Econ674

Economics of Natural Resources and the Environment

Session 4

Externalities and Common Property Resources

Externalities in the Natural Resource Environment

- Theory of markets: equilibrium and optimality
  - Competitive equilibrium (Walrasian model)
  - Pareto optimality
  - Theorems of welfare economics

- Market failures and the environment:
  Environmental externalities and public goods

Three Conditions that Determine the Presence of Externalities

•*Condition 1* - An externality is present whenever some individual, A's, utility or production relationships include real (I.e. non-monetary) variables, whose values are chosen by others (persons, corporations, governments) without particular attention to the effects on A's welfare.

•*Condition 2* - The decision maker, whose activity affects others' utility levels or enters their production functions, does not receive (pay) in compensation for this activity an amount equal in value to the resulting benefits (or costs) to others.

•*Condition 3* - Externalities will always exist in the presence of incomplete contracts and, where energy production and consumption decisions are concerned, through the operation of the laws of thermodynamics. Incomplete contracts derive from the absence of well-defined property rights. Externalities may be mitigated in part through the re-assignment of property rights even though the laws of thermodynamics may prevent a complete elimination.

A General Equilibrium Approach to the Analysis of Externalities

Pareto optimality serves as the initial benchmark for the analysis of externalities.

We use the following notation:

- x_{ij} = the amount of good (resource) i consumed by individual j (i = 1, …, n) (j = 1, …, m);
- y_{ik} = the amount of good (resource) i produced (used) by firm k (i = 1, …, n) (k = 1, …, h);
- r_i = the total quantity of resource i available to the community;
- s_k = the emission of externality (smoke) by firm k;
- $z = \sum s_k$ = total emissions in the community;
- $u^j (x_{1j}, \ldots, x_{nj}, z)$ = individual j's utility function.

and

- $f^k (y_{1k}, \ldots, y_{nk,}, z) \leq 0$ = firm k's production set.

•To find a Pareto optimum, our problem is to

maximize $u^1 (x_{11}, \ldots, x_{n1,}, z$

subject to

$u^j (x_{1j}, \ldots, x_{nj,}, z) \geq u^{*j}$ (j = 2, …, m)

$f^k (y_{1k}, \ldots, y_{nk}, s_k, z) \leq 0$ (k = 1, …, h)

$\sum x_{ij} - \sum y_{ik} \leq r_i$ (i = 1, …, n)

All $x_{ij} \geq 0$, $s_k \geq 0$, $z \geq 0$;

Note that we do not require all $y_{ik} \geq 0$.

A General Equilibrium Approach to the Analysis of Externalities - 2

- The Lagrangian is:

$$L = \sum \lambda_j (u^j(.) - u^{*j}) - \sum \mu_k f^k(.) + \sum_i \omega_i \left(r_i - \sum_j x_{ij} + \sum_k y_{ik}\right)$$

- Kuhn-Tucker conditions together with the constraints (including the complementary slackness conditions) and the concavity-convexity conditions are necessary conditions for any Pareto optimum.

Kuhn-Tucker conditions for optimality with externalities

Variable	Pareto optimality	Market equil.	Prices
X_{ij}	$\lambda_j u_i^j - \omega_i \leq 0$ $x_{ij}(\lambda_j u_i^j - \omega_i) = 0$ (all i, j)	$p_i - \alpha_j u_i^j + t_i^j \geq 0$ $x_{ij}(p_i - \alpha_j u_i^j + t_i^j) = 0$ (all i, j)	$p_i = \omega_i$ $t_i^j = t_i^*$
Y_{ik}	$-\mu_k f_i^k + \omega_i = 0$ (all i, k)	$p_i - \beta_k f_i^k - t_i^k = 0$ (all i, k)	$p_i = \omega_i$ $t_i^k = t_i^*$
$S_{k'}$	$-\mu_{k'} f_s^{k'} + \sum \lambda_j u_z^j - \sum \mu_k f_z^k \leq 0$ $s_{k'}(-\mu_{k'} f_s^{k'} + \sum \lambda_j u_z^j - \sum \mu_k f_z^k) = 0$ (all k')	$-t_s - \beta_{k'} f_s^{k'} \leq 0$ $s_{k'}(-t_s - \beta_{k'} f_s^{k'}) = 0$ (all k')	$t_s = -\sum \lambda_j u_z^j + \sum \mu_k f_z^k$

A General Equilibrium Approach to the Analysis of Externalities - 3

Market equilibrium

- We now consider the equilibrium of the consumer and of the firm
- The consumer is taken to minimize the expenditure necessary to achieve any given level of utility, u^{*j}, so that in Lagrangian form the problem is to find the saddle value of:
- $L_j = \sum p_i x_{ij} + t^j + \alpha_j(u^{*j} - u^j(.))$
- Given the non-negativity constraints, the solution is obtained from the Kuhn-Tucker conditions.

- Similarly, the objective of the (competitive) firm is taken to be maximization of profits after taxes subject to the constraint given by its production relation. Its Lagrangian problem is to find the saddle value of:
- $L_k = \sum p_i y_{ik} - t^k - t_s s_k - \beta_k f^k (.)$
- $s_k \geq 0$, y_{ik} unrestricted.
- Given the non-negativity constraints, the solution is obtained from the Kuhn-Tucker conditions.

A General Equilibrium Approach to the Analysis of Externalities - 4

The price-tax solution

- The tax structure that can sustain a competitive equilibrium that is Pareto-optimal is:

- $t_s = -\sum \lambda_j u^j_z + \sum \mu_k f^k_z$, all $t_i^j = t_i^k = 0$. (1)

- These conditions are sufficient to render identical the competitive equilibrium and the Pareto-optimality conditions. That is, given the assumed convexity conditions, market behaviour subject to this set of taxes will yield an optimal allocation of resources.

- Thus, after some substitution, we will find that the systems will have the same solutions, so that if they are unique

  $$p_i = \omega_i\ ,\ \lambda_j = \alpha_j\ ,\ \ \mu_k = \beta_k \quad \text{(all i, j, k)} \qquad (2)$$

- By (1) and (2) we have, in fact, proven that neither any tax nor any compensation of the victims of externalities is necessary to sustain any Pareto optimum, for $t^j = 0$ and $t^k = 0$ will obviously satisfy (1) if t_s, the tax on the generation of the externality, is set appropriately.

- We can even say conditions (2) are absolutely required if we accept that there is one item, some of which is consumed by every individual.
- The price-tax conditions (1) and (2) necessary to sustain the Pareto optimality of a competitive market solution under the assumed convexity conditions are tantamount to the standard Pigouvian rules, with neither taxes imposed upon, nor compensation paid to, the victims of externalities (except possibly for lump-sum taxes or subsidies).

A General Equilibrium Approach to the Analysis of Externalities - 5

- The tax rate, t_s, per unit of smoke emissions is equal to the marginal social damage of smoke. This can be shown using leisure-labour as the standard of evaluation. After some substitution and keeping output and utility levels fixed, t_s becomes

- $t_s = \omega_{i^*} \left(\sum(\partial x_{i^*j}/\partial z) + \sum(\partial y'_{i^*k}/\partial z)\right)$

- That is, interpreting ω_{i^*} as the shadow price of labour, we see that the above equation is the marginal smoke damage, measured in terms of the value of the labour needed to offset the various types of damage.
- Note also that the results indicate that prices should be proportionate to marginal utilities (in the case of consumers) and proportionate to the ratio of marginal costs (products), all measured in terms of labour.

- Moreover, the prices p_i that can sustain a Pareto optimum will be nonzero only for items used up completely in the corresponding optimal solution, that is,
- $p_{i''} > 0$ implies $\sum x_{i''j} = \sum y_{i''k} + r_{i''}$

A General Equilibrium Approach to the Analysis of Externalities - 6

Extensions of the basic model: some remarks

1) The case of depletable externalities: It remains true that there will be a Pigouvian levy on the generator of the externality equal to marginal social damage and no compensation or taxes on the victims (provided that the victims cannot affect the consumption of the externality by other victims).

2) The case of imperfect mixing: In this case in place of a uniform fee on all sources (as under perfect mixing), we now have a set of Pigouvian taxes that correspond to the marginal damages of the emissions of each source.

3) The case of shiftable externalities: In addition to the Pigouvian tax upon the generator of the externality, the environmental authority must also confront victims with a unit tax on their shifting activities equal to the marginal social damage of transferring the externality to another victim.

A General Equilibrium Approach to the Analysis of Externalities - 7

Market imperfections and the number of participants

1)A firm that generates externalities may not sell its output in a competitive market. In this case an emissions (Pigouvian) tax rate that is appropriate for the pure competitor will not, in general, induce behaviour that is consistent with optimality in the second-best world inhabited by a monopolist.

- Under monopoly, a Pigouvian tax, while reducing the pollution costs, at the same time increases the welfare loss resulting from excessively low levels of production, so that the net effect on social welfare is uncertain.

- 2)The presence of polluters who are not "fee-takers": In this case producers (and perhaps also consumers) of externalities will have an incentive to adjust their behaviour so as to influence not only their tax bills, but also the tax rate they pay per unit of pollution. Such situations will lead to the Coase result calling for a tax on victims.

Are competitive outputs with detrimental externalities necessarily excessive?

If there is one externality-producing activity and if convexity holds throughout, the conventional wisdom on this subject is strictly accurate: the competitive output of a good that generates external benefits will always be less than any of its Pareto-optimal values, and that of an output that yields detrimental externalities must always exceed such an optimum.

A General Equilibrium Approach to the Analysis of Externalities - 8

This can break down if any one of the following four conditions holds:

- the initial position is not a point of perfect competitive equilibrium;
- there is more than one activity in the economy that yields an externality, or where different activities yield different externalities;
- there exists any activity such as recycling or purification that can abate the externality;
- the standard concavity-convexity conditions are violated somewhere in the economy.

Detrimental externalities and nonconvexities in the production set

- Detrimental externalities of sufficient strength will produce a breakdown in the concavitiy-convexity conditions (the so-called second order conditions) usually postulated for a social maximum, so that instead of a unique optimum, society may have the difficult task of choosing among a set of discrete local maxima.
- In a system otherwise characterized by constant returns everywhere (that is, a linear model), any detrimental externalities can produce a nonconvexity. This problem produces some very real and difficult issues in the choice of policy.

A General Equilibrium Approach to the Analysis of Externalities - 9

- Moreover, even in theory, prices and taxes cannot help with this matter. Prices and taxes (which, in general, influence the first order maximum conditions) can affect the decisions of individuals and firms and thereby determine the location of the economy in relation to its production-possibility set.
- However, prices or taxes cannot change the shape of the possibility set itself to transform it from a nonconvex into a convex region, for that is essentially a technological matter.
- In addition, in the presence of nonconvexities, these prices may also give the wrong signals-directing the economy away from the social optimum.

Questions:

1. How does the general theory of externalities account for spillover benefits?
2. How does the general theory of externalities account for the efficiency of prices in a developing economy context?
3. What kinds of taxes/subsidies might be appropriate for the correction of externalities, and are there institutional constraints that affect the efficient choice for developing economies?
4. In what ways can one measure the value of negative and positive externalities, regardless of the particular institutional setting?

Public Goods in Natural Resource and Environmental Economics

Basic Definitions used in the analysis of public goods:

1. **Non-Rival Indivisibility:** A good is non-rival or indivisible when a unit of the good can be consumed by one individual without detracting from the consumption opportunities available to others from that same unit.
2. **Excludability of Benefits**: Goods whose benefits can be withheld without cost by the owner or provider generate excludable benefits. Benefits that are available to all once the good is provided are termed non-excludable.

A simple representation of individual behaviour:

Preferences defined over two goods: a private good, y, and a public good, Q. Quantity of public good acquired by the individual is q. The rest of the community's contribution to Q is $Q' = Q - q$.

Using the budget constraint $y + p_Q\, q = I$, the utility function becomes

$$U(y, Q) = U(I - p_Q\, q, q + Q') = U'(q, Q'; p_Q, I)$$

Thus, indifference curves in (q, Q') space and equilibrium (reaction curves) could be discussed graphically.

Public Goods in Natural Resource and Environmental Economics - 2

Moreover, the contributor's constraint set and indifference curves could be used to determine equilibrium. The non-contributor's constraint set and equilibrium could also be discussed to see the implications of easy riding (free riding).

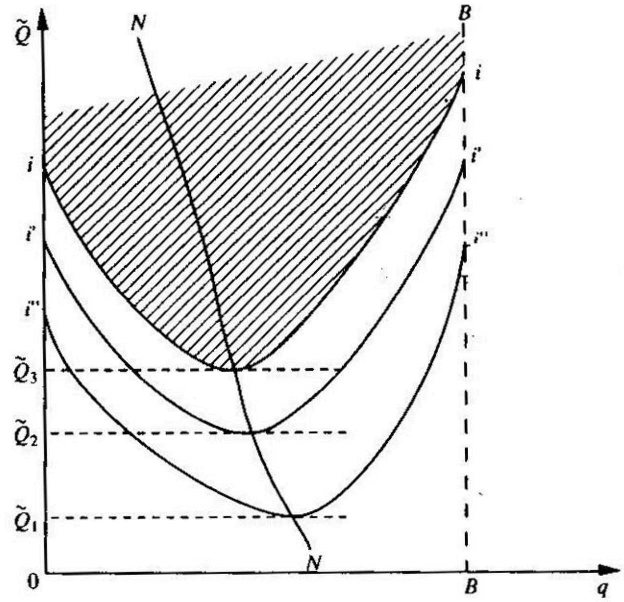
A Nash equilibrium could be discussed using indifference curves and reaction curves of an individual and the rest of the community or of two individuals. One possible problem is that there could be multiple Nash equilibria.

Pareto-efficient allocations could be determined by equating the slopes of the indifference curves and these could be used to indicate the sub-optimality of Nash equilibrium.

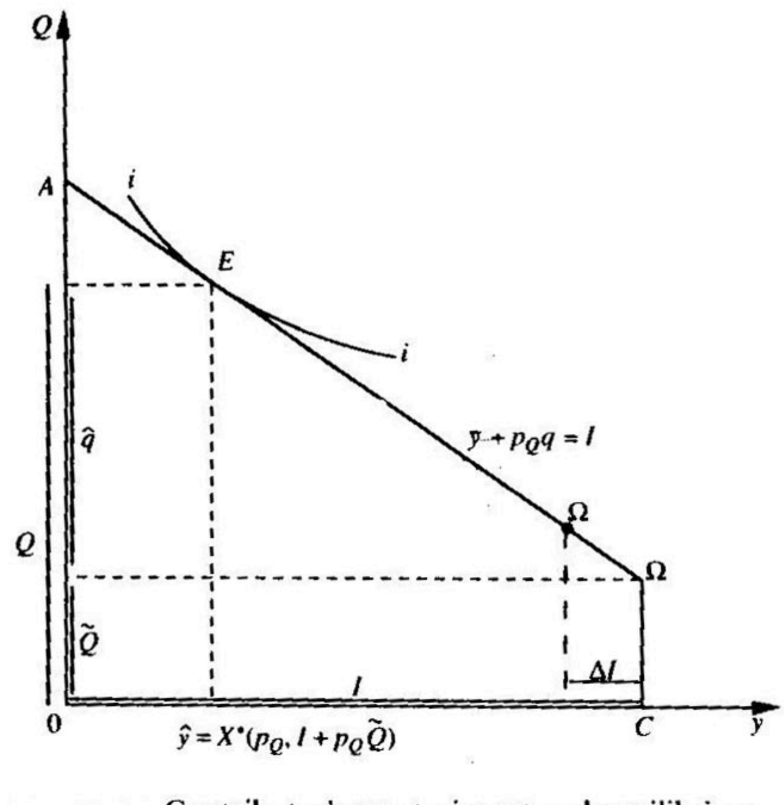
An index of easy riding shows how Nash equilibrium compares with Pareto-optimal allocations.

Equilibrium and optimality in n-person economies could also be presented and the change in the index of easy riding discussed in relation to the number of persons in the economy.

Public Goods in Natural Resource and Environmental Economics - 3

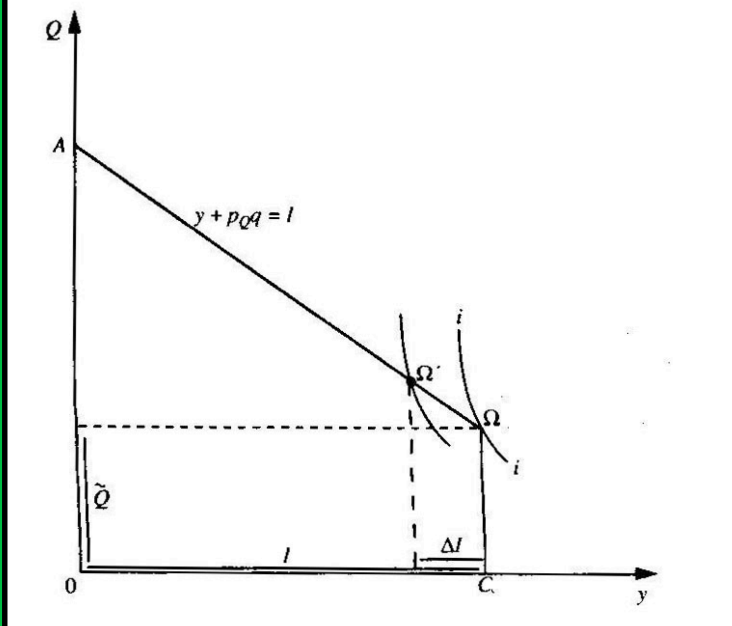


Indifference map in $(q, \tilde{Q})$ space

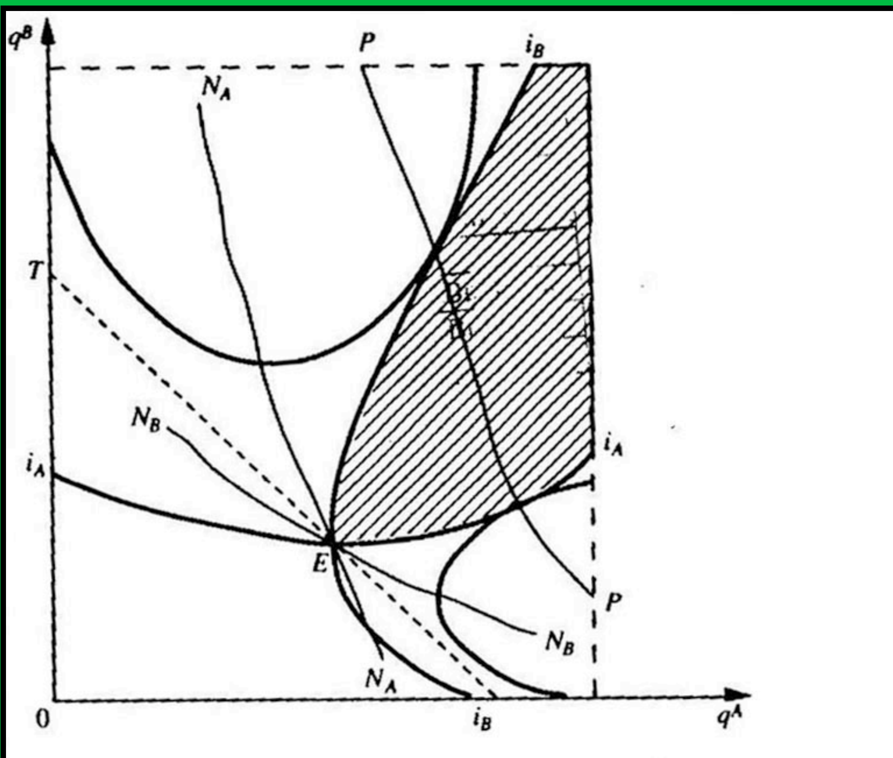


Contributor's constraint set and equilibrium

Public Goods in Natural Resource and Environmental Economics - 4



Noncontributor's constraint set and equilibrium



Nash equilibrium in a two-person public good economy

Public Goods in Natural Resource and Environmental Economics - 5

Mechanism Design for Public Goods:

The systematic tendency toward under-provision of a public good that seems to be implied by the model of Nash-Cournot equilibrium has encouraged extensive analysis of alternative allocative mechanisms and their evaluation against the yardstick provided by the set of Pareto-efficient allocations. Beyond Lindahl's thought experiment regarding majority voting, some of the large and varied literature includes the following alternative allocative mechanisms:

1. **The Clarke-Groves demand-revealing mechanism**: The Clarke-Groves demand revealing mechanism is a scheme that gives an incentive to agents to report their true preferences as a dominant strategy, but there is a cost. It happens at the expense of the other necessary condition that requires full employment of productive resources.

2. **The Groves-Ledyard scheme**: This scheme sacrifices dominance, but is able to achieve full optimality at a truth telling Nash equilibrium at which all individuals are truthfully revealing their private information.

3. **Bayes-Nash demand-revealing mechanism**: The Bayes-Nash mechanism tries to come to grips with the problem of incomplete information by supposing that information about each individual's preference parameter is known to others only in the form of a probability distribution.

All three types of mechanisms are short of providing attractive operational procedures. However, they have served to increase our understanding of some of the problems involved in designing policies to determine resource allocation in the presence of public goods.

Public Goods in Natural Resource and Environmental Economics - 6

Mechanism Design for Public Goods, contd.

The Clarke-Groves demand-revealing mechanism applies Vickery's (1961) discussion of a dominant strategy mechanism for inducing truthful reporting of valuations to the special case represented by public goods provision. The Clarke-Groves scheme encourages true reporting of preferences as a dominant strategy—no matter what others do, each individual's best course is to be honest. It is not, however, without problems. In the first place it relies on a very restrictive class of preferences. The second limitation concerns the tax revenue. Our tax formula ensures that the costs of providing the public good will be covered. It would be good if we could find a scheme that would preserve the incentive to tell the truth and would also allow the government to have exact budget balance. Unfortunately, this generally cannot be achieved. A third limitation concerns the size of individual tax bills. The scheme is not concerned with distributional issues or equity, but simply with eliciting the information required to identify and finance the level of public good that is consistent with Pareto efficiency, which creates a problem.

Groves-Ledyard scheme: The need to rely on a rather special class of preferences is an inherent limitation of the Clarke-Groves demand-revealing mechanism, as is the budget surplus problem. That is to say, it is simply not possible, however ingeniously we devise the tax scheme, to overcome these problems without having to sacrifice some other desirable property. This fact is known as a result of a number of impossibility theorems that the literature has generated. Along the lines of Arrow's famous impossibility theorem, there have now been many analyses considering collections of properties that are individually desirable characteristics of a resource-allocation mechanism, and they have shown that logically it is not possible to find a mechanism that possesses all those properties. In particular, it is known that there exists no mechanism that could simultaneously (i) induce truthful revelation as a dominant strategy, (ii) generate a level of public good provision consistent with the Samuelson necessary condition for Pareto efficiency, and (iii) produce budget balance. This is so even if we restrict attention to the narrow class of preferences considered in the Clarke-Groves mechanism.

Public Goods in Natural Resource and Environmental Economics - 7

Mechanism Design for Public Goods, contd.

If we want to search for a mechanism that will produce a Pareto-efficient equilibrium allocation—that is, a mechanism that will possess properties (ii) and (iii)—then it follows that we need to weaken the first requirement and drop the insistence that truthful revelation be a dominant strategy. Groves and Ledyard (1977b) found such a mechanism. They required only that each individual should find it preferable to tell the truth if everyone else is doing so. In short, they required truthful revelation to be a Nash strategy. The Groves-Ledyard mechanism invites individuals to report not parameters of their utility functions, but increments of the public good. In this mechanism quite general preferences can be accommodated and it seems that in return for dropping the dominance requirement, we have gained a lot. However, the approach has the following limitations: First, the retreat from dominant to Nash strategies is a significant one. Yet the observation that individual valuations of the public good are private information, not known to others, was precisely one of the considerations that led us into the search for allocation mechanisms for public goods. If individuals do not know their fellows' preferences, there is no particular reason to expect Nash strategies to be picked. Second, the scheme also shares with the Clarke-Groves mechanism the possibility that equilibrium may violate individual rationality, even to the extent of bankrupting individuals.

As a mechanism for determining the allocation of resources to public good provision, the Bayes-Nash demand-revealing mechanism has the great attraction of acknowledging the problem of incomplete information, and it deals with this by allowing each individual to have statistical information about the preferences of others. But it shares with Nash mechanisms the problem of multiple equilibria. It does not satisfy individual rationality and therefore shares with the Nash mechanisms an inability to cope with distributional concerns.

Public Goods in Natural Resource and Environmental Economics - 8

Mechanism Design for Public Goods, contd.

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Public Goods in General

Public good provision with exclusion:

Commodities that exhibit non-rivalry, but for which exclusion is possible and worthwhile: exclusion of non-payers from access. It would seem that the ability to exact payment from those who consume a non-rival service should strengthen incentives to provide it and at least mitigate, if not totally overcome, the tendency toward under-provision. These would help explain the murky area between pure private goods on one side and pure public goods on the other.

Public Goods in Natural Resource and Environmental Economics - Game Theory

Game theory and public goods: Cooperative provision of public goods: The concept of 'core allocations': If there is an allocation such that no group of consumers can come together and reallocate their initial endowments in such a way as to advantage each one of them, that allocation is said to be in the core.

In a two-person two-commodity exchange model, the set of core allocations is that segment of the contract curve lying within the region in which both individuals are at least as well off as at their initial endowment points. Points within the region, but not on the contract curve, are not in the core because the two-person coalition can negotiate a mutually preferred allocation.

If the economy is replicated (i.e., if each of the two individuals is replaced by n-economically identical individuals) then as n grows larger, the set of core allocations converges to the set of competitive equilibria.

In the context of public goods one cannot help wondering whether or not, in the presence of many agents, the core is an empirically relevant solution concept. Its implied level of cooperation presupposes costless bargaining and coordination, which is increasingly difficult to justify as the number of agents becomes large. For this reason, it seems worthwhile to return to the model of non-cooperative behaviour.

Non-cooperative binary choice models: Static two-person games:

Prisoners' dilemma: In this case each player can contribute one unit or none of the public good. Assume each unit contributed provides each player with a benefit of 6, at a cost of 8 to just the contributor. The Nash equilibrium is for neither person to contribute which is not Pareto-optimal. The Prisoners' dilemma is likely to result when the cost per unit exceeds the per-person benefit per unit.

Public Goods in Natural Resource and Environmental Economics - Game Theory - 2

The Prisoners' Dilemma

		B's strategy	
		Do not contribute	Contribute
A's strategy	Do not contribute	0, 0	6, -2
	Contribute	-2, 6	4, 4

Fully privileged: Here a unit provides each player with 8 in benefits, at a cost of 6 to the contributor. The resulting game is called fully privileged, because each player is motivated to contribute or to privilege the other player. The dominant strategy is to contribute, and the unique Nash equilibrium is (C, C). For binary-choice scenarios, this game highlights the fact that public good problems need not result in a Pareto-inferior outcome when net benefits are supportive of individual contributions.

The Fully Privileged Game

		B's strategy	
		Do not contribute	Contribute
A's strategy	Do not contribute	0, 0	8, 2
	Contribute	2, 8	10, 10

Public Goods in Natural Resource and Environmental Economics - Game Theory - 3

Assurance: This underscores the importance of the technology of public supply aggregation or the social composition function. The Assurance game is dependent on a weak-link technology, in which both players must contribute a unit of the public good for the players to receive a benefit of 6 from each unit contributed.

The Assurance game has no dominant strategy but possesses two pure-strategy Nash equilibria in which no one contributes or both players contribute. Unlike the Prisoners' dilemma, contracts are reinforcing, because if one person contributes, it is in the interest of the other player to contribute.

The Assurance Game

		B's strategy	
		Do not contribute	Contribute
A's strategy	Do not contribute	0, 0	0, -8
	Contribute	-8, 0	4, 4

The binary-choice model presented above can be extended to increase the number of players, to make it repeated and to consider the possibility that alternative assumptions may lead to departures from Nash behaviour as part of a rational strategy.

Collective action:
The term collective action refers to activities that require the coordination of efforts by two or more individuals. Because of the interdependence among the participants, game theory can be used to illustrate many failures and successes of collective action.

Collective action encompasses a wide range of applications, including the provision of a public good, the establishment of clubs, and the correction of externalities.

Public Goods in Natural Resource and Environmental Economics - Game Theory - 4

Collective Action:

The term collective action refers to activities that require the coordination of efforts by two or more individuals. Because of the interdependence among the participants, game theory can be used to illustrate many failures and successes of collective action.

Collective action encompasses a wide range of applications, including the provision of a public good, the establishment of clubs, and the correction of externalities.

A key concept of collective action is the notion of a privileged group, which contains at least one individual or coalition whose benefits from collective action will exceed the associated costs, even if these costs are solely borne by the individual or coalition.

For public goods, the existence of a privileged group means that the goods will be provided by one or more individuals. The game structure is a crucial consideration when identifying a privileged group. In the case of a single-shot Prisoners' Dilemma, the Nash equilibrium involves no one contributing when all players are identical; hence, the group is not privileged.

In the Assurance game, however, the group may be privileged, but need not be. Chicken games often give rise to a privileged group, since at least one individual wants to contribute to avoid the worst payoff combination. Heterogeneity among agents tends to promote the group being privileged, with the high demanders wanting to contribute even if they have to do it alone.

Olson (1965) put forward a number of propositions concerning collective action that have been very influential. However, in a recent book Sandler (1992) explains the forces behind success and failure in collective actions and indicates that these forces hinge, in large part, on the underlying game structure and dynamics.

Public Goods in Natural Resource and Environmental Economics - Game Theory - 5

Although none of Olson's propositions is true in general, most are valid in many cases that correspond to important real-world scenarios. In essence, the validity of the Olsonian proposition depends on the following: the technology of public supply aggregation, the form of the utility function, the strategic assumption, the intertemporal aspects of the interaction, and the constraints or the rules of the game.

Homogeneous clubs and local public goods:
A club is a voluntary group of individuals who derive mutual benefit from sharing one or more of the following: production costs, the members' characteristics, or a good characterized by excludable benefits. An excludable (rivalrous) public good is a club good.

Characteristics that distinguish a club good from a pure public good:

A. Voluntarism, which functions with the following:

crowding, which leads to finite membership

disposition of non-members of a given club

presence of an exclusion mechanism

a dual decision involved (two stages): members should be distinguished from non-members and then the provision quantity of the shared good must be determined

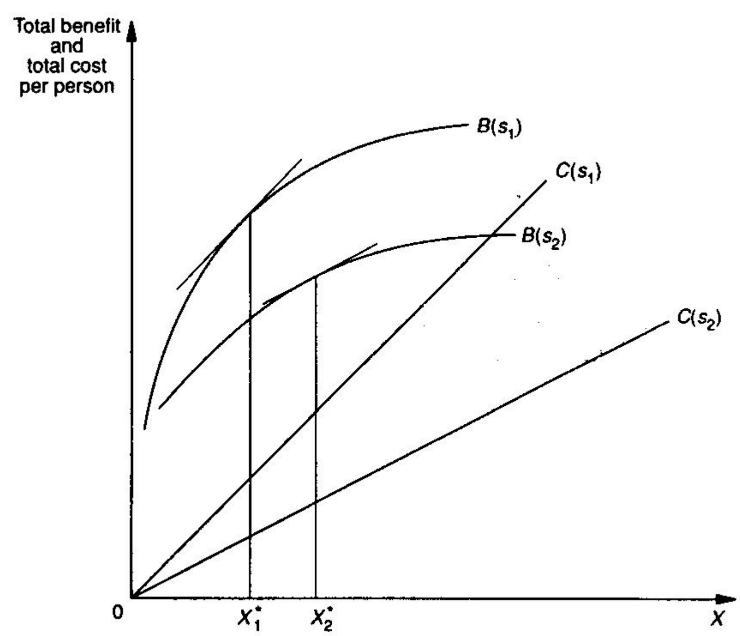
Optimality—unlike pure public goods, clubs can achieve, under a wide variety of circumstances, Pareto-optimal results without resorting to government provision.

Public Goods in Natural Resource and Environmental Economics - Game Theory - 6

B. Functionality

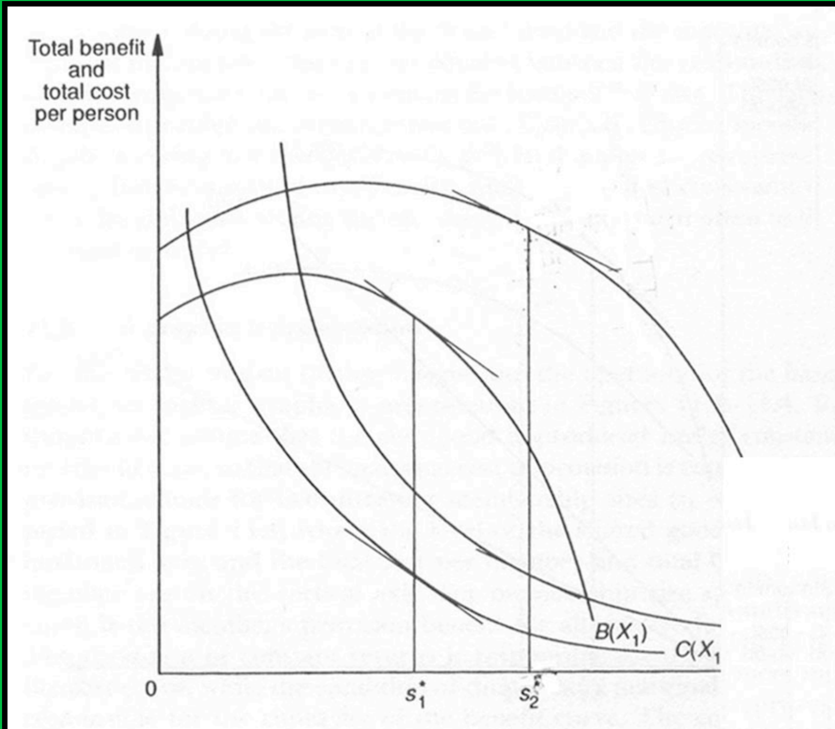
For a cost-sharing club in which all members are identical, the rules are relatively easy to institute. Tolls or membership fees will equal the cost of the club divided among the members. Provision equilibrium will equate the sum of the MRSs (marginal benefits) to the marginal provision cost.

Since all members are identical, the sum of MRSs will be equal to the number of members times the MRS of any member. Hence any member's marginal benefit can be used to determine the club's marginal benefit from provisions. For mixed clubs these calculations will not be so straightforward.

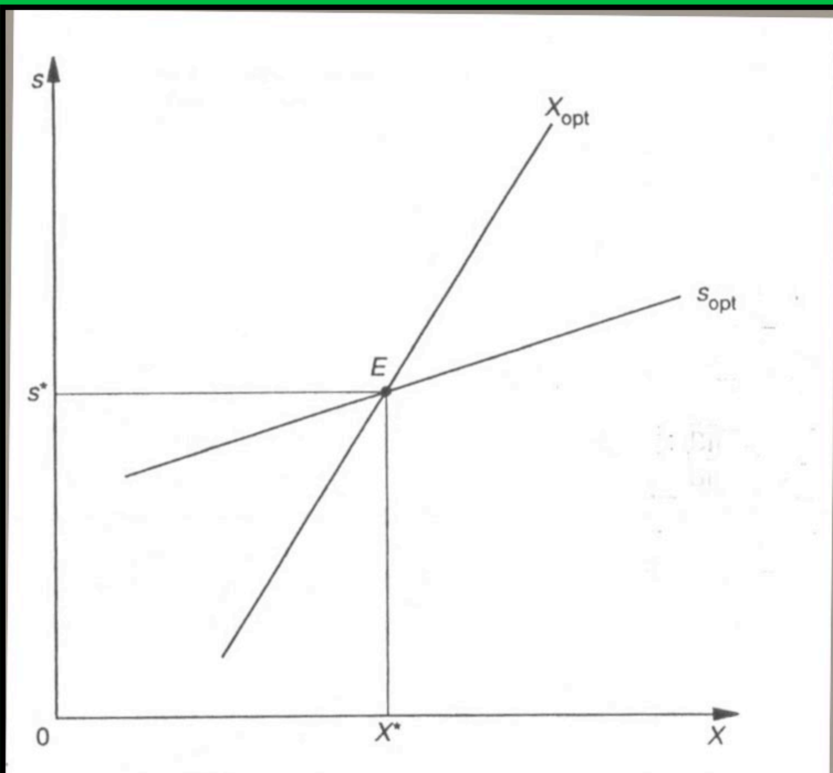


Optimizing provision level for a club

Public Goods in Natural Resource and Environmental Economics - Game Theory - 7



Optimizing membership for a club



Club equilibrium

Public Goods in Natural Resource and Environmental Economics - Game Theory and Club Goods

When clubs are investigated, n-person cooperative games are often appropriate, since all can benefit through voluntary membership.

For pure public goods and many types of externalities, however, private and group incentives conflict, thereby inducing individuals to pursue non-cooperative or defector strategies (e.g., easy riding). Hence non-cooperative games such as the Prisoners' Dilemma or the game of Chicken are employed to study the provision of pure public goods.

Although an association between cooperative game theory and clubs generally holds, recent studies have used modern analyses of non-cooperative game theory to examine clubs. In particular, clubs have been represented with a two-stage game in which the number of clubs is determined in the first stage, while club parameters (e.g., membership size, provision) are chosen in the second stage.

The equilibrium notion is typically that of sub-game perfection, in which each sub-game's solution is that of Nash.

Questions on Public Goods and Natural Resource Economics:

1. How does the theory of public goods explain market structure and dynamics in the context of natural resource economics?
2. How does the notion of clubs resemble the transactions cost model of Coase (1960) and to what extent does it define limits to the theory of public goods in relation to natural resources?
3. Does the theory of public goods provide an adequate theoretical framework for common property resources. If so, how, and if not, why not?
4. Can you define any real-world examples in which the theory of public goods could be validated or rejected empirically and if so, how it applies or does not apply to natural resource economics?