Collective-Action Games

- Almost all games we've explored so far have included two or three players
- Many games, however, involve the action of many players
- Multi-person games often produce outcomes that are deemed not satisfactory
- In games of **collective action**, the socially-optimal outcome is often not the Nash equilibrium

Collective-Action Games With Two Players

Suppose 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
- Only one of you can construct it
- After the project is completed, your neighbor (or you) automatically benefits regardless of the constructing composition

Each person will be tempted to shirk construction responsibility.

Collective-Action Games With Two Players

The irrigation example has two important characteristics.

1. Its benefits are **nonexcludable**, a person who has not contributed to paying for it cannot be prevented from enjoying the benefits

2. Its benefits are **nonrival**, any one person's benefits are not diminished by the mere fact that someone else is getting the benefit

Economists call these types of projects a **pure public good**. A contrasting type of good is a *purely private good*

Collective Action As A Prisoners' Dilemma

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

Collective action as a prisoners' dilemma: Version I

The costs and benefits of the irrigation project depend on who participates.

- Each person alone can complete the project in 7 weeks
- Together it takes 4 weeks
- Each person gets 6 weeks of benefit when the project is completed by one person
- Each person gets 8 weeks of benefit when the project is completed together

Collective Action As A Prisoners' Dilemma

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

Collective action as a prisoners' dilemma: Version I

More generally, we can write costs as dependent on the number of people, n, who participate $C(n)$

- $C(1)$ = my cost when I build alone
- $C(n)$ = my cost when I and $n - 1$ people contribute

Benefits B will similarly depend on the number of people who participate

Collective Action As A Prisoners' Dilemma

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

Collective action as a prisoners' dilemma: Version I

What is individually rational and optimal is not socially optimal.

It is always in your best interest to not build. The same is true for your neighbor.

This game has a **free rider** problem, each neighbor would like to benefit from their neighbor's effort.

The **social optimum** in a collective action game is achieved when the sum of the total players' payoffs is maximized.

Collective Action As A Prisoners' Dilemma

Consider the same game, but the two-person project yields benefits just slightly better (6.3 weeks) than the one-person effort.

- It's still a prisoners' dilemma with the same Nash
- The social optimum is for one of you to build
- Who should build? Who gets to be the free rider?

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

Collective action as a prisoners' dilemma: Version II

Collective Action As Chicken

Now, 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.

- $C(1) = 4$ & $C(2) = 3$
- Benefits remain the same
- Your best response is to shirk when your neighbor works and to work when they don't

The cooperative, socially optimal outcome is better than either Nash & the mixed-strategy Nash is even worse.

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

Collective action as chicken: Version I

Collective Action As Assurance

Let's reduce the benefit of a one-person project to $B(1) = 3$, but leave everything else the same. This change reduces your benefit as a free rider.

Nash equilibria: **(Build, Build), (Not, Not)**

Both players prefer the socially optimal outcome

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

Collective action as an assurance game

Collective Inaction

There is a different kind of game where society as a whole would prefer players to not participate. These are games of collective inaction.

- Players must decide to take advantage of a common resource, be it a freeway or an abundantly stocked pond
- When players overuse the resoure this is called the *tragedy of the commons*
- Suppose that in the irrigation project game, so much water was used to construct the project that little was left for the farmers' livestock

Collective Action Problems In Large Groups

We extend our irrigation-project example to a situation in which a population of N farmers must decide to participate.

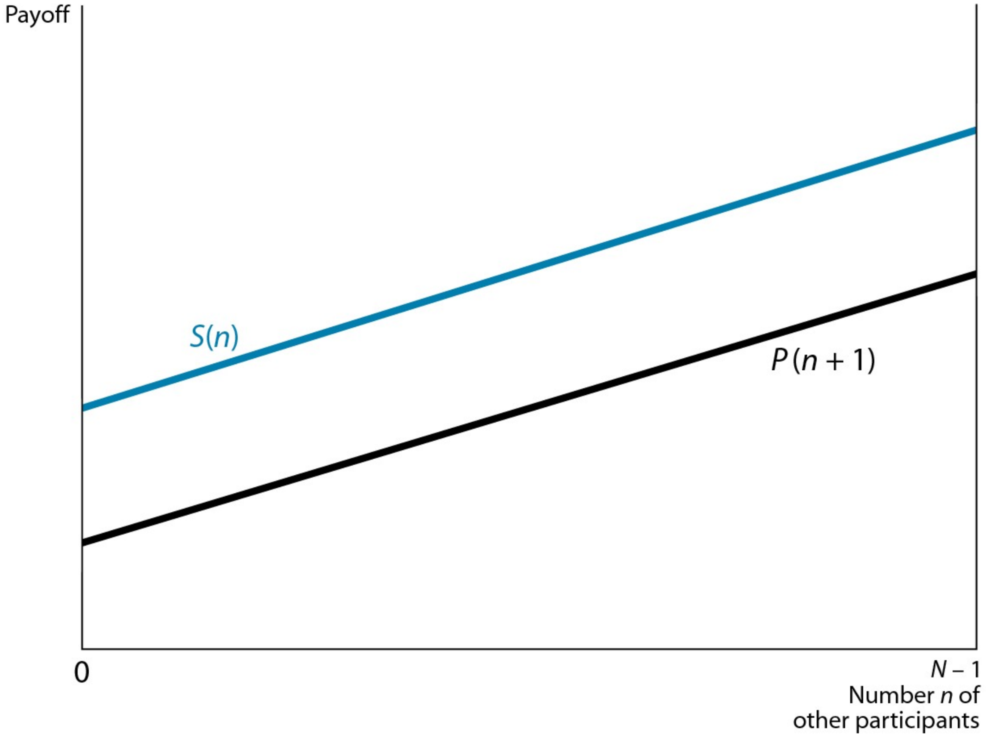
- $C(n)$ represents the cost each participant incurs when n of N farmers choose to participate
- $B(n)$ is the benefit to each regardless of participation
- Each participant gets the payoff $P(n) = B(n) - C(n)$
- Each nonparticipant, or shirker, gets the payoff of $S(n) = B(n)$

Collective Action Problems In Large Groups

When you decide to participate or not, your decision depends on what the other $(N-1)$ farmers do.

- n participants & $(N-1-n)$ shirkers
- If you shirk, your payoff is $S(n)$
- If you participate, your payoff is $P(n+1)$
- You participate when $P(n+1) > S(n)$ and shirk when $S(n) > P(n+1)$

Multiplayer Prisoners' Dilemma



Multiplayer prisoners' dilemma payoff graph

Suppose an entire village of 100 farmers must decide which action to take.

- The project raises each farmer's productivity in proportion to the size of the project
- $P(n) = 2n$
- When you don't work on a project, you enjoy the benefit and earn an additional 4 in some other occupation
- $S(n) = 2n + 4$
- Your participation depends on $P(n+1) = 2(n+1)$ & $S(n) = 2n + 4$

Multiplayer Prisoners' Dilemma

- No matter how many other participate, your payoff is higher if you shirk
- Shirking is the dominant strategy for everyone, & the project is not built
- You are better off if others participate, i.e. your payoff is increasing in n
- $S(0) = 4 < P(N) = 102$, a prisoners' dilemma

Multiplayer Prisoners' Dilemma

How does the Nash equilibrium compare with the social optimum of this game? We need to construct a third function, the total social payoff when n people participate:

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

The social optimum is at the point where n maximizes $T(n)$. Let's make this clear

$$T(n) = NS(n) + n[S(n) - P(n)]$$

We can read this as giving everyone the shirker's payoff but removed the shirker's additional benefit from the n participants

Multiplayer Prisoners' Dilemma

Let's rewrite the total social payoff and plug in what we know

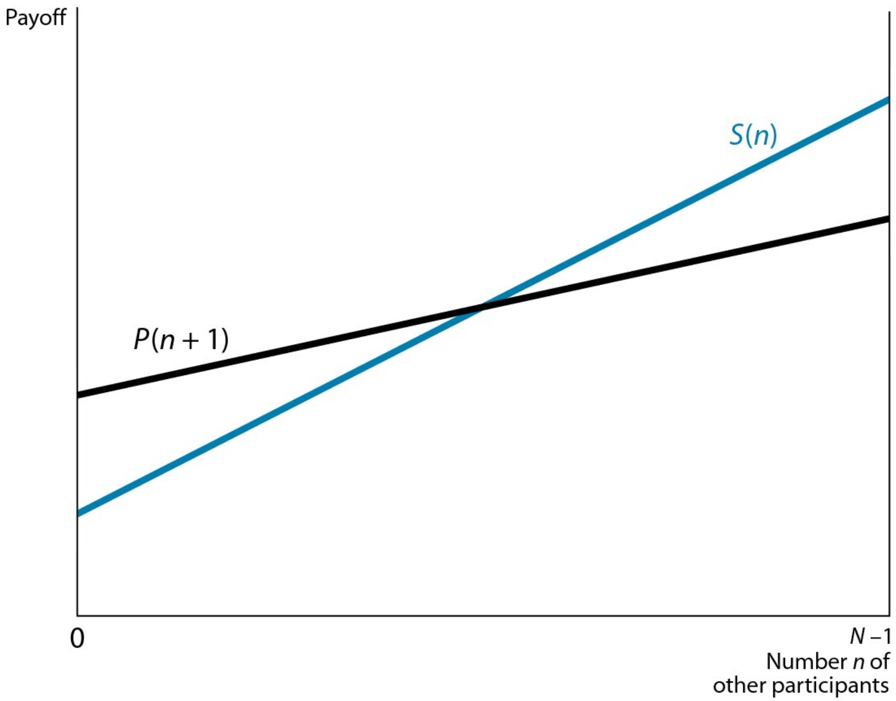
$$\begin{aligned} T(n) &= nP(n) + (N-n)S(n) \\ &= n(2n) + (100-n)(2n+4) \\ &= 2n^2 + 200n - 2n^2 + 400 - 4n \\ &= 400 + 196n \end{aligned}$$

$T(n)$ increases with n so will be maximized at $n = N$ which we could have found using inspection. As an exercise suppose $S(n) = 4n + 4$ instead of $2n + 4$. What is the socially optimal n?

Multiplayer Chicken

Now we can consider some of the other configurations that can arise in the payoffs.

- $P(n) = 4n + 36 \Rightarrow P(n+1) = 4n + 40$
- $S(n) = 5n$
- The functions intersect at $n = 40$
  - $n < 40 \rightarrow$ your choice is to participate
  - $n > 40 \rightarrow$ your choice is to not participate
  - $n = 40 \rightarrow$ you are indifferent b/w working and shirking



Multiplayer chicken payoff graph

Multiplayer Chicken

What is the socially optimal outcome in this multiplayer chicken?

$$T(n) = 536n - n^2$$

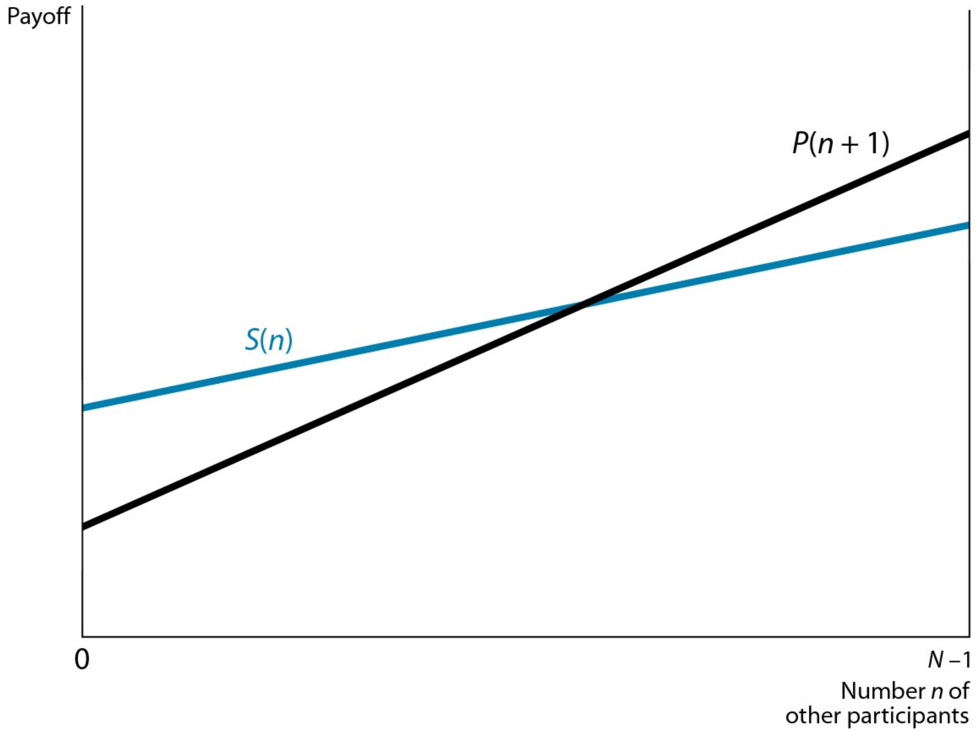
Solving, we find

$$n = 268$$

a value beyond the range of N so the socially optimal value is for all to participate, $n = N$.

Some chicken games will have social optima where it is optimal for some to shirk. e.g. if there were 300 farmers in this game, then 32 should shirk in the socially optimal outcome.

Multiplayer Assurance



Multiplayer assurance game

- $P(n+1) = 4n + 4$
- $S(n) = 2n + 100$
- The functions intersect at $n = 48$
  - $n < 48 \rightarrow$ your choice is to shirk
  - $n > 48 \rightarrow$ your choice is to participate
- Nash equilibria: $\{n = 0, n = N, n = 48\}$
- $T(n) = 2n^2 + 100n + 10000$ which is increasing for all positive values of n so the socially optimum is for all to participate

Spillovers, Or Externalities

Commuting & Spillovers

Consider a group of $8,000$ commuters who drive every day from a suburb to the city and back.

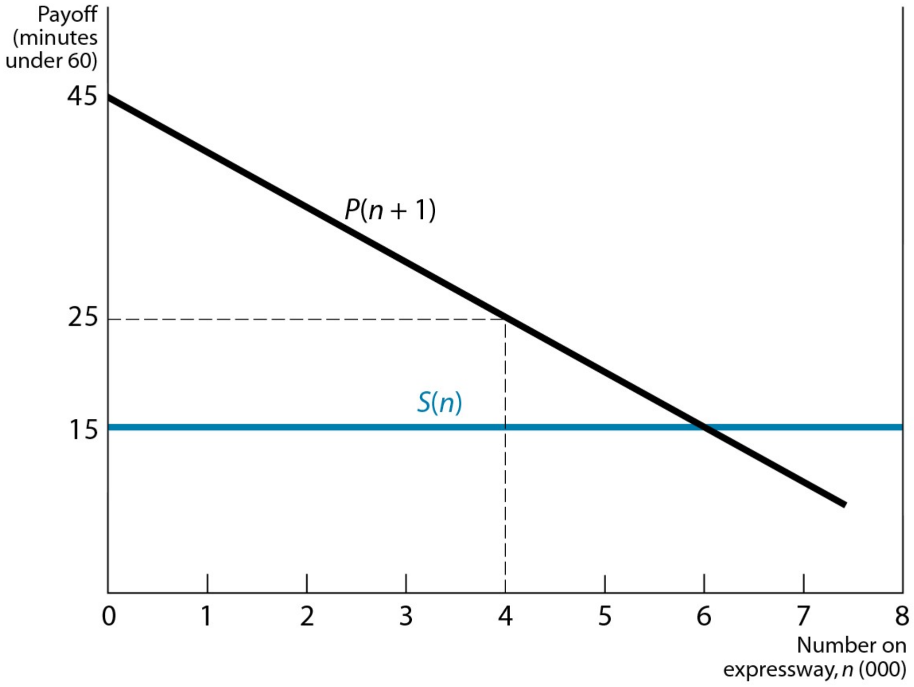
- As one of these commuters, you can take the expressway (P) or a network of local roads (S)
- The local roads take 45 min invariant to the number of cars using it
- The expressway take 15 min when uncongested, but every driver who chooses the expressway increases the time for every other drive by 0.005 minutes (0.25 seconds)

Commuting & Spillovers

We'll measure the payoff by minutes of time saved from an hour. e.g. on the local roads it is a constant $S(n) = 15$ min $(60 - 45)$.

The payoff to drivers on the expressway depends on the number of other drivers $P(n) = 45 - 0.005n$

At $n = 4,000$, switching from the local roads to the expressway yields you a **marginal private gain**, $P(n+1) - S(n) = 24.995 - 15 = 9.995$ min



Commuting route-choice game

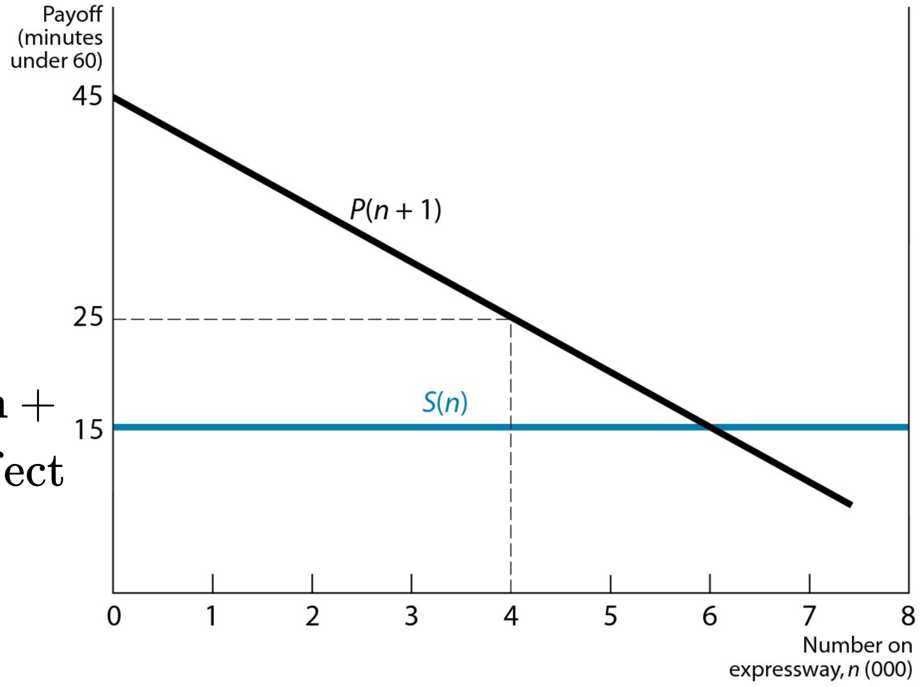
Commuting & Spillovers

However, you inflict a cost on all other drivers $(4000 \times -0.005) = -20$ min

Your private action has caused a **spillover effect (or external effect or externality)**

$$\textbf{Marginal Social Gain} = \text{Marginal Private Gain} + \text{Marginal Spillover Effect}$$

Marginal Social Gain $= 9.995 - 20 = -10.005$ min



Commuting route-choice game

Spillovers: The General Case

We can describe spillovers more generally by returning to our social payoff function, $T(n)$. Suppose, initially, that n people have chosen P and one person switches from S to P. Then,

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

The increase in the total social payoff is the difference between $T(n)$ and $T(n+1)$

$$\begin{aligned} T(n+1) - T(n) &= (n+1)P(n+1) + [N-(n+1)]S(n+1) - nP(n) + (N-n)S(n) \\ &= [P(n+1) - S(n)] + n[P(n+1) - P(n)] \\ &\quad [N-(n+1)][S(n+1) - S(n)] \end{aligned}$$

Spillovers: The General Case

$$\begin{aligned}
\text{Marginal social gain} &= T(n+1) - T(n) \\
\text{Marginal private gain} &= [P(n+1) - S(n)] \\
\text{Marginal spillover effect} &= n[P(n+1) - P(n)] + [N - (n+1)][S(n+1) - S(n)]
\end{aligned}$$

Often, the effect that one person has is very small, but it can be very large when distributed across a large N

Commuting Revisited: Negative Externalities

A negative externality exists when the action of one person *lowers* others' payoffs. We can calculate the precise conditions under which a switch will be beneficial for a particular person versus for society as a whole. The private gain is positive if

$$
\begin{aligned}
45 - (n+1)\times &> 15 \\
44.995 - 0.005n &> 15 \\
n < 200(44.995 - 15) &= 5,999,
\end{aligned}
$$

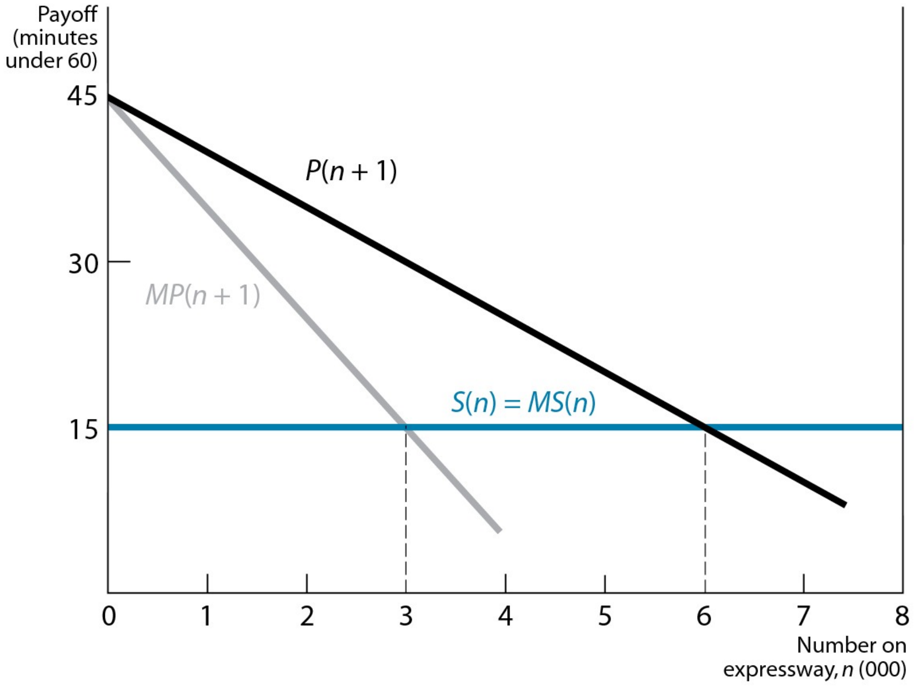
whereas the condition for the social gain to be positive is

$$
\begin{aligned}
45 - (n+1) \times 0.005 - 15 - 0.005n &> 0 \\
29.995 - 0.01n &> 0 \\
n &< 2,999.5.
\end{aligned}
$$

Thus, all crowding beyond $3,000$ reduces the total social payoff.

Negative Externalities

- $MP(n+1)$: marginal payoff for the P-choosing subgroup
- $MS(n)$: marginal payoff for the S-choosing subgroup
- $MP(n+1)$ lies below $P(n+1)$ everywhere because of the negative externality
- How can the individual be made to **internalize the externality**?



Equilibrium and optimum in route-choice game

Positive Spillovers

Positive externalities can be understood as the mirror image of negative externalities. In fact given our general setup, we can have either depending on which action we label S and which we label P.

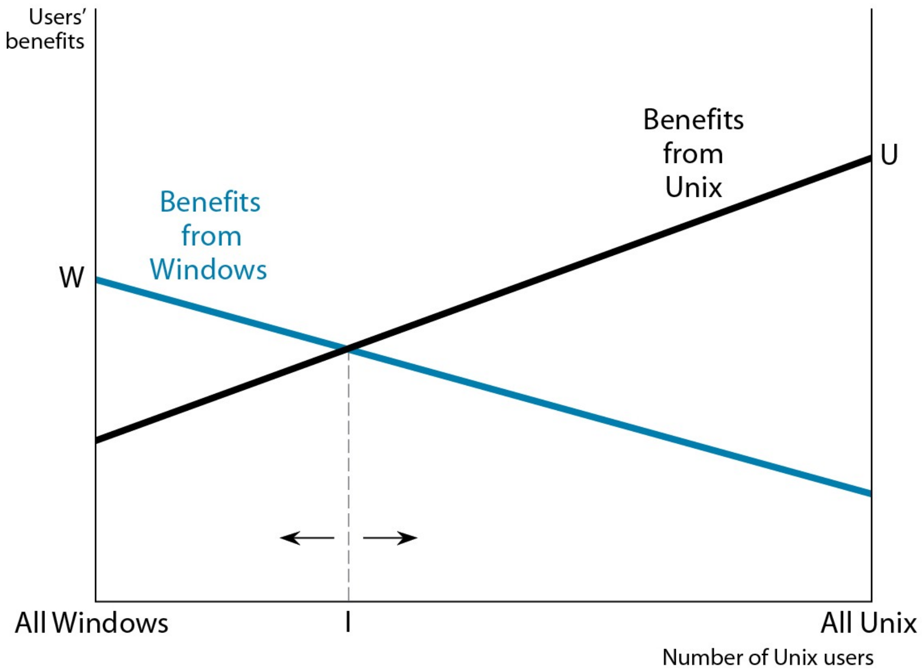
- These actions will be underutilized and their benefits underprovided in the Nash equilibrium
- We can achieve a better outcome by rewarding those persons whose actions create positive spillovers

Positive spillovers have one new feature that distinguishes them from actions with negative spillovers, **positive feedback**

Positive Spillovers

When you buy a computer, you have to choose between one with a Windows OS and one with an operating system based on Unix.

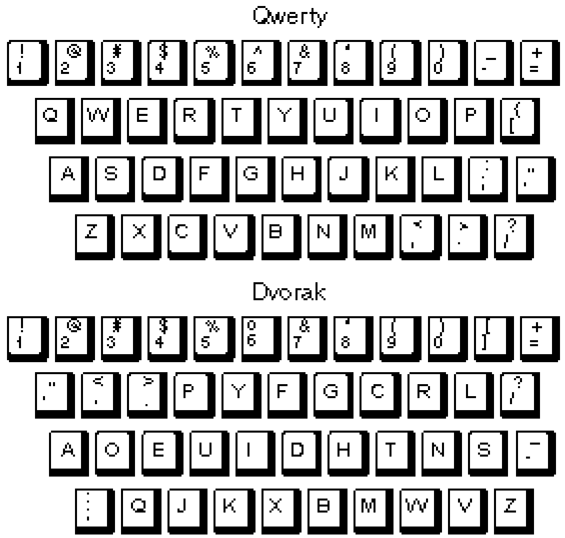
- As the number of Unix users rises, the better it will be to purchase a machine with a Unix OS (fewer bugs, more applications, more experts . . .)
  - Left of I $\rightarrow$ greater benefit to buying Windows
  - Right of I $\rightarrow$ greater benefit to buying Unix
- The two *stable* equilibria: All Unix or All Windows; users become **locked in**



Payoffs in operating-system-choice game

Examples Where We *Locked In* On The Bad Equilibrium

- Gasoline over Steam
- QWERTY keyboard over Dvorak configuration
- VHS over Betamax
- DVD over Blu-ray



Dvorkak v. QWERTY & positive feedback

Brief History Of Ideas - The Classics

Generally, problems of collective action have fallen into two camps

- **Hobbesian** - Thomas Hobbes argued that society would break down in a "war of all against all" unless it was ruled by a dictatorial monarch, the *Leviathan*
- **Smith/Hume** - Adam Smith and Dabid Hume separately argued purely self interested actions lead to what is best for society as a whole

Mancur Olson suggested in the sixties that the optimal collective action outcome may not be reached unless private interests perfectly aligned with social interests.

Modern Approaches & Solutions

Solutions to collective-action problems of all types must induce individual persons to act cooperatively, even though the person's interests may best be served by doing something else.

Humans generally rely heavily on purposive social and cultural customs, **norms**, and **sanctions** in inducing cooperative behavior from their individual members.

2009 Nobel Prize winner Elinor Ostrom, won for her "analysis of economic governance, especially the

Common Features Of Prisoners' Dilemma Collective-Action Problems

Ostrom in her book, *Governing the Commons*, identified several common features that make it easier to solve prisoners' dilemma problems of collective action

1. An identifiable and stable group of participants

2. The benefits of cooperation have to be large enough to make it worth paying all the costs of monitoring & enforcing the rules of cooperation

3. Members of the group can communicate with each other

    - Makes the norms clear
    - Spreads info on the efficacy of detection of cheating
    - Enables group to monitor the effectiveness of existing arrangements

Collective Action, Mixed Strategies, & The Bystander Effect

We know that chicken games have two pure-strategy NE and a mixed strategy one. This also extends to multiplayer games. As a bit of a macabre example, consider the story of Kitty Genovese who was murdered in NY.

- Many people directly observed at least part of the attack; many others heard, yet none intervened. Why?
- An early theory why was **pluralistic ignorance**, i.e. no one can be sure about what is happening & whether help is really needed.
- A later theory would claim that there was a **diffusion of responsibility**, because there were many people who *could have* done something, none of them bore direct responsibility for intervening

Mixed Strategies & The Bystander Effect

Suppose there are N people. When someone notifies the authority everyone receives a benefit of B from stopping the violence. The person who makes the call, however, also pays a cost of C. Note, that $B > C$, so its still gainful to phone the authorities.

- When $N = 1$, it is clearly better to call the police
- When $N > 1$ we have a game of strategic interactions
- It's not a NE when no one calls or when everyone calls
- Quickly intuit there are N pure strategy NE, where only one person makes the phone call
- So let's consider the game where a person uses a mixed strategy

Mixed Strategies & The Bystander Effect

- Let P equal the probability that any one person will not act
- If one person is mixing strategies, they must be indifferent b/w acting and not acting
- Acting receives a payoff of $B - C$ and not acting receives a payoff of $0 \times P^{N-1} + B(1 - P^{N-1})$
- Setting the expected payoffs equal yields, $B - C = B(1 - P^{N-1}) \Rightarrow P = \frac{C}{B}^{1/(N-1)}$, the indifference condition when *one* selected player determines the probability with which the *other* players mix their strategies
- Because N players do this in the NE, the probability Q that *not even one* of them helps is $Q = P^N = \frac{C}{B}^{N/(N-1)}$

Summary

- Multiplayer games generally concern problems of collective action
- The structure of collective-action games can be prisoners' dilemmas, chicken games, or assurance games
- The difficulty of these games is that the NE arising from these games may be different from the socially optimal outcome
- Externalities or Spillovers occur when one person's action effect the payoffs of all of the other players
- Positive spillovers can create positive feedback
- In large group games, diffusion of responsibility can lead to behavior in which persons wait for others to take action and free ride off the benefits of that action