problem**:**

$$\underset{X}{Max.}\{SW(X) = PB(X) + EB(X) - C(X)\}$$

First-Order Condition: $PB_X + EB_X - C_X = 0$,

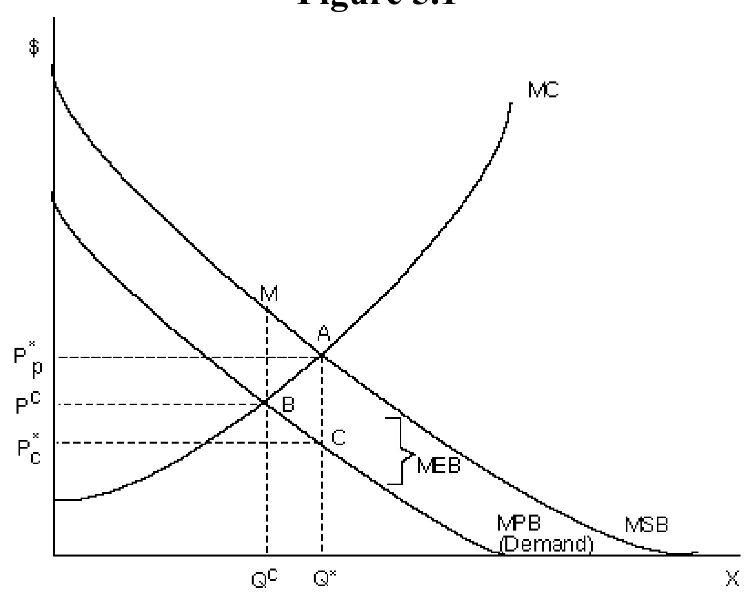
or, MPB + MEB = MC.

Hence, the socially optimal solution is to use X* animal waste, such that:

MSB(X*) = MC(X*)

Positive Externalities

Figure 5.1



Q^* = optimal output

P^*_c = optimal consumer price

P^*_p = $(P^*_c + S^*)$ = optimal producer price

Q_c = competitive output

P_c = competitive price

S^* = $P^*_p - P^*_c$ = MEB = optimal subsidy [note that $S^* = MEB(Q^*)$]

In Figure 5.1, the socially optimal solution, where MSB = MC, occurs at point A. In contrast, the competitive solution is to use fertilizer until MPB = MC, which occurs at point B.

At point B, the quantity of fertilizer used is lower than under the socially optimal solution ($Q^c < Q^*$), which means that the competitive solution results in an insufficient utilization of X.

A subsidy S* = MEB(X*) will achieve the optimal solution. With subsidy S*, the following welfare implications arise:

consumer gain	= $P_c^* P^c$ BC
producers gain	= AB $P^c P_p^*$
environmental gain	= MBCA
subsidy cost	= P_c^* CA P_p^*
net social gain	= BAM.

Note the asymmetry between optimal policies for positive and negative externalities: The likely policy to address positive externalities is a subsidy. The likely policy to address negative externality is direct controls or taxes.

Polluter Heterogeneity and Markets for Pollution

When firms are heterogeneous and differ in their ability to abate, or cut back, their pollution, it is necessary to determine both the efficient amount of total emissions *and* the efficient mix of pollution among alternative sources. The efficient mix of pollution is simply the combination of controls that generates the efficient amount of total pollution at the lowest cost. This may require that all polluting firms in a given location abate pollution to the same level, or perhaps that only one of many firms should abate.

The market approach, or transferable permit system to correct negative externalities attempts to establish markets for pollution. The approach utilizes economic incentives found in conventional markets to allocate pollution abatement between firms in the most cost-effective manner.

Assume there are I groups of polluters (different industries, firms, etc.) emitting pollution into a common medium, for example, an airshed or a lake. We will also assume that the medium is "well mixed", in the sense that pollution emitted by any one polluter does not cause local damage outside the common medium; that is, all pollution is the same in the model and cannot be decomposed by location. Let:

X_i = pollution generated by polluter i.

$B^i(X_i)$ = the monetary benefit of polluter i derived from pollution (we can think of pollution benefits in terms of foregone abatement costs).

Total pollution = $\boldsymbol{X} = X_1 + X_2 + X_3, \ldots, X_I = \sum_{i=1}^{I} X_i$

SC($\boldsymbol{X}$) = social cost of pollution (depends on total pollution).

The social optimization problem is:

$$\text{max.} \sum_{i=1}^{I} B^i(X_i) - SC(X) \quad \text{subject to} \quad X = \sum_{i=1}^{I} X_i \,.$$

Using Lagrange multiplier techniques, this problem becomes

$$\max\ L = \sum_{i=1}^{I} B^i(X_i) - SC(X) + \lambda\left[X - \sum_{i=1}^{I} X_i\right]$$

where, λ, the shadow price of pollution = marginal cost to society from an added unit of pollution.

$$\text{FOC:}\quad L_{X_i} = \frac{\partial L}{\partial X_i} = \frac{\partial B^i}{\partial X_i} - \lambda = 0 \quad \text{for } i = 1, I$$

$$L_X = \frac{\partial L}{\partial X} = -\frac{\partial SC}{\partial X} + \lambda = 0$$

where: $\frac{\partial B^i}{\partial X_i} = B^i_{X_i} = MB_i$ = marginal benefit of polluter i from polluting

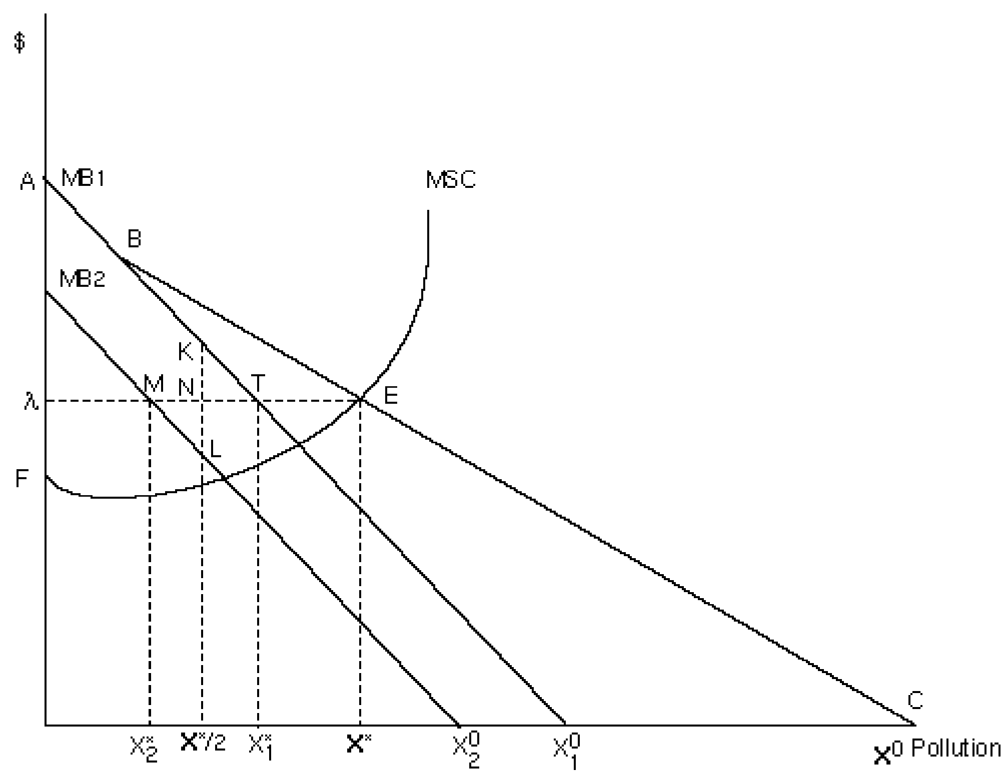
and $\frac{\partial SC}{\partial X} = SC_X$ = MSC = marginal social cost of pollution.

At the optimal solution, $MB_i = MSC = \lambda$ for all i. Marginal benefit of pollution is equal across producers and equal to marginal cost of pollution. The optimal solution can be attained by a unit tax, $t^* = MSC(\boldsymbol{X}^*)$, which could be charged for each unit of pollution.

The optimal solution can also be attained by trading pollution permits, where total pollution is restricted to the optimal pollution level, $\boldsymbol{X}^*$. At the optimal solution, assuming competitive trading, the price of a pollution permit will be λ.

Heterogeneity: The Case of Two Polluters (I = 2)

Figure 5.2



where:

ABC = horizontal sum of MB_1 and MB_2 = aggregate demand for pollution

$\frac{\partial SC}{\partial X} = SC_X = MSC$ = marginal social cost of pollution

$X_1^*, X_2^*, \boldsymbol{X}^*$ = optimal levels of pollution

X_2^0, X_1^0, X^0 = initial unregulated levels of pollution

Recall that to achieve ***X****** using a pollution tax, we could set a per unit tax on pollution equal to the MSC at $X^* = \lambda$. In this case, each individual producer will equate their MB to the tax and will produce the socially optimal level of pollution

With tradable pollution permits, each polluter is assigned $X^*/2$ pollution coupons. They are traded at an equilibrium price of λ. Polluter 1 buys $X_1^* - X^*/2$ from polluter 2. **These are gains from trade**. Welfare is smaller if each polluter is restricted to **X***/2 pollution units and trade is disallowed.

· Seller Gains from trade = revenue received - total benefits of lost pollution

where:
total benefits of lost pollution = area under MB curve for units traded

· Buyer Gains from trade = total benefits of gained pollution - cost of pollution permits

KNT = gains from trade of polluter 1 = $KTX_1^* X^*/2$ - $NTX_1^* X^*/2$.
MNL = gains from trade of polluter 2 = $NMX_2^* X^*/2$ - $LMX_2^* X^*/2$.

Note that the larger the heterogeneity (the larger the difference between MB1 and MB2), the more likely trade is to occur and the larger the volume of trade in pollution permits.

<u>The Benefits of Pollution Trading</u>

The transferable permit system combines some of the best elements of taxes and standards. Although we showed above that the same outcome can be achieved with a pollution tax at $t^* = \lambda$, or with quotas at X_1^* and X_2^*, such a policy requires full knowledge of the true social cost of pollution.

In practice, standard-based controls are often implemented in place of taxes to achieve some arbitrary goal, such as "a 20% reduction in pollution", or to “hold emissions at 1995 levels”. When regulatory policy is designed to achieve an arbitrary pollution standard, the target level can be reached with an efficient mix of pollution with a transferable permit system without requiring the regulator to know the individual benefit functions, MB1 and MB2.

Problems Associated with Pollution Permit Markets

Measurement and monitoring: Pollution may not be easily observed, contained, or measured. If the policy goal is to control actual pollution levels, then technological standards in the form of requirements to install pollution containment and control equipment may be preferred to pollution taxes.

Cost of pollution regulation depends on monitoring and containment costs. Development of new technologies may lead to change in policy tools.

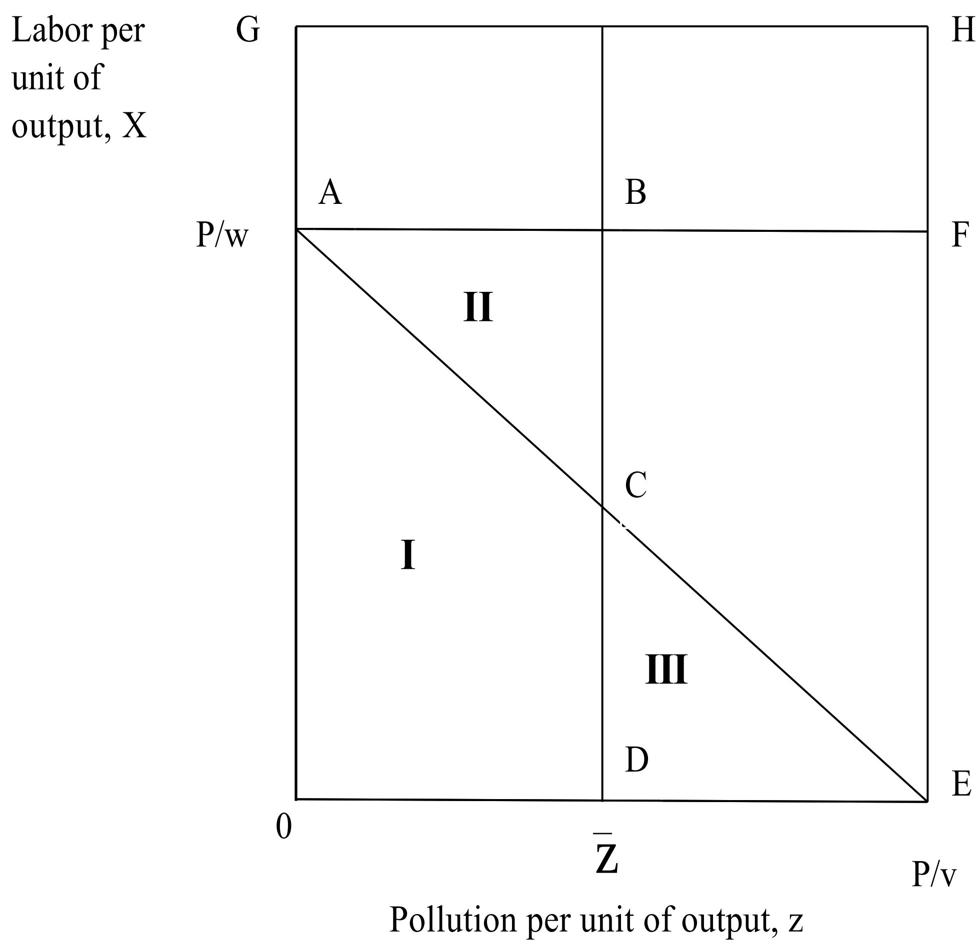
Multitude of pollutants: There are several "greenhouse" gases. Do you regulate them separately and trade in pollution permits in each of them or do you develop equivalence scales and have one market? When small numbers of activities generate multitudes of pollutants, it may be easier to regulate polluting activities, rather than attempting to regulate pollution itself.

Number and variability of polluters: Permit markets are more effective when the number of participants is larger and highly varied. Yet, if pollution impacts differ between locations, should you have many small markets recognizing regional variations or a few large markets that cover heterogeneous regions?

Choice of Pollution Taxes or Standards

Assume that firms have a fixed-proportions production technology; that is, each firm has a fixed labor/output ratio and a fixed pollution/output ratio. In order to model the case of heterogeneous firms, we allow these ratios to differ across firms, so that some firms can produce more output with less labor than other firms and some firms can produce more output with less pollution.

Figure 5.3: (Source: Hochman and Zilberman)



Let:

P = output price,
x = labor used per unit of output (i.e., x = labor/output ratio)
w = the wage rate for labor
z = pollution produced per unit of output (i.e., z = pollution/output ratio)
v = a pollution tax
$\bar{z}$ = a quota/standard on pollution per unit of output.

In the figure, relatively labor-efficient firms (lower labor per unit of output) are represented by points toward the bottom, or horizontal axis of the graph, while relatively pollution-efficient firms (lower pollution per unit of output) are represented by points toward the left, or vertical axis of the graph.

A firm will choose to produce whenever $P \geq wx + vz$, as the output price is enough to cover variable costs. If $P < wx + vz$, however, the output price fails to cover variable costs and the firm will shut down.

First consider the pre-regulation case: There is no pollution tax and no pollution standard in place. In this case, since there is no pollution tax, $v = 0$, and firms will operate provided that $P/w \geq x$; if $P/w < x$, a firm will shut down. The line AF delineates this "survival region". Firms with labor-efficiency below line AF operate in the initial pre-regulation equilibrium, while less labor-efficient firms (those above line AF) do not.

Under a pollution standard/quota, an upper bound is set on pollution per unit of output at $\bar{z}$. When there is no pollution tax, firms with $z \leq \bar{z}$ *and* $P/w \geq x$ will survive. The survival region is the area OABD. Compared with the case of no regulation, a pollution standard eliminates the highly polluting firms in region DBFE.

Under a pollution tax, v, firms with x, z combination such that $P \geq wx + vz$ will continue to operate, while firms with $P < wx + vz$ will shut down. The line AE is the border line of "survival region." Firms below AE will continue to operate; firms above the line AE will shut down. Compared with the case of no regulation, a pollution tax eliminates the highly labor intensive, highly polluting firms in region AFE.

Thus, a given level of pollution can be achieved with either a pollution tax or standard; however, the types of firms which shut down may differ:

(1) A pollution tax achieves a given level of pollution by eliminating highly polluting producers, but some of the remaining low-cost producers may be highly polluting (producers in area CED). Critics may charge the policy maker with "letting big polluters off the hook".

(2) A pollution standard achieves a given level of pollution by eliminating highly polluting firms, but some of the eliminated producers may be low-cost firms (producers in area CED). Additionally, highly labor-inefficient firms continue to produce (producers in area ABC). Critics may charge the policy maker with "shutting down the most efficient businesses."

Although standards achieve the same environmental targets less efficiently (at higher cost), there is another reason they are often used in practice: standards achieve a given level of pollution with a smaller impact on prices. It may be important to policy-makers to moderate the effects of environmental regulation on output, because output is closely related to employment and employment is a sensitive political issue. Similarly, it may be important to policy-makers to moderate the effects of environmental regulations on prices, because consumers can be quite sensitive to significant price changes (especially in poor countries). We will show this result in the example below: standards achieve the same pollution target at a higher cost, but also at higher output levels than pollution taxes.

Standards Are Less Efficient than Taxes, But Result in Higher Output

Consider three groups of firms in the figure:

- Group I will survive under either a pollution tax or a pollution standard (firms in the area OACD).
- Group II will survive only under a standard (firms in the area ABC)
- Group III will survive only under a tax (firms in the area CED)

For Group I, let:

z(I) = pollution per unit of output of group I
Q(I) = output of group I
Z(I) = pollution of group I [i.e., Z(I) = z(I)Q(I)]

where a similar definition applies for Group II and III.

***Comparing the outcomes of taxes and standards**:*

Under a pollution tax: Total pollution = Z(I) + Z(III)
Under a pollution standard: Total pollution = Z(I) + Z(II).

If the same level of total pollution is to be achieved in the economy under either the tax or the standard, then it must be the case that Z(II) = Z(III).

Note that, by definition:

$$Z(II) = z(II)Q(II), \text{ and}$$
$$Z(III) = z(III)Q(III).$$

Since $z(III) > z(II)$, it must be the case that Q(II) > Q(III).
Now, since

$$Q(\text{standard}) = Q(I) + Q(II), \text{ and}$$
$$Q(\text{tax}) = Q(I) + Q(III),$$

it must be the case that Q(tax) < Q(standard)

Thus, given a choice of regulatory policy to achieve the same target level of pollution, a pollution standard will hit the target at a higher (albeit less efficient) level of output. Politicians may prefer the higher output levels associated with pollution standards to the greater efficiency of pollution taxes, because votes often depend on jobs, and jobs are more closely related to output rather than to economic efficiency.

Conclusions

- Taxes achieve environmental targets at the least cost (highest efficiency).
- Standards achieve environmental targets at a lower level of economic efficiency, but with less impact on output and employment.
- Taxes cause the least-efficient plants to close, but some highly polluting firms may remain open
- Standards cause the most highly polluting plants to close, but may allow some inefficient plants to remain open.

Specification of Pollution in Productive Activities:
Is Pollution Caused by an Output or by Inputs?

An economically efficient specification of pollution control policies depends on whether pollution is a function of output or of the inputs used in productive activities. As an illustration, consider a competitive industry with identical firms. For each firm, let:

Y = output
P = output price
X = a single input
W = the per unit cost, or wage rate, of X
M = a second input
V = the per unit cost of M
Z = pollution.

The production function for each firm is: Y = f(X, M).

Pollution damage per firm is h(Z); we assume: $h_Z > 0, \quad h_{ZZ} > 0$.

(Case A) Pollution Z depends on output Y: Z = g(Y)

Then the firm's cost function can be written as C(Y, W, V) and optimal policy can be determined by solving:

$$\max_{Y} \left\{ W(Y) = PY - C(Y,W,V) - h\left(g(Y)\right) \right\}$$

FOC: $P - C_Y - h_Z g_Y = 0.$

or, Price = marginal cost per unit (C_Y)+ marginal external cost per unit ($h_Z \cdot g_Y$),

where ($h_Z \cdot g_Y$) = (marginal damage per unit of pollution)(marginal pollution generated per unit of output)

· Note the use of the chain rule: $h_z g_y = \dfrac{dh}{dg(Y)} \dfrac{dg(Y)}{dY}$

Policies to obtain the optimal solution:

(a) Tax pollution by h_Z (i.e., a per unit tax on pollution), or

(b) Tax output by $h_Z \cdot g_Y$ (i.e., a per unit tax on output)

(Case B) Pollution Z depends on the input X: Z = g(X)

An example of this case would be the situation in which both labor and fertilizer are used as inputs in production. In this case, since pollution depends on a single input, fertilizer, the social optimization problem involves specifying the production function of the firm.

The social optimization problem is now:

$$\underset{X,M}{\text{Max.}}\left\{W(X,M) = Pf(X,M) - VM - WX - h\big(g(X)\big)\right\}.$$

So that we now have two optimality conditions:

(1) $W_M = Pf_M - V = 0$,

which states that the value marginal product of M, Pf_M, is equal to its wage.

(2) $W_X = Pf_X - W - h_Z \; g_X = 0$,

which states that the value of marginal product of X, Pf_X, is equal to its wage plus the marginal environmental cost of output X, ($h_Z \cdot g_X$).

Policies to obtain the optimal solution:

(a) Tax of h_Z on pollution, (i.e., a pollution tax), or

(b) Tax of $h_Z g_X$ on X (i.e., a unit tax on the polluting input).

So which Specification Is Best?

In the case of a single polluting input, with no other inputs, ease of measurement is the only consideration. Sometimes, output is easier to measure than a firms use of an input. Output information, for example, can be derived from sales tax data.

When inputs such as capital cause pollution, a tax on firm output may be suboptimal. A tax on output will cause a reduction in the use of both inputs, including labor, whereas the optimal policy may call for an increase in the use of a non-polluting input, such as M; that is, under the optimal policy, the non-polluting input, M, might substitute for the polluting input, X. A tax on output, Y, in this case, causes an inefficient decrease in the use of the non-polluting input, M, concurrently with the desired decrease in X.

Components of Externality Policy

Education: A preventive policy used to instill environmental values (i.e., do not litter) about new environmental issues (i.e., global warming) and about pollution control technologies. Can also change peoples preferences and develop social norms of behavior.

Clear property rights definition: To enable private parties to efficiently use the legal system to resolve externality problems.

Direct control policies: Often take the form of standards/quotas and technology standard on production or on pollution. Also includes *Building Codes* on houses. Such policies are often less efficient at controlling pollution, because they do not take advantage of financial incentives and the market mechanism.

Taxes: Applied directly to pollution and/or to pollution-generating outputs, inputs, or production activities.

Subsidies: Given to firms for pollution reduction and abatement activities, or for the development of substitute technologies to eliminate pollution-generating activities. An indirect type of subsidy is credit provision to finance investment in pollution control activities when private finance is unavailable.

Trading in pollution rights: Gives firms the right to collect and trade permits for pollution-generating activities. Can often be used to achieve a given pollution reduction at a lower cost to firms.

Support for research and development (R&D): Government assistance to develop better technologies to reduce, mitigate or monitor pollution.

Technology Diffusion

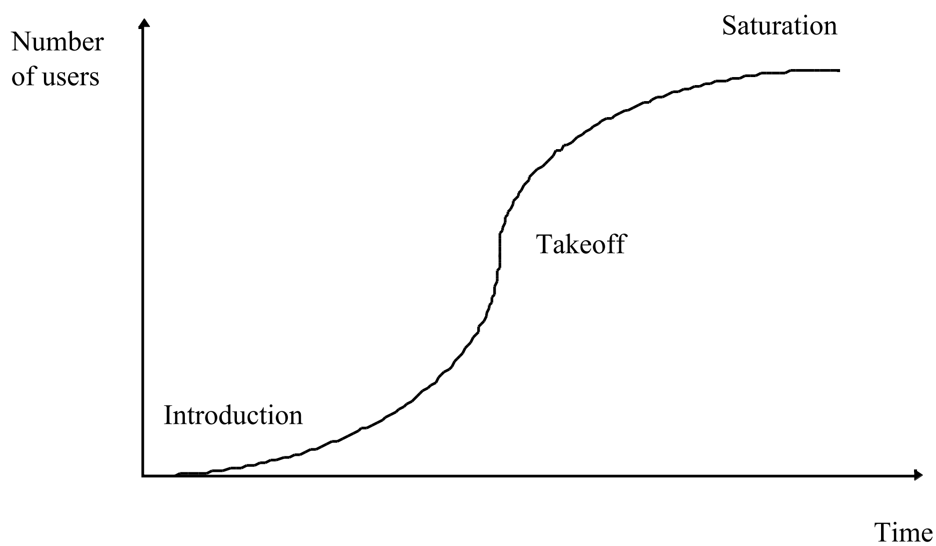
We have already seen some examples of economic models that use direct controls, taxes, or subsidies to correct externalities. We have also seen the effect of heterogeneity and the need for more sophisticated policy applications, such as transferable permit systems, when polluting firms differ. We will next consider the role of the government in achieving an efficient rate of diffusion of new pollution-control technology.

***Technology diffusion**:* A gradual process in which new technology spreads through the economy.

New knowledge or technologies may also change the efficient forms and magnitude of regulation; that is, a lower optimal level of pollution can occur in the economy as the marginal cost of abating pollution decreases. Hence, it may be efficient for pollution control policies to change over time in response to improved technology.

***Diffusion curve**:* Denotes number of adopters of new technology as a function of time. Diffusion curves tend to be S-shaped.

Figure 5.3: Diffusion Curve



It is important to realize that new technologies are not adopted overnight. It takes time for a new technology to spread through an industry. If a new technology can reduce negative externalities or increase positive externalities, then it might be efficient for the government to allocate some of its resources to promote the adoption of the new technology. The government can accelerate diffusion of pollution-reducing policies by:

- Engaging in extension and education activities
- Subsidizing new technology
- Regulating technology adoption (setting a timetable for diffusion).

Example: Catalytic converters
Drip irrigation
Scrubbers in Coal-Fired Electric Plants

If the government promotes a new technology, the technology will be adopted more readily, and the diffusion curve will shift to the left. This implies that externalities would be addressed more rapidly.