

Economics of Environmental Pollution

Introduction

- The material balance approach indicates that the environment provides three services to the economy i.e. (resource extraction, assimilation of residuals and amenities).
- Extractive services refer to the exhaustible and renewable resources that are used in the production of commodities.
- Residual assimilation services refer to the assimilation of production and consumption residuals by various environmental receptors (air, land and water).
- Amenity services include the natural beauty, solitude and recreation provided by the environment.
- This chapter addresses efficient use of the residual assimilation services provided by the environment, which constitutes environmental sector of the material balance model.
- Two major issues arise regarding the efficient use of the environment's capacity to assimilate residuals.
- First the residual assimilation services provided by the environment tend to be over exploited because they are un-priced.
- When the environment's capacity to assimilate residuals is exceeded, pollution occurs.

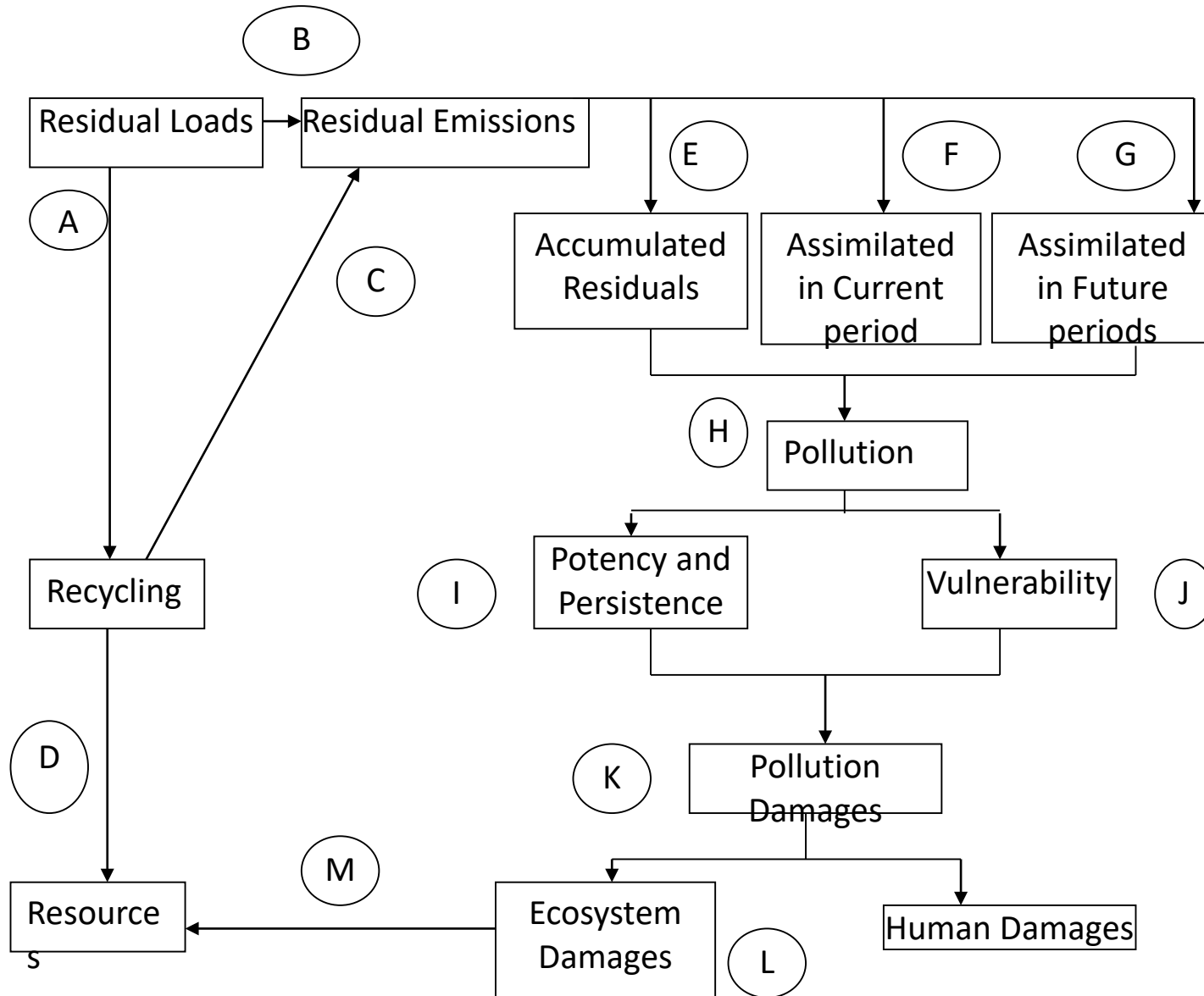
- Second pollution reduces the environment's capacity to provide services, such as outdoor recreation; and ecological services, such as air and water purification.
- Pollution damages are an external diseconomy that can have a negative effect on both humans and ecological systems.
- A major goal of environmental economics is to determine efficient levels of environmental pollution or pollution abatement and the effectiveness of alternative public policies in controlling pollution.
- This part expands the environmental segment of the material balances model to account more fully for the relationships among residual loads, residual emission, pollution and pollution damage.
- In addition, efficient allocation of pollution reduction to pollution generators and the role of government in reducing pollution-related externalities are addressed. .
- Finally, specific public policies for reducing point and/or nonpoint sources of pollution are evaluated

Residual Emissions, Pollution and Pollution Damages

- Emissions of residuals to the environment come from multiple Sources and have wide range of impact.
- Consider global warming, which results from the accumulation of carbon dioxide, methane and other greenhouse gases in the upper atmosphere.
- Carbon dioxide, which is the largest sources of greenhouse gases, is produced when fossil fuels are burned.
- Because the bulk of past carbon dioxide emissions were generated by developed countries, most of the global warming that has already taken place is attributed to developed countries.
- The greatest growth in future carbon dioxide emission is expected to occur in developing countries and advanced technology for reducing carbon dioxide emission resides in developed countries
- The effect of global warming will be different to different countries depending to their locations.
- International agreements to curb global warming are difficult to negotiate because of the high degree of uncertainty regarding the extent and timing of benefits from reducing global warming and the huge investments needed to reduce it.

- Unlike global warming, localized pollution has a much smaller sphere of influence.
- There are two types of localized pollution: point source and non-point source.
- Point source pollution that can be traced to a single, well-identified source, such as a paper mill that disposes of its effluent in a pipeline that empties-into a river.
- A pesticide holding tank that is rinsed near a wellhead is a point source of pollution for groundwater.
- Nonpoint source pollution is pollution from diffuse sources such as agricultural fields in a watershed.
- It is difficult to trace nonpoint source pollution to specific sources. Runoff from cropland treated with herbicides can pollute receiving water bodies such as streams and lakes.
- Environmental economics does not provide a comprehensive framework for dealing with environmental pollution and damages from non-point source.
- For the most part, the economic theory of pollution control deals primarily with damages from a single point source of pollution

Extended Material Balance Model



Efficient Reduction in Environmental Pollution

- If pollution damages in the current period depend only on residual emission in the current period, then the efficient level of pollution externality can be determined using static efficiency criteria.
- we will discuss only the static principles for controlling pollution under perfect competition, emission restricted model and with defensive expenditure.

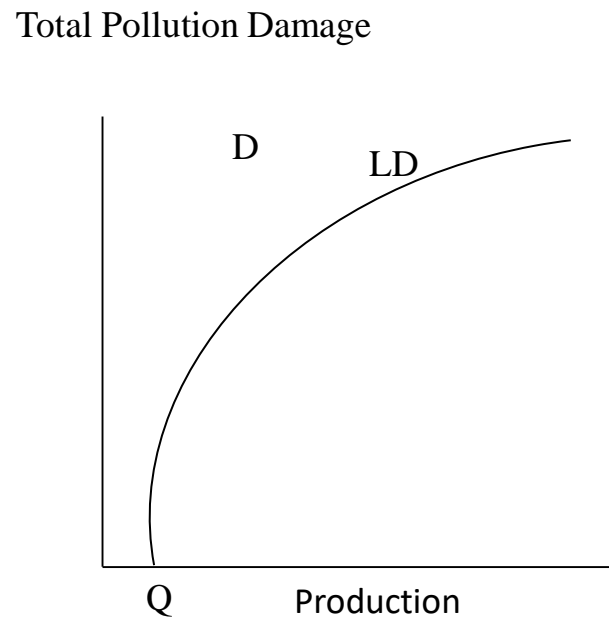
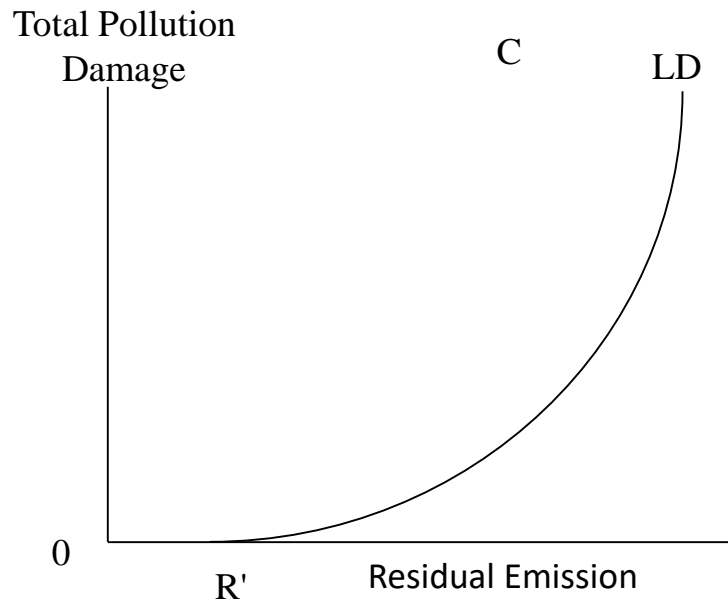
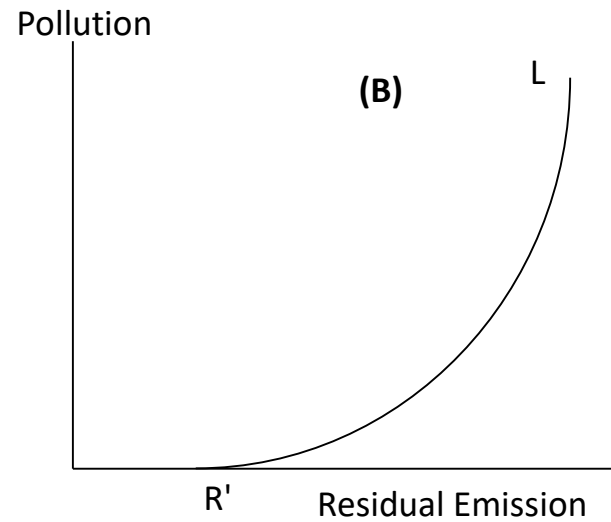
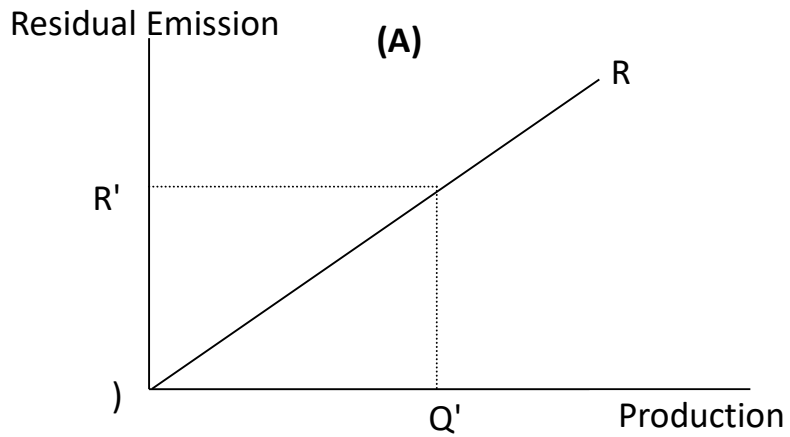
- **STATIC EFFICIENCY WITH PURE COMPETITION.** Static efficiency criteria are used to determine the efficient level of pollution under pure competition when residual emissions in the current period are capable of causing pollution damages in the current period.
- Several sources of pollution satisfy this requirement.
- For example, particulate emissions from a coal-fired power generates soot, which falls on the surrounding communities.
- Households and businesses in that community are likely to incur pollution damages in the form of higher cleaning bills that occur shortly after the particulates are emitted.
- The efficient level of pollution can be achieved by restricting the production of commodities that cause pollution when there is a fixed, proportional relationship between residual emissions and production rates.
- This implies that emissions cannot be reduced by utilizing other inputs.
- While this assumption of the production-restricted mode is quite restrictive; the model is helpful in demonstrating the basic relationships among consumption, production, emissions and pollution

- The model is as follows:
- Utility function; $U = U(Q, L)$ ($L =$ pollution)
- Production Function: $Q = F(X)$
- Emission Function: $R = R(Q)$
- Pollution Function: $L = L(R)$
- The utility function states that a household's satisfaction or utility (U) depends on consumption (Q) and a decreasing function of L . In other words, U increases when Q increases or L decreases, or conversely, U decreases when Q decreases or L increases.
- The production function implies that each firm's production rate (Q) is an increasing function of input use (X). Firms are allowed to dispose of their residuals to the environment freely, which implies that the residual assimilation capacity of the environment is un-priced.
- The emission function states that emission of residuals to the environment (R) is an increasing function of production (Q).
- Because the production-restricted model does not allow substitution between inputs and emission, X does not appear in the emission function.
- The pollution function indicates that pollution (L) is an increasing function of emission (R). Taken collectively, these functions imply that a) firms are the acting parties (polluters) and households are the affected parties (pollution victims), b) there is only one pollutant, and c) pollution impairs humans and/or ecosystems.

- The external cost of pollution depends on the relationship between residual emission (R) and production (Q) as shown in Figure A and between pollution (L) and residual emission as depicted in Figure B Let residual emission be related to production in the following manner (see Figure A):
- $R = aQ$ ($a > 0$) .
- This relationship states that residual emission (R) increase in fixed proportion to the production rate(Q), Which implies that firms are unable to reduce emission by using different inputs and/or technology .
- The relationship between pollution and residual is expected to have a threshold effect. This means for $R \leq R'$, residual are assimilated by the environment and pollution is Zero. For $R > R'$, however, pollution is expected to increase at an increasing rate as R increases (Fig B).
Therefore:
- $L = 0$ for $R < R'$ and $L = bR^\gamma$ for $R > R'$ ($b > 0, \gamma > 1$).
- This relationship is consistent with a decrease in the environment's capacity to assimilate additional residual as residual emission increase. The more rapidly assimilative capacity decreases with increased emissions, the higher the value of γ .

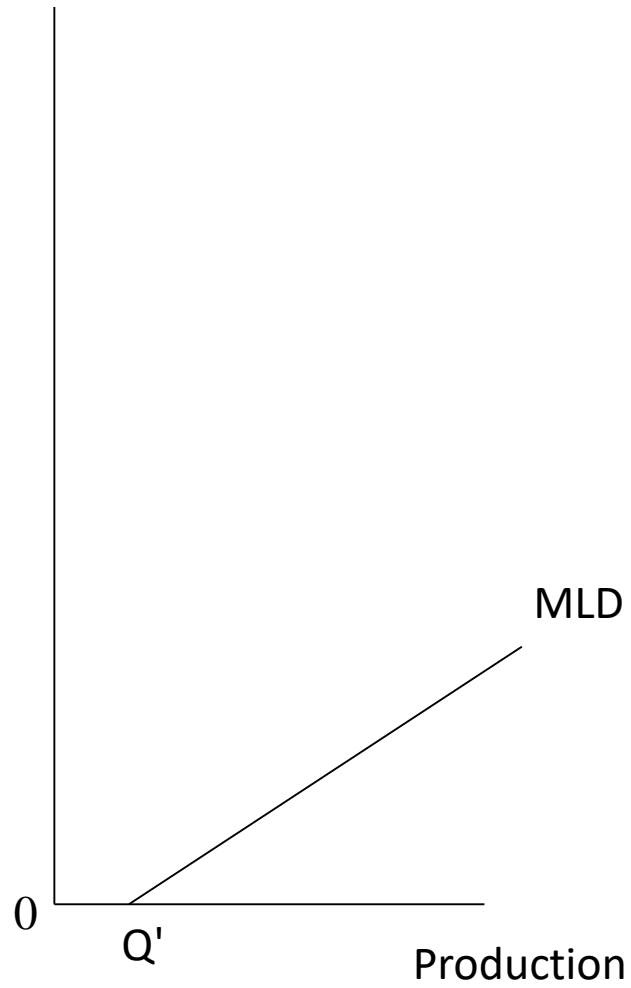
- The b term captures local environmental conditions that influence the extent to which residual emission causes pollution. For example, pesticide residues from surface application of pesticides to cropland is more likely to result in pesticide pollution of surface water when application is followed by a major rainstorm than when rain follows application by several weeks.
- Combining the residual emission-production relationship (Fig(A) and the pollution-residual emission relationship (Fig(B) indicates that Q' is the production rate above which pollution occurs. That is, for $Q > Q'$, $R > R'$, and $L > 0$.
- The relationship between total pollution damage (LD) and emission of residuals is shown in figure C and that between pollution damage and production in figures D. LD equals damage per unit of pollution (d) times the level of pollution (L), namely.
- $LD = dL = dbR^\lambda$ for $R > R'$. (where $L = bR^\lambda$)
- If per unit damage (d) does not depend on the level of pollution, then LD is an exponential function of R for $R > R'$ as shown in figure C. When d increases with pollution, LD increases more rapidly as R rises for $R > R'$.

- The pollution damage function is more complex when damage is caused by more than one pollutant and/or lifestyle factors influence vulnerability to pollution. For example, exposure to two pollutants at levels above the maximum contaminant levels could result in human damages because of interactions between the two pollutants. In this case, d is a function of emission levels for both pollutants.
- Quite often, averting behavior can reduce pollution damage. A potential decline in recreational swimming in a lake due to pollution might be partially averted by building a community swimming pool. Similarly, damage from pollution of well water might be reduced by substituting bottled water or water obtained from a rural water district.
- In some cases, averting behavior is less costly than reducing pollution. While bottled water reduces the human health risk of drinking polluted well water; it does nothing to reduce the ecological damages caused by water pollution. Therefore, averting behavior not necessarily eliminate pollution damage.



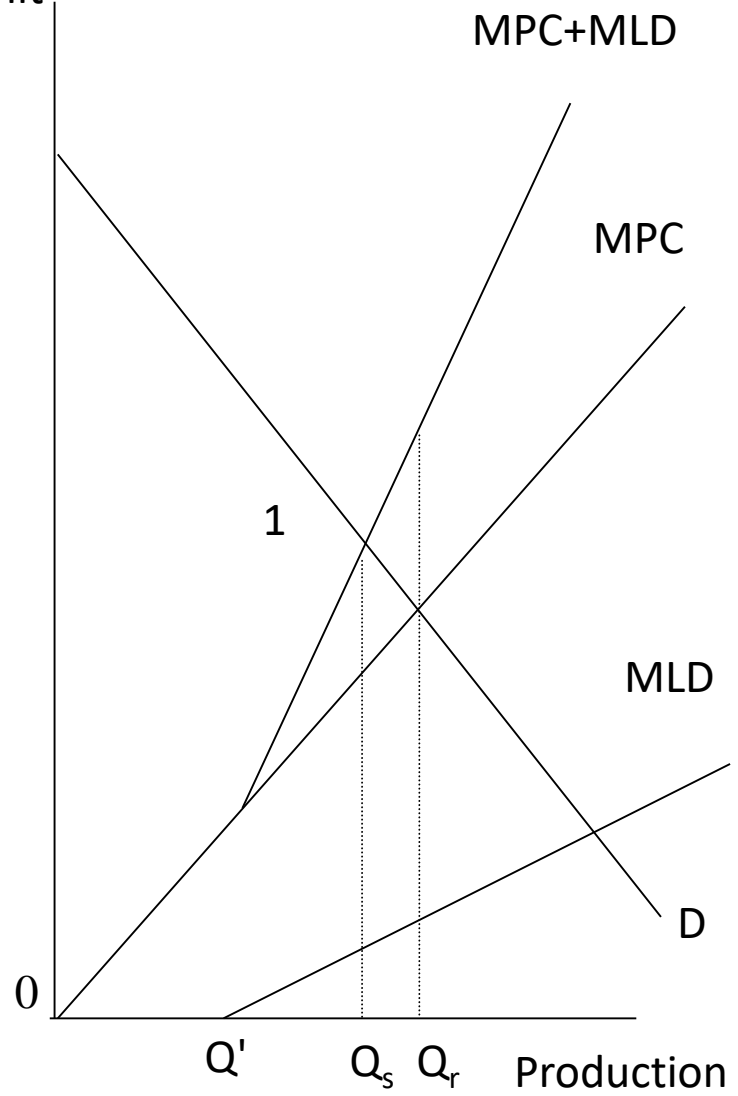
2A

Damage per unit



2B

Value per Unit



- The privately efficient production rate occurs where output price equals marginal production cost ($p=MPC$), profit is increased by raising production. Conversely, when price is less than marginal production cost ($P < MPC$), profit is increased by reducing production. (Figure 2B)
- Therefore, in a purely competitive industry, profit is maximized at the output where price equals private marginal production cost ($P=MPC$) which occurs at Q_r in figure 2B.
- The socially efficient production rate is determined by equating P to MLD (Marginal Pollution damage) + MPC , which occurs at Q_s in Figure 2B. Increasing production beyond Q_s , causes total pollution damages to increase more than net private benefit, which decreases net social benefit. Conversely, decreasing production below Q_s causes net private benefit to decrease more than pollution damages, which reduces net social benefit .
- An example of the privately and socially efficient rates of production is given in table . The figures in the table are based in the following MLD , MPC and demand (D) functions, respectively .
- $MLD=2.5Q^{1.5}$ for $Q > 3$
- $MPC=0.25Q^2$
- $D:p=44-1.9Q$.

An example

Q	MLD	MPC	MLD+MPC	P
3	12.99	2.25	15.24	38.3
4	20.00	4.00	24.00	36.4
5	27.95	6.25	34.20	34.5
6	36.74	9.00	45.74	32.6
7	46.30	12.25	58.55	30.7
8	56.57	16.00	72.57	28.8
9	67.50	20.25	87.75	26.9
10	79.06	25.00	104.06	25.0

- **In summary**
- 1. The privately efficient production rate exceeds the socially efficient production rate ($Q_r > Q_s$).
- 2. The socially efficient production rate approaches the privately efficient production rate as the threshold production rate increases, which causes pollution damage (Q') to decrease.
- 3. Zero pollution is generally not socially efficient.

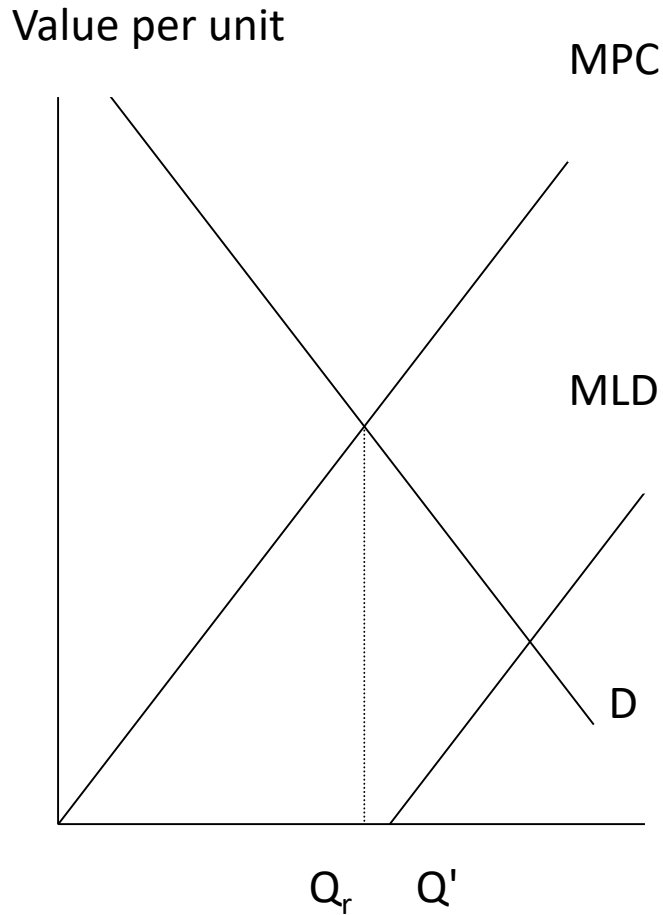
- **Emission Restrictions.**

- In the emission-restricted model, firms can reduce emission by employing more inputs or changing technologies.
- For example, sulfur dioxide emission from power plants can be reduced by substituting low sulfur coal for high sulfur coal or natural gas for coal. Alternatively, a cleaner technology could be used to reduce emission

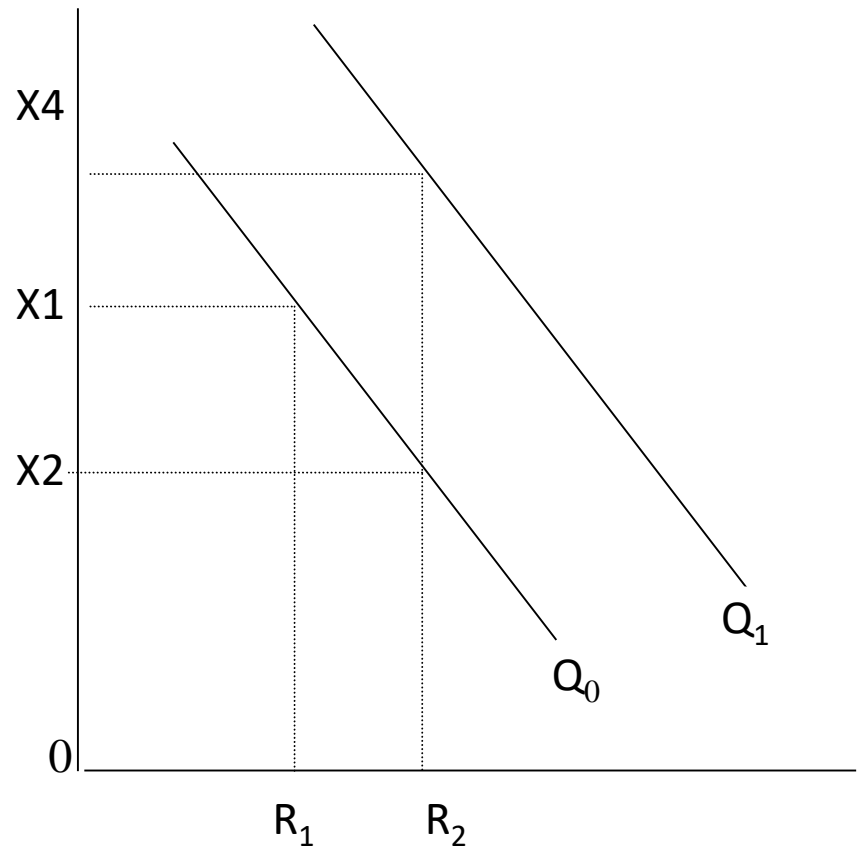
The firm's production function in the emission-restricted model is:

- $Q=G (X, R)$,
- Where X represents input and R represents emission of residuals. The production function in the production-restricted models only X, whereas the production function in the emission-restricted model includes both X and R.
- This allows a given production rate, say Q_0 to be achieved with various combinations of X and R
- When X and R are substitutions, the current production rate can be maintained while reducing emission by employing more x.
- For example, electrical power production can be maintained, and particulate emission reduced, by installing electrostatic precipitators that remove particulates from smoke before it leaves the smokestack.

- Alternatively, the production rate can be increased without increasing emissions. Increasing the production from Q_0 to Q_1 while maintaining emission at R_2 can be achieved by increasing the input level from X_2 to X_4 .
- Installation of precipitators entails an investment in manufactured capital and labor that increases the cost of production.
- If pollution reduces not only the general welfare of consumers but also the firm's production, then L enters the production function:
- $Q = H(X, R, L)$
- Q is a decreasing function of L , other things constant. Suppose waste water emissions from a shrimp pond result in pollution (L) of the water supply for the pond (Q).
- This is not uncommon in countries like Thailand.
- Then, L enters into the production function for shrimp. Reducing water pollution is beneficial to the firm because it improves shrimp health and hence the productivity of the pond.
- If pollution decreases production may increase

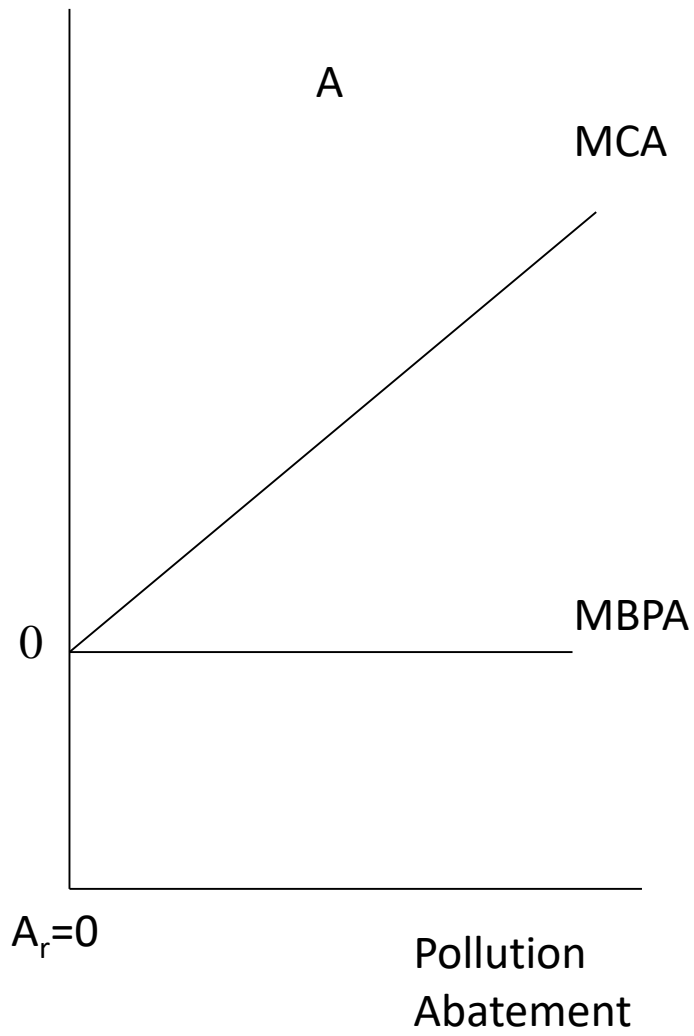


Marginal pollution damage after the private equilibrium. Hence ML is not applicable

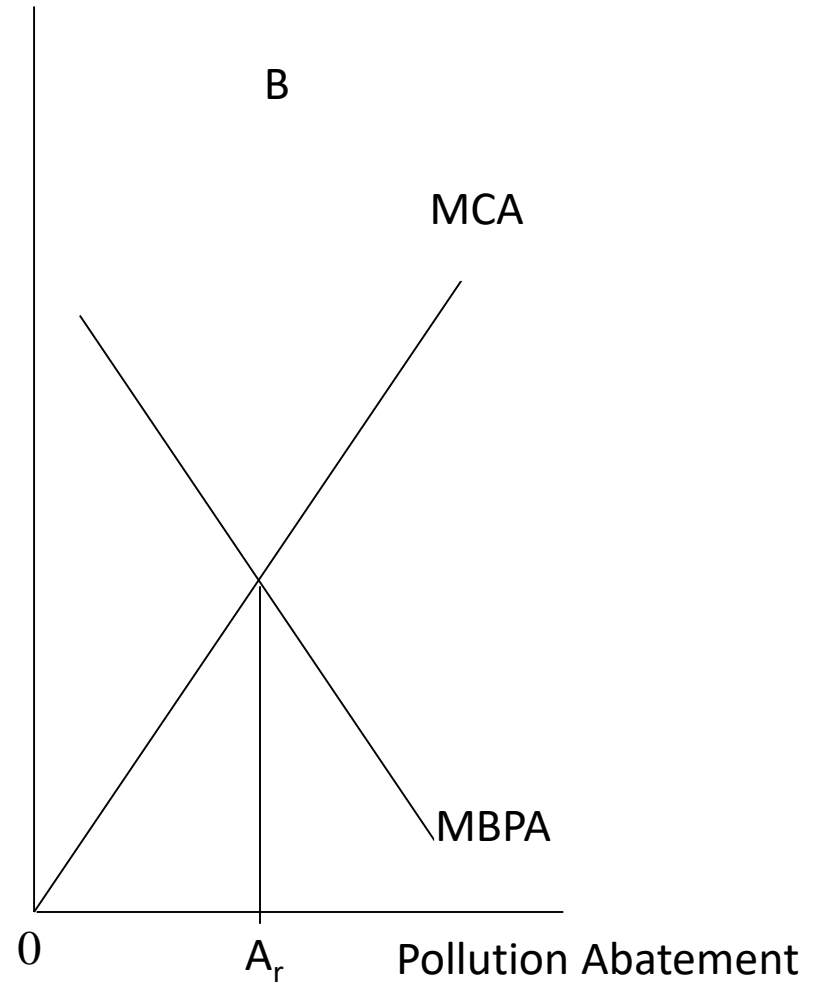


More output can be produced with same level of pollution by increasing inputs

Value per unit



Value per unit

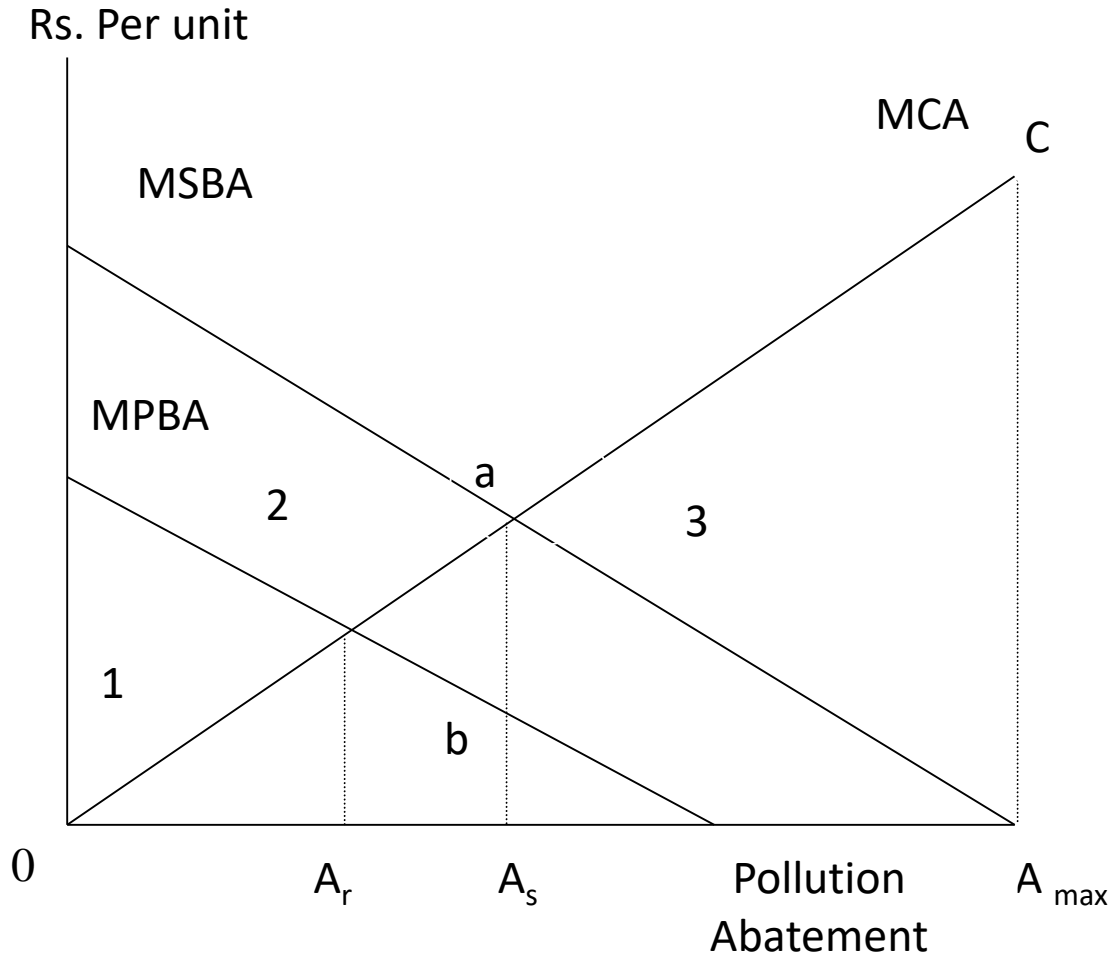


• **Optimum Level of Defensive Expenditure**

- Just as producers can make investments to reduce the emissions and pollution, households can make defensive expenditures to reduce the adverse effects of pollution.
- For example, households might relocate to a less polluted area to reduce water pollution-related illnesses caused by wastewater emission from the shrimp pond.
- Alternatively, the household can install a water filtration system to purify the water. Defensive behavior by households is incorporated in the utility function as follows:
- $U=V (Q, F (L, Y))$.
- In this modified utility function, L is replaced by a sub function $F (L, Y)$, that represents the household's exposure to pollution. Exposure depends on the level of pollution (L) and the level of defensive expenditure (Y). Because F is a decreasing function of L , the household can reduce pollution damages by undertaking defensive expenditures.
- Determination of the efficient level of pollution abatement for a single polluting firm in a purely competitive market is illustrated in above Figure .
- It is assumed that additional units of pollution abatement can only be achieved by employing increasingly expensive abatement technologies.

- Therefore, the marginal cost of pollution abatement (MCA) is an exponentially increasing function of pollution abatement as shown in above figure B.
- When the firm receives no benefit from pollution abatement (L does not enter the production function), the marginal private benefit of pollution abatement (MPBA) is zero and the privately efficient level of pollution abatement (A_r) is zero as shown in above figure A.
- When pollution abatement enhances the firm's own production (L enters the production function), MBPA is nonzero as shown in figure B.
- For example, since wastewater emission from the shrimp pond pollute the water supply for the pond, reducing water pollution improves the shrimp production.
- Reducing pollution of the pond increases income from shrimp production, but the increments in income become successively smaller as pollution abatement increases. In this case, equilibrium can be attained when $MPBA = MCA$ as in figure B

Pollution Abatement



- If the wastewater from shrimp ponds degrades the quality of water used by nearby households, then water pollution abatement results in an external community benefit.
- Let the marginal community benefit of pollution abatement (MCBA) be an exponentially decreasing function of abatement.
- This means that equal increments in pollution abatement result in smaller and smaller increments in community benefits. Marginal social benefit of pollution abatement ($MSBA = MPBA + MCBA$) as shown in above figure .
- Because MPBA and MCBA are exponentially decreasing functions of abatement, so is MSBA. Equating MCA to MSBA gives the socially efficient level of pollution abatement of Q_s .
- Because $A_r < A_s$, there is a relevant externality at A_r . In particular, the loss in net social benefit from reducing pollution to A_r instead of A_s is area 2 in figure . Reducing pollution beyond A_s is Pareto-inferior because the cost of abatement exceeds the social benefit.
- An example of the privately and socially efficient level of pollution abatement is given in Table . The figures in this table are based in the following MCA, MPBA and MSBA functions:

- $MCA=5A^{1.5}$
- $MPBA= 2200e^{-A}$
- $MSBA=8200e^{-A}$
- In this example, the privately efficient level of pollution abatement occurs at $A_r=4$ where $MCA=MPBA$ ($40=40.29$) and the socially efficient level of pollution abatement occurs at $A_s=5$ where $MCA=MSBA$ ($55.90=55.25$)
- The production-restricted and emission-restricted model both indicates that a Pareto-relevant externality is present. The production-restricted model shows that the privately efficient production rate exceeds the socially efficient production rate ($Q_r > Q_s$) and the externality generated by Q_r is excessive from a social viewpoint.
- The emission-restricted model shows that the privately efficient level of abatement is less than the socially efficient level of pollution abatement ($A_r < A_s$).
- A is the level of pollution abatement MCA =marginal cost of abatement; $MPBa$ =marginal private benefit of abatement; $MSBA$ =marginal benefit of abatement. $A=4$ is the privately efficient level of pollution abatement and $A=5$ is the socially efficient level of pollution abatement.

Example of privately and socially efficient levels of pollution abatement.

A	MCA	MPBA	MSBA
1	5.00	809.33	3,016.61
2	14.14	297.74	1,109.75
3	25.98	109.53	408.25
4	40.00	40.29	150.19
5	55.90	14.82	55.25
6	73.48	5.45	20.33
7	92.60	2.01	7.48
8	113.14	0.74	2.75