Collective Action Games

Prelude

- So far we have considered games with only two or three players interacting with each others. But, many social, economic, and political interactions are strategic situations in which ***numerous players participate at the same time***.

- Strategies for career paths, investment plans, rush-hour commuting routes, and even studying have associated ***benefits and costs that depend on the actions of many other people***.

- Problem – too many players (too many students, investors, and commuters crowding just where you wanted to be); too few willing volunteers for some worthy cause

- Multiple-person games in society often seem to produce outcomes that are not deemed satisfactory by many or even all of the people in that society

Collective Action

- In the most general form, such many-player games concern problems of **collective action.**
- The aims of the whole society or collective are best served if its members take some particular action or actions, but these actions are not in the best private interests of those individual members.
- In other words, the ***socially optimal outcome*** is not automatically achievable as the Nash equilibrium of the game
- We must examine how the game can be modified to ***lead to the optimal outcome or at least to improve*** on an unsatisfactory Nash equilibrium
- They come in three forms, all of them familiar to you by now: the prisoners' dilemma, chicken, and assurance games

Collective-action Games with Two Players

- Imagine that you are a farmer.
- A neighboring farmer and you can both benefit by constructing an irrigation and flood-control project.
- The two of you can join together to undertake this project, or one of you might do so on your own.
- However, after the project has been constructed, the other automatically benefits from it.
- Therefore, each is tempted to leave the work to the other (***free ride***).
- That is the essence of your ***strategic interaction*** and the ***difficulty of securing collective action***

Collective-action Games with Two Players

- Our irrigation project has two important characteristics.

- First, its benefits are **non-excludable:** a person who has not contributed to paying for it cannot be prevented from enjoying the benefits.

- Second, its benefits are **non-rival:** any one person's benefits are not diminished by the mere fact that someone else is also getting the benefit.

- Economists call such a project a **pure public good;** national defence is often given as an example.

Collective-action Games with Two Players

- In contrast, a ***pure private good*** is fully excludable and rival: non-payers can be excluded from its benefits, and if one person gets the benefit, no one else does. A loaf of bread is a good example of a pure private good.

- Most goods fall somewhere on the two-dimensional spectrum of varying degrees of excludability and rivalness.

Collective Action as a Prisoners' Dilemma

- The costs and the benefits associated with building the irrigation project depend, as do those associated with all collective actions, on which players participate.

- In turn, the relative size of the costs and benefits determine the structure of the game that is played

- The irrigation project can be finished in 7 weeks if you work alone, whereas if the two of you acted together, it would take only 4 weeks of time from each.

- The two-person project is also of better quality; each farmer gets benefits worth 6 weeks of work from a one-person project (whether constructed by you or by your neighbor) and 8 weeks' worth of benefit from a two-person project.

Collective Action as a Prisoners' Dilemma

- More generally, we can write benefits and costs as functions of the number of players participating.
- Costs can be written as $C(n)$ where cost, C, depends on the number, n, of players participating in the project. In this case, here $C(1) = 7$ and $C(2) = 4$.
- Similarly benefits can be written as $B(n)$; in this case $B(1) = 6$ and $B(2) = 8$
- The benefits are the same for each farmer regardless of participation due to the public-good nature of this particular project.
- Each farmer has to decide whether to work toward the construction of the project or not—that is, to shirk (***free ride***)

Collective Action as a Prisoners' Dilemma

- Payoffs are determined on the basis of the difference between the cost and the benefit associated with each action
- So the payoff for choosing Build will be B(n) - C(n) with n = 1 if you build alone and with n = 2 if your neighbor also chooses Build.
- The payoff for choosing Not is just B(1) if your neighbor chooses Build, because you incur no cost if you do not participate in the project.

		NEIGHBOR	
		Build	Not
YOU	Build	4, 4	–1, 6
	Not	6, –1	0, 0

Best responses and NE

- If neighbour doesn't participate then best response is not to participate as your benefit from completing the project by yourself (6) is less than your cost (7) with a net benefit of (-1) as compared to (0) when you don't participate

- IF neighbour participates then best response is to free ride and get the benefit (6) from his work at no cost to yourself

- Though both will be benefitted if they work together and get (4) each, the NE is not building for both the players – PD game

- Individually optimal choices (in this case, not to build regardless of what the other farmer chooses) may not be optimal from the perspective of society as a whole, even if the society is made up of just two farmers.

Social Optimum and NE

- The ***social optimum*** in a collective-action game is achieved when the sum total of the players' payoffs is maximized; in this prisoners' dilemma, the social optimum is the (Build, Build) outcome.

- Nash-equilibrium behavior of the players does not consistently bring about the socially optimal outcome.

- Suppose we have a different social optimal (let's assume 1 person project has the same quality as 2 person project and if built, each farmer saves 6.3 weeks of work)

		NEIGHBOR	
		Build	Not
YOU	Build	2.3, 2.3	–1, 6
	Not	6, –1	0, 0

Social Optimum and NE

- The ***social optimum*** is one person building and the other free riding (with a joint payoff of 5)
- The game is still a prisoners' dilemma and leads to the equilibrium (Not, Not)
- Achieving the social optimum in this case then poses a new problem: Who should build and suffer the payoff of -1 while the other is allowed to be a free rider and enjoy the payoff of 6?

Collective Action as Chicken

- Suppose the cost of the work is reduced so that it becomes better for you to build your own project if your neighbor does not.

- Specifically, suppose the one-person project requires 4 weeks of work, so $C(1) = 4$, and the two-person project takes 3 weeks from each, so $C(2) = 3$ (to each); the benefits are the same as before.

		NEIGHBOR	
		Build	Not
YOU	Build	5, 5	2, 6
	Not	6, 2	0, 0

Collective Action as Chicken

- Best response is to shirk when your neighbor works and to work when he shirks.
- In form, this game is just like a game of chicken, where shirking is the Straight strategy (tough or uncooperative), and working is the Swerve strategy (conciliatory or cooperative)
- If this game results in one of its pure-strategy equilibria, the two payoffs sum to 8; this total is less than the total outcome that both players could get if both of them build (10).

Collective Action as Chicken

- That is, neither of the Nash equilibria provides so much benefit to society as a whole as that of the coordinated outcome, which entails both farmers' choosing to build

- What if they play mixed strategy?

Collective Action as Chicken

- If the outcome of the chicken game is its mixed-strategy equilibrium, the two farmers will fare even worse than in either of the pure-strategy equilibria

- Their expected payoffs will add up to something less than 8 (4, to be precise)

Collective Action as Chicken (II)

- Suppose each farmer's benefit from the two-person project, B(2), is only 6.3, whereas each still gets a benefit of B(1) = 6 from the one-person project

- Cost remain same, that is, C(1) = 4 and C(2) = 3

		NEIGHBOR	
		Build	Not
YOU	Build		
	Not		0, 0

Collective Action as Chicken (II)

		NEIGHBOR	
		Build	Not
YOU	Build	3.3, 3.3	2, 6
	Not	6, 2	0, 0

- It is still a game of chicken — Nash equilibria in each of which only one farmer builds, but the sum of the payoffs when both build is only 6.6, whereas the sum when only one farmer builds is 8.

- The social optimum is for only one farmer to build.

- Each farmer prefers the equilibrium in which the other builds.

Collective Action as Assurance

- Suppose the benefit of a one-person project to $B(1) = 3$ and everything same as the PD game [$B(2) = 8$, $C(2) = 4$; $C(1) = 7$]

- This change reduces your benefit as a free rider so much that now if your neighbor chooses Build, your best response also is Build.

		NEIGHBOR	
		Build	Not
YOU	Build	4, 4	–4, 3
	Not	3, –4	0, 0

- This is now an assurance game with two pure-strategy equilibria: one where both of you participate and the other where neither of you does

Assurance Vs Chicken

- As in the chicken II version of the game, the socially optimal outcome here is one of the two Nash equilibria.

- In chicken II, the two players differ in their preferences between the two equilibria, either of which achieves the social optimum (B, NB) or (NB, B).

- In the assurance game, both of them prefer the same equilibrium, (B, B) and (NB, NB) and out of which (B, B) is the socially optimal outcome.

- Therefore, ***achieving the social optimum should be easier in the assurance game than in chicken***.

Collective Inaction

- Our farmers find themselves in a situation in which the social optimum generally entails that at least one, if not both, of them participates in the project.
- Thus the game is one of ***collective action***.
- Other multiplayer games might better be called games of ***collective inaction***.
- In such games, society as a whole prefers that some or all of the individual players do not participate or do not act.
- Examples: choices between rush-hour commuting routes, investment plans, or fishing grounds.

Tragedy of the Commons

- All of these games have the attribute that players must decide whether to take advantage of some common resource, be it a freeway, a high-yielding stock fund, or an abundantly stocked pond.

- These collective "inaction" games are better known as ***common-resource games***; the total payoff to all players reaches its maximum when players refrain from ***overusing the common resource***.

- The difficulty associated with not being able to reach the social optimum in such games is known as the "***tragedy of the commons***"

- What if the outcome of both farmers' building was that the project used so much water that the farms had too little water for their livestock?

Tragedy of the Commons

- Then each player's payoff could be negative when both choose Build, lower than when both choose Not Build

- Again PD where the socially optimal outcome entails neither farmer's building even though each one still has an individual incentive to do so

- If one farmer's activity causes harm to the other, as would happen if the only way to prevent one farm from being flooded is to divert the water to the other. Then each player's payoffs could be negative if his neighbor chose Build.

- Again, one variant of chicken could also arise. In this variant, each of you wants to build when the other does not, whereas it would be collectively better if neither of you did

Collective-action Problems in Large Groups

- We extend our irrigation-project example to a situation in which a population of N farmers must each decide whether to participate
- $C(n)$ representing the cost each participant incurs when n of the N total farmers have chosen to participate
- Similarly, $B(n)$ and payoff for each participant is $P(n) = B(n) - C(n)$; whereas each nonparticipant, or shirker, gets the payoff $S(n) = B(n)$
- Participate or shirk? Depends on what the other $(N - 1)$ farmers in the population are doing.
- In general, you will have to make your decision when the other $(N - 1)$ players consist of n participants and $(N - 1 - n)$ shirkers

Collective-action Problems in Large Groups

- If you decide to shirk – the number of participants in the project is still *n*, so you get a payoff of S(n).
- If you decide to participate, the number of participants becomes n + 1, so you get P(n + 1)
- So, if P(n+1)>S(n), you participate and
- if P(n+1)<S(n), you shirk
- This comparison holds true for every version of the collective-action game

Collective-action Problems in Large Groups

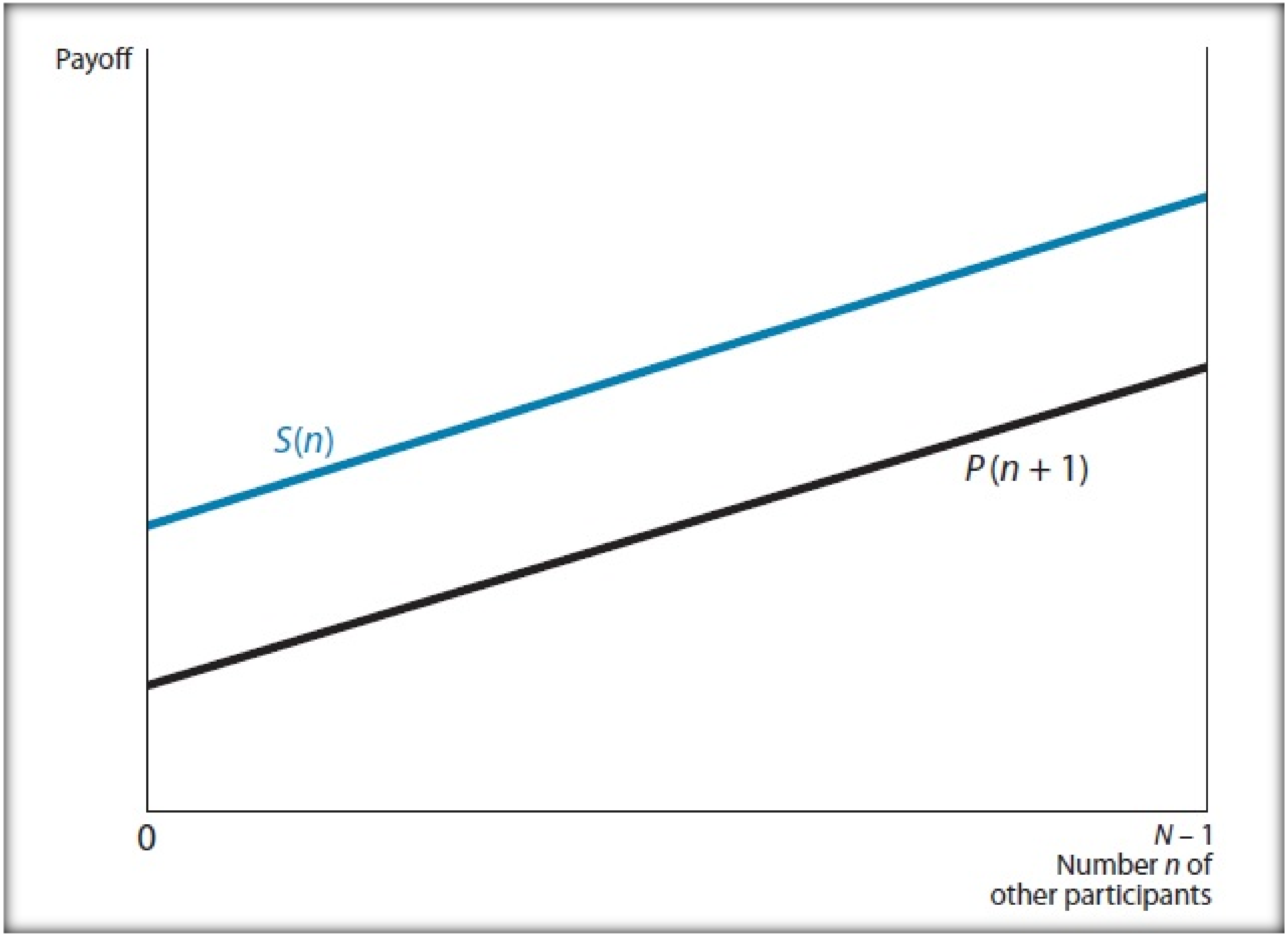
		NEIGHBOR	
		Build	Not
YOU	Build	$P(2)$, $P(2)$	$P(1)$, $S(1)$
	Not	$S(1)$, $P(1)$	$S(0)$, $S(0)$

- The above game is a PD if – **P(2) < S(1); P(1) < S(0) and P(2) > S(0)**
- The dilemma is of type I if **2P(2) > P(1) + S(1)**, so the total payoff is higher when both build than when only one builds

Multiplayer Prisoners' Dilemma

- Version of the irrigation project: an entire village of 100 farmers must decide which action to take
- The irrigation project raises the productivity of each farmer's land in proportion to the size of the project, specifically $P(n) = 2n$.
- If you are not working on the project, you can enjoy this benefit and use your time to earn an extra 4 in some other occupation, so $S(n) = 2n + 4$
- If you are working, then you get $P(n+1) = 2(n+1)$
- We can represent it graphically

Multiplayer Prisoners’ Dilemma



Multiplayer Prisoners' Dilemma

- Full range of n is from 0 to (N – 1)
- High number of participants, right hand side of the graph and vice-versa
- Continuous curves – large N (taking care of discrete nuumbers)
- Linear $P(n + 1)$ *and* $S(n)$
- The curve $S(n)$ *lies entirely* above the curve $P(n + 1)$ as $(2n+4)>2n$ for all $n \geq 0$
- Hence, no matter how many others participate, your payoff is higher if you shirk

Multiplayer Prisoners' Dilemma

- These payoffs are identical for all players, so everyone has a dominant strategy to shirk.
- Therefore, the Nash equilibrium of the game entails everyone shirking, and the project is not built
- Also, $S(0) < P(N)$ implying if everyone including you shirks, your payoff is less than if everyone including you participates
- Everyone would be better off than they are in the Nash equilibrium of the game if the outcome in which everyone participates could be sustained – PD

Multiplayer Prisoners' Dilemma

- How to compare NE with Social Optimum in this case?

- Need to describe total social payoff at each value of n

- The total payoff to society when there are n participants consists of the value $P(n)$ for each of the n the value $S(n)$ for each of the $(N - n)$ shirkers: $\boldsymbol{T(n) = nP(n) + (N - n)\ S(n)}$.

- The social optimum occurs when the allocation of people between participants and shirkers maximizes the total payoff $T(n)$, that is, the number of participants (n) that maximizes $T(n)$

- To do so we rearrange: $\boldsymbol{T(n) = NS(n) - n\ [S(n) - P(n)]}$

Multiplayer Prisoners' Dilemma

- We calculate $T(n)$ by giving every one of the N people the shirker's payoff but then removed the shirker's extra benefit $[S(n) - P(n)]$ from each of the n participants.

- In collective-action games we normally expect $S(n)$ to increase as n increases, hence, the first term $\boldsymbol{NS(n)}$ increases with n

- If the second term does not increase too fast as n increases—as would be the case if the shirker's extra benefit, $[S(n) - P(n)]$, is small and constant—then the effect of the first term dominates in determining the value of $T(n)$.

- When N=100, $T(n) = 400 + 196n$ and $T(N)$ maximized at $n = N$

Multiplayer Prisoners' Dilemma

- Society as a whole would be better off if all of the farmers participated in building the irrigation project and $n = N$.

- But payoffs are such that each farmer has an individual incentive to shirk.

- The Nash equilibrium of the game, at $n = 0$, is not socially optimal

- In other situations, $T(n)$ can be maximized for a different value of n, *that is*, society's aggregate payoff could be maximized by allowing some shirking

Multiplayer Prisoners' Dilemma

- If the gap between *S(n)* and *P(n)* widens sufficiently fast as *n* increases, then the negative effect of the second term in the expression for *T(n)* outweighs the positive effect of the first term as n approaches *N*; then it may be best to let some people shirk—that is, the socially optimal value for *n* may be less than *N*.

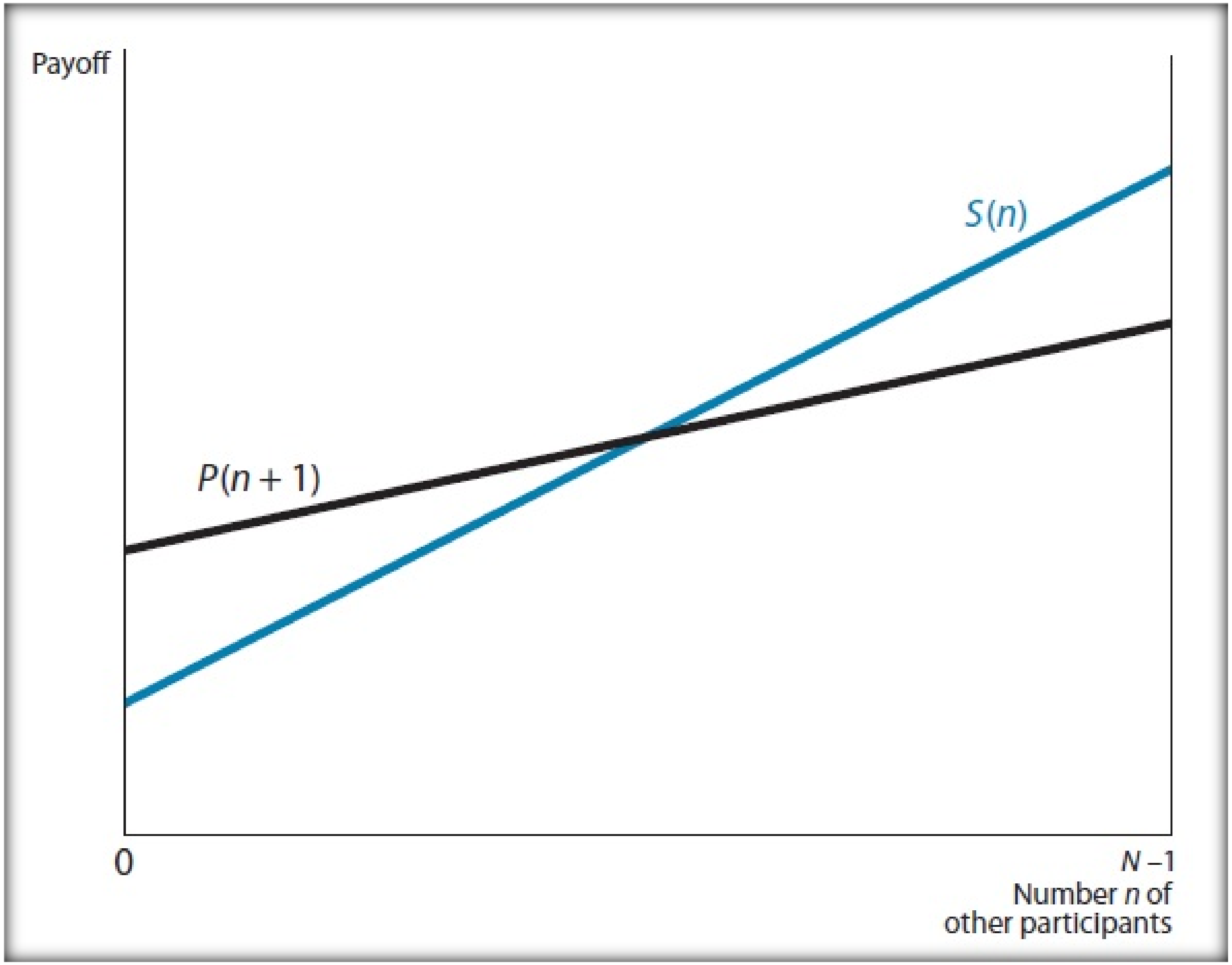
- Assume, $S(n) = (4n + 4)$

- $T(n) = -2n^2 + 396n + 400$ implying, $n=99$

- The change to the payoff structure has created an inequality in the payoffs—the shirkers fare better than the participants—which adds another dimension of difficulty to society's attempts to resolve the dilemma.

Multiplayer Chicken

- Assume, $P(n) = 4(n + 9)$ and $S(n) = 5n$
- So, $P(n+1)$ and $S(n)$ intersect at $n=40$



Multiplayer Chicken

- For small values of n, $P(n + 1) > S(n)$, so if few others are participating, your choice is to participate.
- For large values of n, $P(n + 1) < S(n)$, so if many others are participating, your choice is to shirk
- Analogous to the 2-player version: you shirk if your neighbor works and you work if he shirks
- More generally, the ***chicken case*** occurs when you are given a choice between two actions, and ***you prefer to do the one that most others are not doing***

Multiplayer Chicken: Equilibrium

- This location where $P(n+1)$ and $S(n)$ intersects, represents the equilibrium value of n.

- If, $P(n+1)$ and $S(n)$ doesn't intersect, strictly speaking the game has no Nash equilibrium

- In practice, if the current value of n in the population is the integer just to the left of the point of intersection, then one more person will just want to participate, whereas if the current value of n is the integer just to the right of the point of intersection, one person will want to switch to shirking

- Hence, the number of participants will stay in a small neighborhood of the point of intersection

Multiplayer Chicken

- What is the socially optimal outcome in the chicken form of collective action?

- If each participant's payoff P(n) increases as the number of participants increases, and if each shirker's payoff S(n) does not become too much greater than the P(n) of each participant, then the total social payoff is maximized when everyone participates.

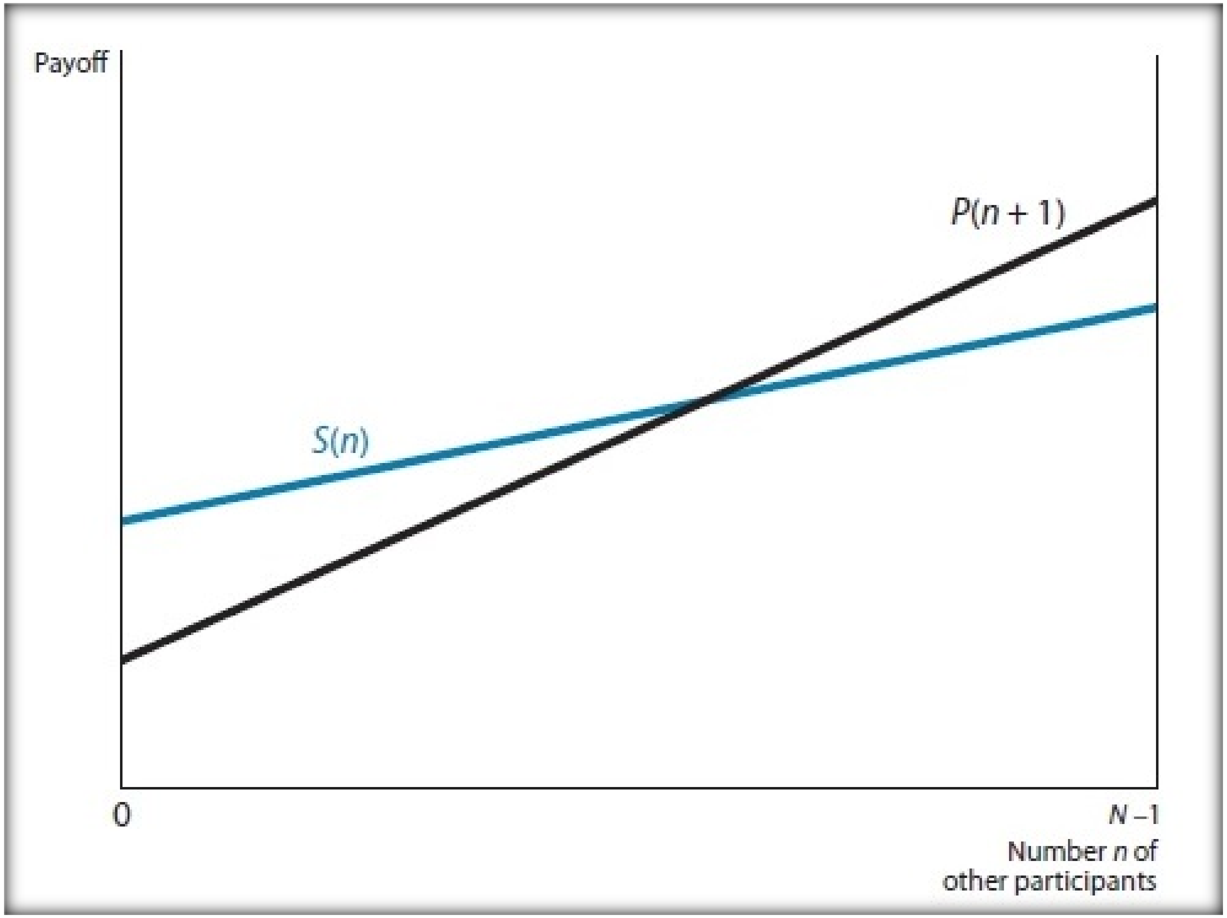
- Example: $T(n) = 536n - n^2$ implying social welfare optimising n is greater than N, hence, social welfare maximized at $n=100$.

Multiplayer Assurance

- What if $P(n + 1) = 4n + 4$ and $S(n) = 2n + 100$?

Multiplayer Assurance

- Solution: $n = 48$.



Multiplayer Assurance

- $P(n + 1) = 4n + 4$ and $S(n) = 2n + 100 \Rightarrow n=48$

- Here $S(n) > P(n + 1)$ for small values of n, so if few others are participating, then you want to shirk, too.

- But $P(n + 1) > S(n)$ for large values of n, so if many others are participating, then you want to participate too.

- ***Assurance is a collective-action game in which you want to make the choice that the others are making***

Multiplayer Assurance: Equilibrium?

- If n were exactly 48, we would see an outcome in which there were some participants and some shirkers.
- This situation could be an ***equilibrium*** only if the value of n is exactly 48. Even then, it would be a highly unstable situation.
- If any one farmer accidentally joined the wrong group, his choice would alter the incentives for everyone else, driving the game to one of the endpoint equilibria.
- Social optimum: both curves are rising—so each person is better off if more people participate—then clearly the right-hand extreme equilibrium is the better one for society. **Check**!

Externalities

- We delve further into the differences between the individual (or private) incentives in such games and the group (or social) incentives

- What is the effect of individual decision on the collective?

- We bring in the concept of ***externalities and spillovers***

Commuting and Spillovers

- A large group of 8,000 commuters who drive every day from a suburb to the city and back

- One can take either the expressway (action P) or a network of local roads (action S)

- Local-roads route takes a constant 45 minutes, no matter how many cars are going that way

- The expressway takes only 15 minutes when uncongested. But every driver who chooses the expressway increases the time for every other driver on the expressway by 0.005 minutes

- Measure the payoffs in minutes of time saved (say from 1 hour)

Commuting and Spillovers

- The payoff to drivers on the local roads, S(n), is a constant (60 – 45) = 15
- The payoff to drivers on the expressway, P(n), depends on *n*
- P(n) = (60 – 15) = 45 for n = 0
- $P(n) = 45 - 0.005n$ for $n>0$
- Suppose initially, there are 4000 cars in the expressway, then,

  $P(4000) = 45 - 0.005(4000) = 25$
- What if one more car adds up? (You, a local-road driver, might therefore decide to switch from driving the local roads to driving on the expressway)

Commuting and Spillovers

- Hence, if there are 4001 cars in the expressway, then,

  $P(4000) = 45 - 0.005(4001) = 24.995 > 15 = S(4001)$

- This payoff is still higher than the 15 from driving on the local roads.

- Thus, you have a ***private incentive to make the switch***, because for you,

  $P(n + 1) > S(n)$

- Your switch yields you a private gain (equal to the difference between your payoffs before and after the switch); this private gain is $P(n+1) - S(n) = 9.995$ minutes

- You a small part of the whole group, the gain in payoff that you receive in relation to the total group payoff is small, or ***marginal***.

Commuting and Spillovers

- We call your gain the ***marginal private gain*** associated with your switch.
- The ***cumulative effect*** on all of these other drivers is 4,000 X (-0.005) = -20 (minutes)
- Your action, switching from local roads to expressway, has caused this effect on the others' payoffs.
- Whenever one person's action affects others like this, it is called a ***spillover effect, external effect, or externality***.
- Because you are but a very small part of the whole group, we should actually call your effect on others the ***marginal spillover effect***.

Commuting and Spillovers

- Taken together, the ***marginal private gain*** *and* ***the marginal spillover effect*** are the ***full effect of your switch*** on the group of commuters, or the overall marginal change in the whole group's or the whole society's payoff.

- We call this the ***marginal social gain*** associated with your switch**.**

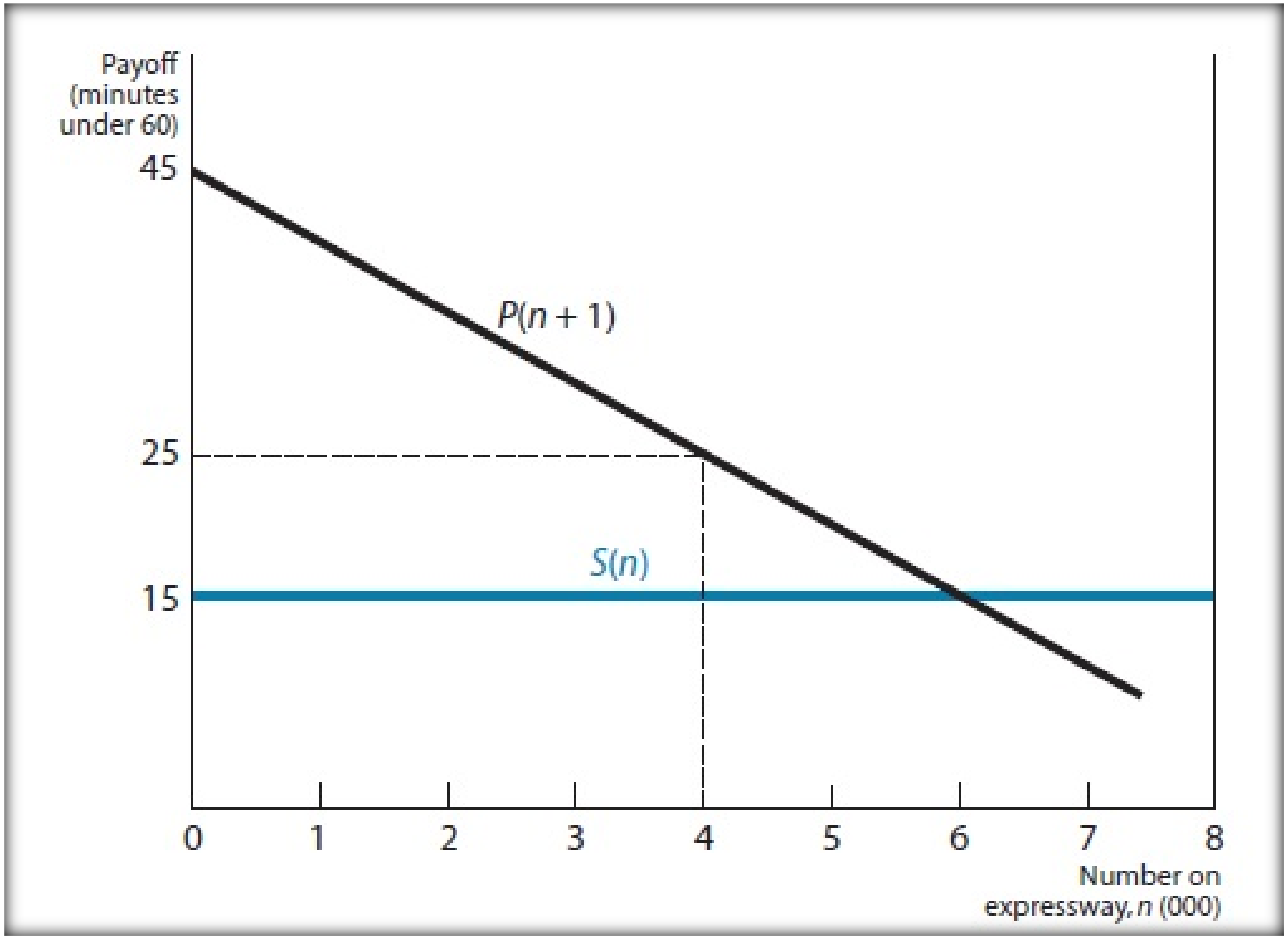
- This "gain" may actually be positive or negative, so the use of the word gain is not meant to imply that all switches will benefit the group as a whole.

- In fact, in our commuting example, the overall marginal social gain is $9.995 - 20 = -10.005$ (minutes).

- Thus, the overall social effect of your switch is bad; the social payoff is reduced by a total of just over 10 minutes.

Commuting and Spillovers

- Solving for $P(n+1) = S(n)$, we get at $n=6000$, you become indifferent



Spillovers: The General Case

- For the generalised version we resort to total social payoff function, T(n), where n represents the number of people choosing P, so (N – n) is the number of people choosing S.

- Suppose that initially n people have chosen P and that one person switches from S to P.

- Then the number choosing P increases by 1 to (n + 1), and the number choosing S decreases by 1 to (N - n - 1) implying –

$$T(n+1) = (n+1)\,P(n+1) + [N - (n+1)]\,S(n+1)$$

$$\Rightarrow T(n+1) - T(n) = (n+1)\,P(n+1) + [N - (n+1)]\,S(n+1) - n\,P(n) - (N-n)\,S(n)$$

$$= [P(n+1) - S(n)] + n\,[P(n+1) - P(n)] + [N - (n+1)]\,[S(n+1) - S(n)]$$

Spillovers: The General Case

$$\Rightarrow T(n+1) - T(n) = [P(n+1) - S(n)] + n\,[P(n+1) - P(n)] + [N - (n+1)]\,[S(n+1) - S(n)]$$

- First term $[P(n+1) - S(n)]$ is the marginal private gain enjoyed by the person who switches – which drives a person's choice, and all such individual choices then determine the Nash equilibrium

- The second and third terms are the quantifications of the spillover effects of one person's switch on the others in the group

- The 2nd term captures – for the n other people choosing P, each sees his payoff change by the amount $[P(n + 1) - P(n)]$ when one more person switches to P

Spillovers: The General Case

- The 3rd term captures – There are also $(N - n - 1)$ others still choosing S after the one person switches, and each of these players sees his payoff change by $[S(n + 1) - S(n)]$

- The effect that one driver's switch has on the time for any one driver on either route is very small, but, when there are numerous other drivers (that is, when N is large), the full spillover effect can be substantial

- So we can re-interpret the change in social payoff function as –

Marginal social gain = marginal private gain + marginal spillover effect

Marginal social gain = $T(n + 1) - T(n)$

Marginal private gain = $[P(n + 1) - S(n)]$

Marginal spillover effect = $n\,[P(n + 1) - P(n)] + [N - (n + 1)]\,[S(n + 1) - S(n)]$

Solving using calculus

- If N is large, then we can assume n as infinitesimally small and hence treat n as a continuous variable and apply calculus

- $T(n) = nP(n) + (N - n)\, S(n)$

$\therefore\ T'(n) = P(n) + nP'(n) - S(n) + (N - n)\, S'(n)$

$$= [P(n) - S(n)] + nP'(n) + (N - n)S'(n)$$

- In the commuting example we had: $P(n) = 45 - 0.005n$ and $S(n) = 15$

$\therefore\ [P(n) - S(n)] = 30 – 0.005n$; $P'(n) = - 0.005$ and $S'(n) = 0$

Negative Externalities

- A negative externality exists when the action of one person lowers others' payoffs
- the marginal spillover effect of one person's switch to the expressway was negative, entailing an extra 20 minutes of drive time for other commuters
- individual who changes his route to work does not take the spillover (the externality) into account when making his choice
- He is motivated only by his own payoffs – he will change his action from S to P as long as this change has a positive marginal private gain

Negative Externalities

- But society would be better off if the commuter's decision were governed by the marginal social gain.

- In the commuting example, the marginal social gain is negative (-10.005), but the marginal private gain is positive (9.995)

- Generally, in situations with negative externalities, the marginal social gain will be smaller than the marginal private gain due to the existence of the negative spillover effect

- Recall that if *n* people are already using the expressway and another driver is contemplating switching from the local roads to the expressway

Negative Externalities

- He stands to gain from this switch if $P(n + 1) > S(n)$

$\Rightarrow 45 - (n + 1) \times 0.005 > 15$

$\Rightarrow n < 5999$

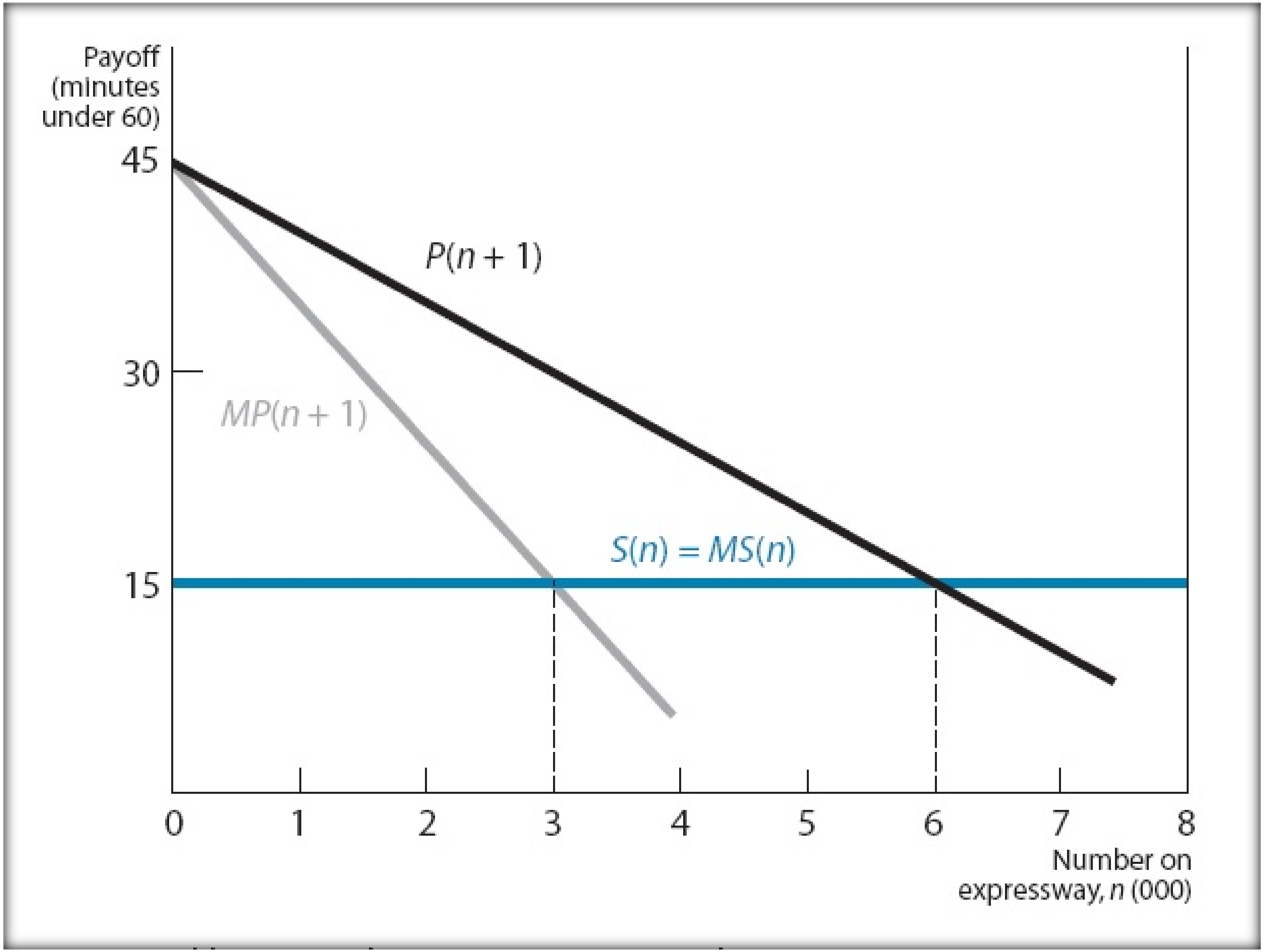
- Total social payoff increases if $T(n + 1) - T(n) > 0$

$\Rightarrow 45 - \{(n + 1) \times 0.005\} - 15 - 0.005n > 0$

$\Rightarrow n < 2999.5$

- Therefore, commuters will crowd onto the expressway until there are almost 6,000 of them, but all crowding beyond 3,000 reduces the total social payoff

Negative Externalities



How to achieve social optimum?

- Different cultures and political groups use different systems
- The society could simply restrict access to the expressway to 3,000 drivers. But how would it choose those 3,000?
- ***First-come, First-served Rule***: but then drivers would race each other to get there early and waste a lot of time
- ***Bureaucratic Society*** using complex rules based on needs and merits: everyone will undertake some costly activities to meet these criteria
- ***Politicized Society***: important "swing voters" or organized pressure groups or contributors may be favored

How to achieve social optimum?

- ***Corrupt Society***: bribery

- ***Egaliterian Society***: allocate the rights to drive on the expressway by lottery or could rotate them from one month to the next (odd-even rule in Delhi), but rich can have two cars, hence, not exactly egaliterian

- ***Economist***: Impose tax on expressway such that n automatically becomes 3000. How?

- Make $P(n) - t = S(n)$ and plugging $n=3000$ in the equation get $t=15$.

- But t is in minutes. So, assume minimum wage is \$5 per hour, so, 15 minutes is equivalent to \$1.25 – put a tax of \$1.25 and achieve social optimum – ***internalizing the externility***

Positive Spillovers

- A person's private benefits from undertaking activities with positive spillovers are less than society's marginal benefits from such activities.

- Therefore, such actions will be underutilized and their benefits underprovided in the Nash equilibrium.

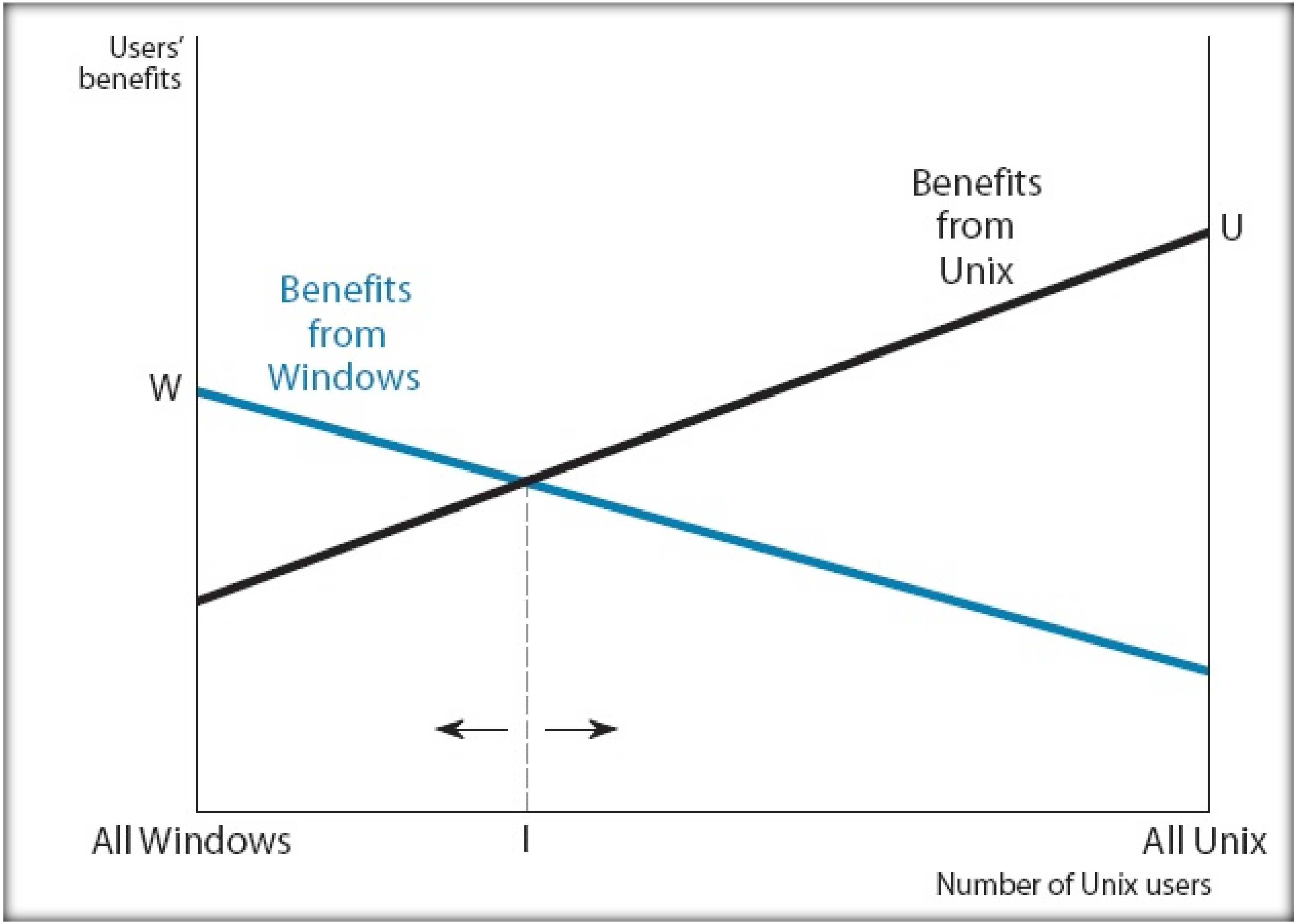
- A better outcome can be achieved by ***augmenting people's incentives***; providing those persons whose actions create positive spillovers with a ***reward*** just equal to the spillover benefit will achieve the social optimum

- Example: consider vaccination against some infectious disease.
- Each person getting vaccinated reduces his own risk of catching the disease (marginal private gain) and reduces the risk of others' getting the disease through him (spillover).

Positive Spillovers

- When you buy a computer, you have to choose between one with a Windows operating system and one with an operating system based on Unix (Ubuntu).
- As the number of Unix users rises, the better it will be to purchase such a computer.
- The system will have fewer bugs because more users will have detected those that exist, more application software will be available, and more experts will be available to help with any problems that arise.
- Similarly, a Windows-based computer will be more attractive the more Windows users there are.

Positive Spillovers



Positive Spillovers

- Left of I - current population has only a small number of Unix users - each individual user finds it better to choose Windows

- Right of I - larger number of Unix users in the population - it is better for each person to choose Unix

- At I – no one has the incentive to switch. But, this is unstable. Any movement from I leads to either all Windows or all Unix

- Which of the two stable equilibria will be achieved in this game?

- Depends on which side of I – ***industry lock-in***

Positive feedback and lock-in

- Production is more profitable the higher the level of demand in the economy, which happens when national income is higher.
- In turn, income is higher when firms are producing more and are therefore hiring more workers.
- This positive feedback creates the possibility of multiple equilibria, of which the high-production, high-income one is better for society, but individual decisions may lock the economy into the low-production, low-income equilibrium.
- The possibility of unemployment due to a deficiency of aggregate demand can be interpreted as the result of a failure to solve a collective-action problem

The Case of Easter Island

- Easter Island - one of the most isolated spots on earth (2,100 miles to the west of Chile and 4,000 miles to the southeast of Hawaii)

The Case of Easter Island

- Renowned for its massive stone faces that stoically gaze over the Pacific, the ***moai statues***, carved by the native Rapanui half a millennium ago [if interested NatGeo documentary https://www.youtube.com/watch?v=IEIoL95IakU]

The Case of Easter Island

- This thriving island civilization of perhaps 10,000–15,000 inhabitants once survived on cultivation of sweet potatoes, yams, bananas, domesticated chickens and fishing.

- By the arrival of Dutch explorers in 1722, the Rapanui had dwindled to a few thousand; by 1877, the entire population of Easter Island had plummeted to just 111 half-starved natives.

- ***The principal blunder of the Rapanui civilization:*** **deforestation**

- Trees and timber had been vital to the ancient Rapanui. Trees prevented soil erosion and provided a native habitat for birds and animals important for supplementing the local diet. Wood provided raw materials for hand tools, logs used in the erection of the moai statues, fuel for warmth during cool and rainy nights, and most importantly, for constructing fishing canoes

The Case of Easter Island

- Careful study by archaeologists of the ancient Rapanui's rubbish dumps has shown that by the time island forests began to disappear around 1500, fish likewise began to disappear from diet of natives.

- Large trees, once used for canoe-making, had vanished. Crop yields began to fall from soil erosion, so that nuts, apples, and other wild fruits dwindled as a food source. Lacking a natural habitat, native birds and animals became extinct on the island.

- When Captain Cook arrived in 1774, he described the islanders as "small, lean, timid, and miserable"

- By 18th century, the Rapanui were reduced to feeding on rodents and, later, to cannibalism

Environment, Development and Collective Action

- Since Easter Island receives only 50 inches of rainfall per year (scanty by tropical standards), trees grow slowly, leaving the island's inhabitants more vulnerable to the "***tragedy of the commons***"

- The ***relationship between economic development and the natural environment is one of the most critical relationships in the development process***, but it is also a peculiar one.

- In many indigenous cultures, such as the native Rapanui, humans often live in tandem with their environment and thus directly rely on it for their subsistence.

Environment, Development and Collective Action

- However, in the initial phases of economic development, significant degradation of the environment can occur as population pressure and modern technology induce society to sacrifice natural resources and environmental quality for higher income.

- This pattern occurs regularly across most parts of the developing world.

- During this period, critical intermediate institutional structures often fail to regulate this early exploitation of environmental resources.

- The strongest protection of environmental resources is typically found in the high-income countries.

Environment, Development and Collective Action

- A rich society becomes increasingly eager to pay for a clean environment, and it begins to demand that the state take a leading institutional role in natural resource regulation and protection.

- Consequently, economists generally view the relationship between per capita income and environmental quality as being **U-shaped**.

- Thus depending on the stage of development and the quality of institutional structures that regulate the use of the commons, ***economic development can be the natural environment's best friend – or its worst enemy***

Environment, Development and Collective Action

- The ***depth of the environmental plunge*** in the intermediate phases of development depends on the ***health of local institutions*** that exist to govern the environmental commons.

- The health of these institutions is shaped by an array of factors related to ***human social organization*** and the ***science of environmental resource sustainability***.

- It is thus one of the very few areas of serious investigation in which economists, political scientists, anthropologists, biologists, and legal scholars actually communicate with one another, and simple game-theoretic models have become a principal means of this communication

Environment, Development and Collective Action

- The outcome in the real world, resulting from the interplay of these different human and environmental factors, is far from straight forward.

- A bewildering assortment of outcomes exists, ranging from comprehensive environmental destruction, to instances in which environmental resources are efficiently and sustainably utilized, enjoyed, and preserved.

CPRs

- Focus on the use (and abuse) of environmental resources such as forests, water, fisheries, and grazing lands.

- These are all examples of ***common-pool resources*** (CPRs), which share a pair of common characteristics –

  (1) their consumption is ***rival***, but

  (2) it is ***non-excludable***

- Rivalry means that consumption by one party precludes consumption by another
- Excludability means that it is easy to control access to a resource, and to exclude others from consuming it
- I can exclude you from eating my fish, but not from using my lighthouse to guide your fishing boat to safety

Types of Goods

	Excludable	Non-Excludable
Rival	**Private Goods** *e.g.* banana, toothbrush	**Common-Pool Resources** *e.g.* forests, fisheries
Non-rival	**Club Goods** *e.g.* cable TV, honor society	**Public Goods** *e.g.* lighthouse, national defense

CPRs and Tragedy of Commons

- The combination of rivalry and non-excludability is what creates the ***individual incentive to exploit a common-pool resource for personal gain***, collectively leading to a ***Pareto inefficient outcome*** for society – often called the "***tragedy of the commons***."

- ***Population pressure*** among the rural poor in developing countries is another critical ingredient in the commons tragedy

- The rural poor in less-developed countries tend to be heavily dependent on the local availability of common-pool resources (such as firewood for cooking and for heating the home), the ***lack of institutional controls*** can lead them to ***collectively overexploit*** a natural resource as each household attempts to satisfy its short-term needs.

CPRs and Tragedy of Commons

- Addressing this predicament, however, is a ***problem of collective action***.

- A group of people may understand that they will be better off by placing ***communal limits*** on fishing or cutting down trees in a forest.

- But the ***temptation*** of each individual to free-ride on the goodwill of others may create a set of ***individual incentives*** that leads to the ***collectively inferior outcome***.

- Unless there is some device to ***enforce cooperative agreements*** between individuals, ***individual rationality can produce collective irrationality***.

Tragedy of Commons as PD

- Consider the following payoffs from a game with two strategies – conserve and plunder

		Player 2	
		Conserve	Plunder
Player 1	Conserve	s, s	v, r
	Plunder	r, v	t, t

- If $r > s > t > v$ we have PD with unique NE (P, P)
- Explore options so that outcomes other than (P, P) can be attained and sustained

Solution I (Repeated interaction)

- Commons game repeated between same players – avert the tragedy
- Zeke and Deke story – Zeke offers Deke a deal: He will never plunder the lake if Deke never plunders, but if Deke ever does, Zeke will plunder in response for *n* days thereafter
- Folk Theorem of Repeated Games - when a game between players is repeated infinitely, and players are sufficiently "patient," just about any type of Nash equilibrium behavior is possible.
- Both Zeke and Deke discounts future payoff by a factor δ ($0<\delta<1$)
- One can interpret δ in three possible ways

Solution I (Repeated interaction)

1. a measure of a player's increasing patience, defined as his value of obtaining payoffs one period into the future relative to the present

2. the probability that a repeated game continues to the next period

3. the frequency of player interactions (with $\delta \to 1$ means that little time separates episodes of interaction between players)

- The possibility of obtaining the cooperative (Conserve; Conserve) outcome is greatly enhanced in a repeated-game context

- Particularly, in an infinitely repeated game, both players may opt for sustained cooperation

Solution I (Repeated interaction)

- Grim Trigger – both will choose conserve if payoff ***s*** for infinite period exceeds the sum of ***r*** for one period followed by ***t*** for infinity

$$\Rightarrow \frac{s}{1-\delta} > r + \frac{\delta t}{1-\delta}$$

$$\Rightarrow \delta > \frac{r-s}{r-t}$$

- So, higher value of δ (their patience, belief in future repetition of the interaction, higher frequency of interaction) might ensure (Conserve, Conserve) as the NE. ***Thus in stable, tightly knit communities, conservation is more likely***.

- With a lighter punishment, such as Tit-For-Tat, the requirements on the parameters lie in the same direction, but are stronger, because the threatened punishment is weaker

Solution I (Repeated interaction)

- What if Deke doesnot keep the promise?
- What if the number of players are very large?
- What if the initial “trust” is hard to be realized?
- What if the people are mobile an are replaced by new subsets?

The top-down approach

- What happens when CPR use involves a large number of parties with short-term interests in resource exploitation?
- One possible method of preventing environmental degradation is a “top-down” approach by a strong central state with a long-term interest in future resource needs.
- In such an approach, the state steps in to penalize private parties for non-conservation of CPRs.
- Although the state allows open CPR use, it employs a “sheriff” to ensure individual compliance congruent with a long-term conservation strategy.

The top-down approach

- Suppose that the sheriff monitors CPR users, and catches violators with some fraction of the time equal to ***m***, and if they are caught, they are immediately slapped with a fine, F, making the expected fine equal to $mF = f$

		Player 2	
		Conserve	Plunder
Player 1	Conserve	s, s	v, $r - f$
	Plunder	$r - f$, v	$t - f$, $t - f$

- Either $(r\text{-}f) < s$ or $(t\text{-}f) < v$ ensures (C, C) as unique NE

Self Governance

- The primary problem with top-down CPR regulation, especially in developing countries, is nearly always the ***monitoring problem***: It is often too costly for the state to hire enough monitors to catch violators often enough such that plundering the commons doesn't pay.

- Alternative structure for CPR regulation that instead relies on the ***informational advantages of local CPR users themselves***

- in some instances ***self-governance*** may involve the communal hiring of a "sheriff," while in others it may be easier for local commons users to take up the task of monitoring and sanctioning amongst themselves, particularly when ***local users have informational advantages over outsiders in monitoring and the ability to enforce sanctions***

Self Governance

- Let, ***e*** be the cost of monitoring shared by the two players

	Conserve	Plunder
Conserve	$10-\frac{e}{2}$, $10-\frac{e}{2}$	-1, $11-f$
Plunder	$11-f$, -1	$-f$, $-f$

- The value of ***e*** may be smaller (*e* must be <20), and ***f*** may be larger (*f* must be >1) when group members themselves carryout monitoring and punishment

Self Governance: Problems

- There exists a possibility of “free-riding” by members in both the monitoring of neighboring users, and in the application of sanctions – if individuals find sanctioning others against their own interests

- In a homogeneous group of small users none may have a vested interest that is large enough to ensure that the commons is preserved

- Thus sometimes the CPR dilemma can be resolved if one Big Player exists with a lot to lose if everything falls apart (Leadership)

- The Big Player may have an incentive to shoulder the entire burden of solving the CPR dilemma for the entire group

Exploitation of the strong by the weak

		Cashmere	
		Contribute	Don't Contribute
Pet Meat	Contribute	13 3	Go to Game A
	Don't Contribute	Go to Game B	0 0

Game A:
Pet Meat Contributes

		Cashmere	
		Conserve	Plunder
Pet Meat	Conserve	20 -4	21 - f -15
	Plunder	-1 -(3+f)	- f -(14+f)

Game B:
Cashmere Contributes

		Cashmere	
		Conserve	Plunder
Pet Meat	Conserve	6 10	7 - f -1
	Plunder	-15 11 - f	-(14+f) - f

Herd Behavior and the Commons

- In the real world, the incentives that affect how people relate to the natural environment are in a significant way shaped by the behavior of others

- In many instances the tragedy of the commons may not always be best represented as a Prisoners' Dilemma, but as a Coordination game, where the incentives to Conserve depend on how many others Conserve

- Herd behavior may stem from number of sources

Herd Behavior and the Commons

- A sense of social norms changing the internal psychological costs to players from engaging in behavior contrary to the common good

- The increased fear of social sanctions as a result of standing out as a Plunderer;

- The increased likelihood of being caught by those obeying the rules

- Assume the payoff to Conserve is constant at 10, but that the payoff to Plunder declines as the number of Conserving players increases, so that the payoff to Plunder is, say, equal to $17 - 2n$

Herd Behavior and the Commons

- Here the leader can convince a critical mass of CPR users that sustainable practices will be followed, the resource use settles into the Pareto efficient Nash equilibrium of Conservation

Number of *other* players Conserving:	$n = 0$	$n = 1$	$n = 2$	$n = 3$	$n = 4$	$n = 5$	$n = 6$	$n = 7$
Payoff to Conserve:	10	10	10	10	10	10	10	10
Payoff to Plunder: $(= 17 - 2n)$	17	15	13	11	9	7	5	3

Assignment Rules in CPR Usage

- Consider the example of a fishery with a number of discrete fishing spots, where some of the spots are more alluring than others from the perspective of a fish.
- Even if there are an equal number of fishers as fishing spots, fights are likely to break out over who gets the best spot, and who is stuck with the worst.
- Recreational fishermen may be content to rely upon simple social norms such as "the best spot to the first; the last gets the worst."
- Such informal mechanisms may be reasonably efficient.

Assignment Rules in CPR Usage

- The fisherman who wants the best spot the most, will be willing to pay the highest price to secure it.
- Nevertheless, inefficiencies may arise, say, between two fishermen both wanting the prime spot - if only one of them will end up with the coveted spot anyway, both would be better off using an assignment rule
- In large-scale fishing operations, where there is more at stake, such rules may be critical

Assignment Rules in CPR Usage

- Suppose that there are two desirable fishing spots on the lake of our Appalachian fishermen, but of the two best spots, the fishing spot “on top of the Granite Rock” enjoys a higher yield than the spot “near the Mud Hole.”

		Zeke	
		Granite Rock	Mud-hole
Deke	Granite Rock	$\frac{k_G}{2}$, $\frac{k_G}{2}$	k_G, k_M
	Mud-hole	k_M, k_G	$\frac{k_M}{2}$, $\frac{k_M}{2}$

Assignment Rules in CPR Usage

- If both fight over the Granite Rock they split the high yield, k_G
- If both fight over the Mud Hole they split the low yield, k_M
- Note ($k_G > k_M$)

- Option 1: $k_G > ½\ k_M$
- Option 2: $k_M > ½\ k_G$

- Option1 leads to Chicken game
- Option 2 is pareto inferior as total catch will be k_G instead of ($k_G + k_M$)

Privatization of Rights over CPRs

- Because ambiguities and conflicts sometimes remain with informal assignment rules over a natural resource, in some instances the state has encouraged privatization of CPRs.

- Two main arguments favor CPR privatization:

- First, if individuals take a long-term view of resource use, privatization should ostensibly be linked to an incentive for sustainable resource use and hence some form of conservation. In this respect, privatization reduces the short-term incentive to engage in the Plunder strategy. Rendering the resource "excludable" for the sole use of a single private party eliminates resource-degrading "catch as catch can" behavior by multiple users.

Privatization of Rights over CPRs

- Second, many economists advocate privatization of resources on Pareto efficiency grounds – Coase Theorem – Pareto efficiency in resource use can be achieved if private property rights over the resource can be created and if bargaining between parties is costless

- Two villages share use of a river. The first village, Alto, lies upstream, and Alto residents use the river to bathe and wash their clothes (using soap). The unfortunate downstream village, Bajo, tries to use the river to fish, despite declining levels of fish in the sudsy water.

- Suppose the value to Alto of using the river for washing is X, the value to Bajo of fishing in a clean river is Y, and the cost to Alto of using a pollution-free soap is Z

Privatization of Rights over CPRs

- If Y is greater than either X or Z, then no matter which village starts out with river rights, the Coase Theorem says that the two villages will end up with a pollution-free outcome.

- For example, if rights over the river are given to Alto, then Bajo can pay Alto X or Z (whichever is less) to eliminate the pollution, and Bajo ends up better off while Alto is no worse off. If Bajo has river rights, Alto is forced to pay the lesser of X and Z to clean up its act.

- If Y is less than both X and Z, irrespective of who has the property rights, the value of fishing to Bajo is insufficient to entice Alto to clean up. Even if Bajo has river rights, Alto can pay Bajo an amount equal to Y in place of reducing its pollution, leaving Bajo no worse off and Alto better off than if it stopped washing in the river or began using the pollution-free soap.

Privatization of Rights over CPRs

- There are reasons to question whether the effects of privatization of CPRs should be unambiguously positive, especially in the context of developing countries.

- First, if many parties are affected by use of the resource, bargaining may be so logistically cumbersome that the costs of reaching a solution may overwhelm any benefit that might be derived from it.

- A second set of caveats related to privatization are related to problems of wealth distribution. Take the example of a MNC that makes a profitable chemical resin, but in so doing, dumps noxious waste into a common-access lake used for subsistence fishing by local residents of a developing country.

Privatization of Rights over CPRs

- Even if the multinational has been granted property rights to pollute, it may be impossible for local residents to purchase rights to the lake from the multinational if they are extremely poor – even if lake pollution results in a tremendous local welfare loss for them.

- Some have argued that privatization can also worsen an existing income distribution. The idea is that when a resource such as an open-access pasture is privatized, a drop in the intensity of CPR usage implies a general drop in the demand for CPR labor. Consequently, those left outside the privatization scheme may be worse off, although the natural resource may in the end be used more sustainably under privatization.

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