pollution permits (Dales, 1968). The choice between these instruments depends on their efficacy in achieving the target level of emissions as well as on the relative size of welfare losses they produce (Baumol and Oates, 1988).

COMMAND AND CONTROLS

The CAC instruments are in the form of fines, penalties and threats of legal action for closure of the polluting factories and imprisonment of the owners. They can be used either for facilitating the use of specific technologies for environment management or for the realization of specific environmental standards. There are theoretical and practical problems with the use of CAC instruments. It can be shown that the costs of compliance are generally higher when CAC instruments are used than when economic instruments can be used. Under CAC instruments, there can be no incentives for firms to innovate or invest in more efficient pollution control technologies or in cleaner process technologies.

ECONOMIC INSTRUMENTS

Economic instruments can be divided into three categories: price based instruments, quantity based instruments and hybrid instruments. These instruments are known as market-based instruments since they complement the market processes to achieve Pareto efficiency even with the presence of environmental externalities like air and water pollution. In other words, if these instruments are used, free-market equilibrium of the economy will be Pareto optimal even when environmental externalities are present.

Price Based Instruments

The price based instruments were first suggested by Pigou in the form of taxes and subsidies to deal with detrimental and beneficial environmental externalities in production and consumption. They are pollution taxes on a polluting commodity either through its production (paper, leather, electricity etc.) or consumption (cigarettes, packed food etc.) or on a polluting input (fuel inputs, chemicals etc.). Also, they can

be subsidies on the commodities, the production of which generates environmental benefits (neighbour's rose garden). The pollution tax, or Pigouvian tax is a corrective instrument to realize the socially optimal level of economic activity generating pollution. This is illustrated in Figure 3.1, where MPC, MSC stand respectively for marginal private cost, marginal social cost (marginal private cost plus pollution abatement cost); MPB, MSB represent respectively marginal private benefits (marginal benefit from the commodity produced), marginal social benefits (marginal private benefits plus the marginal benefits from reduced pollution); O^P, O^* represent respectively free market level of output, the optimal level of output and t stands for the optimal tax. With pollution externality free market level of output O^P is larger then the optimal level, O^*. A pollution tax equivalent to 't' will bring the level of polluting economic activity to O^*, the optimal level. Also, this tax is equivalent to the difference between the marginal social cost and the marginal private cost at the optimum.

In Figure 3.2, MCA, MD respectively represent the marginal cost of abatement, and marginal damages from pollution; E^*, E^m stand respectively for pollution loads with and without tax instrument and 't' stands for the pollution tax. With the polluters using the pollution abatement technologies, the Pareto optimality requires that the pollution has to be reduced up to the level at which MCA is equal to MD as shown in Figure 3.2. If a tax equivalent to 't' is levied per unit of pollution on the polluter, based on the polluter pay principle, the polluter has an
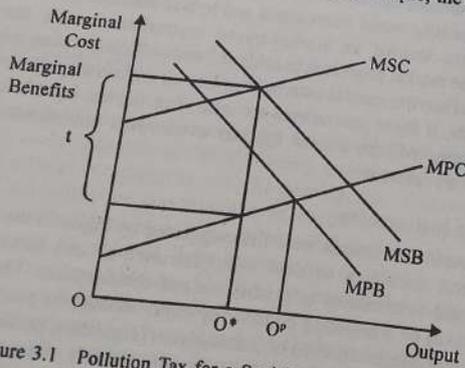
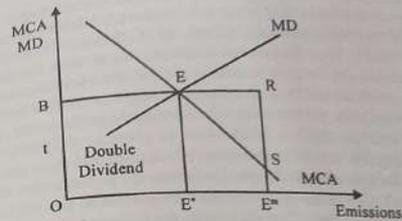Figure 3.1 Pollution Tax for a Socially Optimum Output Level.

Figure 3.2 Pareto Optimal Solution for a Polluting Industry.

incentive to reduce pollution up to the optimal level, E^* in the free market. The polluter has two choices: Pay tax equivalent to E^*ERE^m or reduce pollution load from E^m to E^* incurring the cost equal to E^*ESE^m. If he reduces the pollution, he will save cost equal to ERS as in Figure 3.2. Therefore, given the tax rate equivalent to 't', he chooses to reduce pollution rather than pay the tax.

The models of general economic equilibrium based on Pigou's original analysis (Baumol, 1972; Baumol and Oates, 1988; Murty and Nayak, 1982; Cornes and Sandlers, 1986) have shown that with Pigouvian taxes and subsidies, the competitive equilibrium of an economy with environmental externalities is Pareto optimal. It is in this sense, that Pigouvian taxes and subsidies are regarded as the best instruments. The Pareto optimality with externalities requires that the marginal environmental pollution abatement cost of the firm is equal to the marginal damages from pollution in addition to other optimality conditions for the supply and demand for private goods. The damages from pollution (for instance air and water pollution) accrue to a large number of people and therefore the damages from increasing a unit of pollution at the margin is the sum of marginal damage to all the affected people. Therefore, to design a Pigouvian tax, we require information about abatement cost functions of polluting firms and damage functions for all the affected people. The cost of collecting the information to estimate these functions can be prohibitively high (for example millions of people are affected by the pollution of a major river like the Ganges and an urban airshed like Delhi) and therefore it may not be economically feasible to design the Pigouvian tax.

Recently, it has been argued that pollution tax has double dividend benefits in the sense that it not only controls pollution but also earns revenue for the government (Oates, 1991; Pearce, 1991; Rajah and Smith, 1993). Given the revenue constraint, the revenue earned through pollution tax can be used to reduce the distortionary taxes on income and commodities and thus save the dead weight or welfare losses. If the polluter pay principle is the basis for levying the pollution tax, in Figure 3.2 the total tax liability of the firm is given as OBRE^m. The cost minimizing firm has an incentive to reduce pollution up to the level E* because the cost of abatement is lower than the pollution tax. However, for the pollution loads up to E*, the firm prefers to pay the tax rather than reduce pollution. Therefore, with the pollution tax rate of 't' the firm ends up paying the tax equivalent to OBEE* to the regulator or Government. In many cases these tax payments may be significant enough to increase the commodity prices and the resources available to firms for their expansion. The general equilibrium analysis of pollution taxes may suggest that the magnitude of benefits other than benefits from the reduction of pollution depends upon the welfare gains from reduced distortionary taxation, and welfare losses from the rise in commodity prices, and reduced growth of industry and employment (Bovenberg and Mooij, 1995). There are also welfare gains associated with the effects of pollution tax on income distribution or equity. Since the environment belongs to society at large, those who use it must compensate the owners. The pollution tax does just this because it is based on the polluter pay principle.

Quantity Based Instruments

D.H. Dales (1968) suggested an alternative to the pollution tax, a system of tradeable pollution rights for the management of the environment. He has proposed that property rights be assigned to environment and offered for sale to the highest bidder. This system like tax can achieve the specified environment target at minimum cost. For example in the case of air pollution, this approach first determines the optimal level of pollution in a given geographical area. This level of pollution is then divided into a number of permits among the various polluting units within the area (either by free distribution or by auctioning). Firms which are comparatively more efficient in controlling their wastes (the ones that face lower unit cost for pollution control) may not only be able to continue their original level of production and emissions but may even have some pollution permits to spare. This

surplus may be sold to firms which are less efficient in controlling their wastes (the ones that face higher unit costs for pollution abatement). Provided monitoring is possible and effective, the net result is that total pollution is kept within the prescribed levels. The more efficient firms will sell their surplus permits to less efficient firms which require more permits in order to continue with original production plans. In this process, a market for pollution permits is created in which trading in permits takes place upto the point at which the aggregate supply of permits is equal to the aggregate demand for permits and the equilibrium permit price is equal to the marginal cost of abatement to each firm.

The problem is not as simple as explained above for the marketable permit system. The ambient air quality or pollution concentrations at different receptor points in an airshed can be different. One unit of emission from a particular source has different contributions to concentrations at different receptor points. Therefore, the permits that are issued by the environmental authority have to be defined in terms of permissible concentrations at different receptor points. Then there will be a permit market for each receptor point. A source has to acquire a portfolio of permits from different markets. This form of permit market is called an ambient permit system (APS) in which the permits refer, not to a source's emissions, but to the effects of these emissions on levels of pollution at a particular point. In this system, emission entitlements are not generally exchanged between the sources on one–for–one basis. A source from which a unit of emissions will be contributing to more concentrations of pollutants at a particular receptor point will have to purchase more emission entitlements from another source from which a unit discharge of emissions contribute to relatively less concentrations at that receptor point. It can be shown that the competitive bidding for permits by different sources of pollution will result in the least cost solution for achieving the pre-specified levels of environmental quality or concentrations at different receptor points.[1] There are some problems for the practical application of this system. First, the transaction costs for polluters (sources) are very high. If there are n polluters and m receptor points in an airshed, there are m markets for permits. A polluter has to acquire a portfolio of permits from all m markets or at least from a subset of markets. Second, this method requires the analysis to be done in terms of a fixed set of receptor points. The polluters may change the location pattern of emissions to create

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[1] See. Montgomery, 1972.

hotspots that will not coincide with the original fixed set of receptor points. To avoid this problem, a relatively fine mesh of receptor points not involving prohibitively higher transaction costs to polluters are needed.

In an alternative system which is known as the environmental permit system (EPS), the permits are issued by the environmental authority in terms of emissions from the sources. The airshed is divided into zones and within each zone sources will trade emission entitlements on one-for-one basis. The transaction costs for polluters will be less in this method since each source has to trade in one zone or one market. However, this system cannot achieve the least cost solution[2].

There is a third method which is called the pollution offset (PO) system.[3] It is a kind of hybrid system in which permits are defined in terms of emissions. However, the sources are not allowed to trade on one-for-one basis. The transfer of permits under this system is subject to the restriction that the transfer does not violate the environmental quality standard at any receptor point. If the proposed transfer of permits encounters a binding constraint at some receptor point, then the
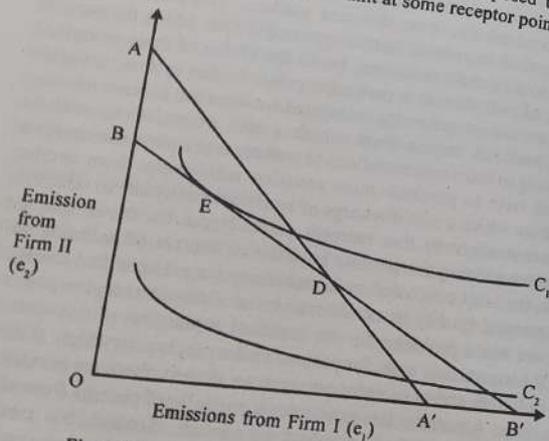

Figure 3.3   Least Cost Solution through the PO System.

[2]See Baumol and Oates, 1988.
[3]See Krupnick et al., 1980.

sources should trade at a rate at which the substitution of emissions from one source to the those from another source does not result in the change of pollution concentrations at the binding receptor point. For example, if a unit of emission from source A contributes twice as much to pollutant concentrations at the binding receptor point as a unit of source B's emissions, then A will be required to obtain two of B's unit permits before it is allowed to increase its own emissions by one unit.

As an APS system, the PO system leads to least cost solution through the mutually beneficial trade of emissions and this result is independent of the initial allocation of permits. This can be explained with the aid of Figure 3.3 where the horizontal and vertical axes represent emissions from sources I and II. The curves C_1 and C_2 are isocost curves for pollution abatement costs with the assumption that both the firms are facing a schedule of rising marginal cost. The higher curves correspond to lower total abatement costs. The lines A A' and B B' represent respectively the pollution constraints associated with the receptor points A and B. For example, points on A A' represent combinations of e_1 and e_2 for which the ambient air quality or pollution concentration at receptor point A is kept constant at a given level. The slope of A A' represents the rate at which the emission from firm II can substitute for emission from firm I with no change in pollution concentrations at receptor point A. The combination of emissions from both the firms that satisfy the pollution constraints at both receptor points are thus the set of points OBDA'. In the figure, the least cost solution occurs at E, the point at which the highest isocost curve (curve corresponding to the lowest cost) is tangential to the line representing the pollution constraint. This means that the least cost solution requires that trade in emissions between the firms I and II has to take place up to the point at which the marginal rate of substitution between emissions is equal to the ratio of marginal costs of pollution abatement of both the firms.

Mixed Instruments

In practice, we should have a mixture of both command and controls and economic instruments. Economic instruments alone may not be feasible because of prohibitively high information costs and command and control measures alone are inefficient measures (they result in the use of costly pollution abatement technologies by the firms). The estimation of damage functions of affected people in the case of pollution tax, and knowing *a priori* the optimal level of pollution in the case of tradable permits pose practical problems for the design of economic

instruments. Fixation of pollution standards *a priori* and using either pollution tax or marketable permits instrument to induce the polluter to meet those standards is a hybrid method using regulatory and economic instruments. However, in this case the criteria for fixation of environmental standards are a subject of debate; do they have to be decided on a scientific basis or on the basis of as referendum or political process? Scientifically they have to be based on the evidence concerning the effects of air pollution on health or of polluted water on fish life. They can alternatively be decided through a political process by having a referendum on the choice among alternative sets of pollution standards.

Once the environmental standards are given *a priori*, the difficult problem of estimating the damage functions for all the people affected by pollution can be avoided for designing the economic instruments. However, we need an estimate of the pollution abatement cost function. It is economically feasible to obtain an estimate of pollution abatement cost function because (a) the polluters may normally be much less in number than the affected people, and (b) tangible information can be obtained about technologies used by the polluters, pollution loads and levels of production. Given the environmental standards and an estimate of the marginal abatement cost function, a rate of tax can be fixed such that the firms will automatically have an incentive to reduce pollution for meeting the standards. This is explained in Figure 3.4.

If the firm has to reduce pollution load from D to E as per the environmental standard, the rate of tax equivalent to OA will make the

Figure 3.4 Pollution Abatement Cost.

firm do so. The rate of tax 't' in this case is the marginal abatement cost corresponding to the level of pollution permitted by the given standard. The firm has an incentive for pollution abatement rather than paying tax because the cost of abatement given by the area BFDE in the figure is lower than the tax liability given by the area BCDE. Similarly marketable pollution permits can be used to obtain the reduction in pollution loads by the firms as required by the environmental standards (*a priori* fixed ambient pollution concentrations). It can be shown that the taxes and standards or tradable permits and standards method result in the adoption of least cost technologies by the firms.[4]

There can be many situations in which command-and-control instruments are unavoidable. In several cases, the social cost of a particular activity depends on the variables beyond the control of those directly involved. For example, the effects of discharge of effluents into a river depends upon the conditions of the river at that particular point of time. Similarly, stagnant air can trap air pollutants, perhaps even collecting them until they become hazardous. Therefore, exogenous meteorological conditions may contribute to occasional crisis, requiring temporary emergency measures in the form of commands and controls. Pollution tax rates cannot be changed on short notice to deal with emergencies and even if the changes are effecte-' ˏne polluter's response follows with a longer time lag. Marketable permits also result in long run adjustments in environmental quality and are not suitable for emergencies. Command-and-control measures on the other hand can be quickly operated to deal with more than normal amount of emissions arising out of emergencies, since they do not require extra monitoring. Therefore, in practice neither economic instruments nor commands and controls alone constitute an optimal environmental strategy. The cost minimizing strategy to realize given environmental standards is a mixed strategy consisting of economic instruments and commands and controls.

PROPERTY RIGHTS AND COSEAN BARGAINING PROBLEM

The government is given the power of designing and implementing the commands-and-control measures and economic instruments described above with the assumptions that it is benevolent and has supporting legal and other institutions. In many countries, the government may not

[4]See Baumol and Oates, 1988.

produced pollution intensive commodities. There is a choice between two instruments to reduce pollution in the exporting country. The first is to reverse the trade reform by imposing taxes on exports or by banning exports of polluting industries and the second is to have domestic environmental instruments discussed above to deal with the domestic pollution. The first instrument is inferior and is called the second best instrument since it curbs growth of exports and therefore the growth of the economy while controlling pollution. The second instrument is called the best instrument since it results in a win-win situation.

There is also an interesting argument about the structural adjustment programme resulting in a win-win situation in the long run. There are some studies now that show that the relationship between the per-capita Gross Domestic Product (GDP) and environmental quality is U-shaped. This relationship is called the environmental Kuznet curve, which suggests that the quality of environment deteriorates initially as per capita GDP grows, and then improves after a certain critical value of per capita GDP has been reached. This hypothesis is based on the assumption that part of the increased incomes due to the structural adjustment programme will be spent on reducing pollution.

MONITORING AND ENFORCEMENT

WHAT IS MONITORING AND ENFORCEMENT?

Monitoring and enforcement of environmental regulations are an important component of environmental policy. The ineffectiveness of environmental policy as observed in some developed countries and in most of the developing countries can be attributed to the laxity in monitoring and enforcement. Monitoring and enforcement constitute a major component of activities of environmental agencies and they are meant to promote continuous compliance of environmental regulations by the sources of pollution. Monitoring is meant for determining whether pollution sources are in compliance with applicable regulations. Enforcement is for deterring sources from violating the regulations and to force violators to return to compliance.

Environmental agencies currently use many methods for checking compliance by the sources of pollution. Inspection is the most commonly used method for monitoring. A trained observer attempts to take note

Box 3.1: Optimal Pollution Tax

Let

N: number of people affected by pollution
M: number of polluting firms
X: $(X^1,.....X^M)$, a vector of outputs of firms.
E: $(E^1,.....E^M)$, a vector of emissions of firms.
$C_i(E^i, X^i)$:cost of pollution abatement to firm i, i = 1......M.
$D_j(E)$: Damages to jth individual, j = 1......N

The total cost of emissions to the economy is given as:

$$TC(E, X^1,......X^M) = \sum_{i=1}^{M} C_i(E^i, X^i) + \sum_{j=1}^{N} D_j(E)$$ (B3.1.1)

The optimal level of emissions by firms for a given output vector can be derived by minimizing A1.1 with respect to E^i, i = 1......M. Representing the derivatives of variables by a prime against it, the first order cost minimizing conditions are given as:

$$C_i' = \sum_{j=1}^{N} D_j', i = 1.......M$$ (B3.1.2)

or MCA = MD as given in Figure 3.2 in the text. If a pollution tax 't' is levied on each firm such that

$$t = \sum_{j=1}^{N} D_j' = MD$$ (B3.1.3)

the cost function for firm i now becomes:

$$TC^i = C_i(E^i) + t E^i, i = 1......M$$ (B3.1.4)

Each firm minimizes its cost with respect to emissions, E^i given the tax 't'. The first order condition for cost minimization by the firm is:

$$C_i' = t, i = 1......M$$ (B3.1.5)

From B3.1.3 and B3.1.5 we have B3.1.2, the condition for optimal emissions by the firms for a given vector of outputs of firms. Therefore, if there is a Pareto optimal vector of outputs in the economy, correspondingly there will be a Pareto optimal pollution tax. If such a tax is levied on the firms, it can be shown that the competitive equilibrium of market economy will be Pareto optimal even with the environmental externality of pollution (Baumol, 1972; Murty and Nayak, 1982).

of the compliance status of a source of pollution from evidence found in the plant and equipment in operation and the visual quality of current pollution. Another simple form of monitoring applicable mainly for air

pollution is remote visual reading. In the case of air pollution, the stack gas plume opacity can be checked by making use of this method. Sophisticated instruments can be used for estimating concentrations and velocities of particular pollutants in smoke stack plumes. Material balance is yet another method of monitoring the emissions. Using this method, an account is made of pollutants contained in all inputs and outputs of the production process.

Also, environmental agencies use several instruments for enforcement of regulations. Notice of violation is the simplest of all the enforcement methods, in which the pollution controlling agency informs the source that a violation has been detected and gives the date before which the violation must end. Alternatively, the agency can call a conference in which the operator is asked to explain the actions he will be taking to restore compliance. The environmental agencies are authorized to impose legal and administrative sanctions on the sources if they do not respond to the gentler methods like notice of violation. There are problems in implementing the legal sanctions because of their cumbersomeness and the difficulty of gathering evidence of non-compliance from the sources. The sources by contesting the imposition of sanctions in the court can make the effort expensive for the agency. In many cases, the agency may not win the court cases. In the case of administrative sanctions, penalties are imposed without taking the source to the court. Therefore, the cost of implementation or transaction cost of administrative sanctions is low in comparison to those of legal sanctions. The penalties may be related to type of source and violation history, and damages to the public or economic benefits to the source from the violation.

PENALTIES, COST OF ABATEMENT AND DAMAGES FROM POLLUTION

Normally, there are two sources of environmental violation: (a) a firm may intentionally violate the law by not complying with a regulatory standard or by not paying the appropriate emission fees and (b) pollution may be of stochastic nature in which case it may not be obvious *a priori* whether the existence of pollution is due to wilful violation of the law, or a random act of nature. The monitoring and enforcement instruments that an environmental agency can use may have to be different with different types of environmental violation. Also, the environmental agency has to face the situations of perfect monitoring (probability of

detecting violation is one) and monitoring with uncertainty (probability of detecting violation is less than one). Therefore, the enforcement instrument used by the agency depends upon the type of violation by the source and the nature of monitoring.

We have several models of monitoring and enforcement of environmental laws incorporating some or all of the features of environmental agency and polluters described above.[5] The intellectual foundations of these models have been laid by Becker (1968), and Mckean (1980).

As an illustration, let us consider the problem of fixing optimal penalty on a violator in a situation in which there is uncertain monitoring by the agency and wilful violation by the source. A source is said to be violating if its actual pollution level is higher than the standard fixed a priori or the optimal level of pollution defined in the section 'The Design'. Let the size of violation by a source be V. Also, the probability of detection of violation p(V) is a function of the size of violation and it increases with V. The fine imposed by the agency F(V) is also a function of V and it increases with V. Therefore the expected penalty on the source is

$$P(V) = p(V)F(V) \tag{3.1}$$

The effect of penalty on the actual emissions of the source may vary with the type of regulatory instruments used: whether they are command and controls or economic instruments. Figures 3.6(a) and 3.6(b) explain respectively the effect of a penalty on the actual emissions of a source with command and control measures with standards (as we now have in India) and the pollution tax. In Figure 3.6(a), the x axis measures pollution and y axis measures marginal expected penalty (MEP) and marginal cost of pollution abatement (MCA). If the standard is fixed at S_1, there will be a violation with emissions exceeding S_1. The distance between the x axis and the line MEP_1 represents the expected penalty on each successive unit of violation. The actual level of emissions with penalty is E_1, at which MCA is equal to MEP_1. If the probability of detection is constant, it can be shown that the equilibrium penalty, r is equal to marginal abatement cost divided by the probability of detection. For the pollution standard, S_1 in Figure 3.6(a), r is E_1C or E_1B/p if p = 0.5. The liability of the source with the penalty r is

[5]See Cohen (1998) for a review of literature update and Russell *et al.* (1986) for an earlier review.

r$(E_1 - S_1)$ which is equal to S_1E_1CD. With the increase in the standard from S_1 to S_2, the actual level of pollution reduces from E_1 to E_2. Given the penalty S_1E_1CD the firm has an incentive to reduce pollution up to S_1 because the penalty S_1E_1CD the cost of abatement S_1E_1BF as shown in the Figure 3.6(a).
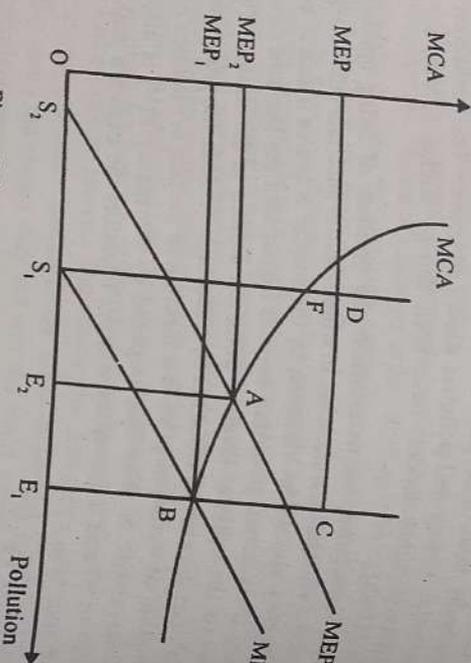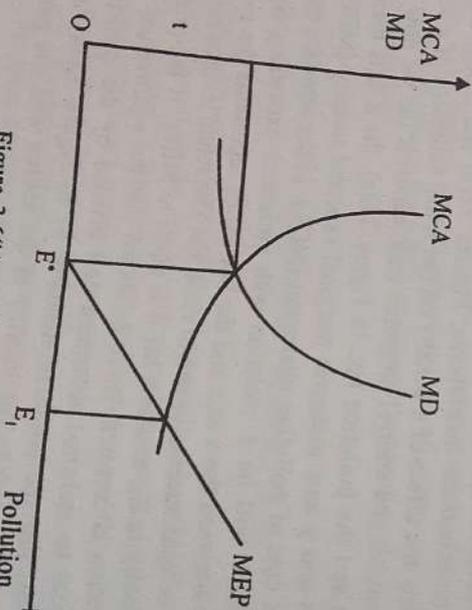

Figure 3.6(a) Command and Control Measures.

Figure 3.6(b) Pollution Tax.

Figure 3.6 Effect of Penalties on Actual Emissions.

In Figure 3.6(b), MD, MCA, MEP represent respectively marginal damages from pollution, marginal cost of abatement and marginal expected penalty. The optimal level of pollution tax is 't'. Any emissions higher than E^* results in violation. The actual level of emissions with uncertain equal to MCA and the optimal pollution tax is 't', at which MD is monitoring is E_1 at which MCA is equal to MEP. Therefore, the level of violation is $(E_1 - E^*)$. The source has to pay tax as well as penalty on the amount of violation. The total liability of the source in this case is $(t + r) (E_1 - E^*)$.

In the above model, the expected penalty is equal to the marginal cost of pollution abatement at equilibrium. Therefore, the equilibrium penalty is equal to the marginal cost of abatement divided by the probability of detection of violation. In the optimal penalty literature originating from Becker's seminal work, penalty is based on damages to the public or benefits to the source from violation. The optimal penalty is equal to the marginal damages divided by the probability of detection. The deterrence for violation by the source can be increased either by increasing the penalty or by increasing the probability of detection. The probability of detection can be raised by increasing the monitoring activities which requires increase in expenditures. Therefore, the policy prescription is to set the probability of detection low and thus increase the penalty. However, there can be limits for raising the penalty for political reasons, economic viability of sources of pollution etc.

INCENTIVES TO SOURCES TO COMPLY WITH ENVIRONMENTAL REGULATIONS

Firms may voluntarily comply with environmental standards due to various reasons. The managers may care about the firm's public image and therefore voluntarily work towards meeting the standards. Firms may feel that compliance is simply the right thing to do because of the operation of social norms.

Incentives provided by the environmental agency to the firms can also help explain voluntary compliance. For example the agency can discriminate between the firms found to be in compliance and the firms not found to be in compliance during the last inspection. The firms not found to be in compliance during the last inspection are subjected to either higher monitoring probability or higher fines. This scheme allows the regulatory agency to increase the proportion of firms in compliance for a given level of monitoring or penalties.