FDP Series – IIHMR

Application of Games Theory to Public Health

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Agenda

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- Self-Governance

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Reproduction Number

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What is Game Theory (GT)

When the well-being of one person depends on the action of another and *vice versa*, it is a game

Example: pollution, traffic, hygiene, public health, preservation of clean air, clean water

Prisoner's Dilemma (PD)

- Two individuals, Bonnie and Clyde, are detained for questioning, for a crime, kept in separate rooms and cannot communicate with each other
- Police have insufficient information to convict them for a long period unless one of the players reveals the information
- Without more information the police can imprison them for petty crime only
- Each player has two strategies: **Confess** (C), **Don't Confess** (DC)

Prisoner’s Dilemma (PD)

- In all there are four possible outcomes when:
  - Both Confess
  - Both Don’t Confess
  - Only one player Confesses

Prisoner’s Dilemma (PD)

Consider the outcomes:

- If both Confess each will get 10 years in prison
- If both Don’t Confess each will get 1 year in prison
- If Bonnie confesses and Clyde does not, then Bonnie (as a state’s witness) will not be penalized and Clyde will have to serve 20 years in prison
- If Clyde confesses and Bonnie does not, then Clyde will not be penalized and Bonnie will have to serve 20 years in prison

Prisoner's Dilemma (PD)

		Clyde			
		Confess		Don't Confess	
Bonnie	Confess	10 years in prison	10 years in prison	0	20 years
	Don't Confess	20 years	0	1 year	1 year

		Clyde	
		Confess	Don't Confess
Bonnie	Confess	10, 10	0, 20
	Don't Confess	20, 0	1, 1

Prisoner's Dilemma (PD)

		Clyde	
		Confess	Don't Confess
Bonnie	Confess	10, 10	0, 20
	Don't Confess	20, 0	1, 1

Consider the following questions:

- If Clyde confesses what should Bonnie do?

Prisoner’s Dilemma (PD)

		Clyde	
		Confess	Don't Confess
Bonnie	Confess	10, 10	0, 20
	Don't Confess	20, 0	1, 1

Consider the following questions:

- If Clyde confesses what should Bonnie do?

  Confess

- If Clyde does not confess what should Bonnie do?

Prisoner's Dilemma (PD)

		Clyde	
		Confess	Don't Confess
Bonnie	Confess	10, 10	0, 20
	Don't Confess	20, 0	1, 1

Consider the following questions:

- If Clyde confesses what should Bonnie do?
  Confess
- If Clyde does not confess what should Bonnie do?
  Confess
- Does Bonnie have a dominant strategy?

Prisoner's Dilemma (PD)

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Bonnie	Confess	10, 10	0, 20
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  Confess

- If Clyde does not confess what should Bonnie do?

  Confess

- Does Bonnie have a dominant strategy?

  Yes, Confess

- If Bonnie confesses what should Clyde do?

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- Does Bonnie have a dominant strategy?

  Yes, Confess

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- If Clyde does not confess what should Bonnie do?

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- Does Bonnie have a dominant strategy?

  Yes, Confess
- If Bonnie confesses what should Clyde do?

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- If Clyde confesses what should Bonnie do?
  Confess
- If Clyde does not confess what should Bonnie do?
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- Does Bonnie have a dominant strategy?
  Yes, Confess
- If Bonnie confesses what should Clyde do?
  Confess
- If Bonnie does not confess what should Clyde do?
  Confess
- Does Clyde have a dominant strategy?
  Yes, Confess

Prisoner's Dilemma (PD)

		Clyde	
		Confess	Don't Confess
Bonnie	Confess	10, 10	0, 20
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Consider the following questions:

- What is the equilibrium?

Prisoner's Dilemma (PD)

		Clyde	
		Confess	Don't Confess
Bonnie	Confess	10, 10	0, 20
	Don't Confess	20, 0	1, 1

Consider the following questions:

- What is the equilibrium?
  - Confess, Confess
  - Equilibrium outcome (10, 10)
- Is the equilibrium outcome good for the players?

Prisoner's Dilemma (PD)

		Clyde	
		Confess	Don't Confess
Bonnie	Confess	10, 10	0, 20
	Don't Confess	20, 0	1, 1

Consider the following questions:

- What is the equilibrium?

  Confess, Confess

  Equilibrium outcome (10, 10)
- Is the equilibrium outcome good for the players?

  NO
- What is the good outcome for the players?

Prisoner's Dilemma (PD)

		Clyde	
		Confess	Don't Confess
Bonnie	Confess	10, 10	0, 20
	Don't Confess	20, 0	1, 1

Consider the following questions:

- What is the equilibrium?
  - Confess, Confess
  - Equilibrium outcome (10, 10)
- Is the equilibrium outcome good for the players?
  - NO
- What is the good outcome for the players?
  - Don't Confess, Don't Confess with payoffs (1, 1)
- What can players do to obtain that outcome?
  - Million $ question ??
  - Direction for policy action
  - Allied work on Mechanism Design

Prisoner's Dilemma (PD)

		Clyde	
		Confess	Don't Confess
Bonnie	Confess	10, 10	0, 20
	Don't Confess	20, 0	1, 1

In a PD game

- Each player has a dominant strategy
- Equilibrium outcome is not in the common interest of the players

In other words, in a PD game:

- Individually rational, collectively irrational, or
- Pursuit of self-interest does not lead to collective interest

Vaccination Example

Player 1 has two choices:

- Vaccinate (good deed, say)
- Do not Vaccinate

Whether he chooses V or NV, suppose there are two outcomes

- Infection
- No infection

Player 2 has similar choices

Four possibilities

- Both vaccinated
- Both not vaccinated
- One gets vaccination

Vaccination Example

The costs and benefits associated with vaccination are individual specific

However infection or no infection is dependent on the action of the other player in the mix

Specifically,

Assume player 1 gets vaccinated

- The probability of player 1 getting infection would be lower if player 2 also gets vaccinated and higher if player 2 does not get vaccinated
- Using these probabilities and the perceived costs and benefits, let the payoffs be

Vaccination Example

		Player 2	
		V	NV
Player 1	V	30, 30	20, 75
	NV	75, 20	25, 25

Costs and benefits are

- Monetary and non-monetary
- Individual specific

The payoffs are dependent on:

- Cost of vaccination (side effects, price, travel, time...)
- Expected Benefits (taking into a/c infection, no inf), and
- Actions both players take

The equilibrium is (NV, NV) with each getting 25 even though each would get 30 if (V, V) – it is a PD game

Discussion on the Vaccination Example

If the costs are low but perceived to be very high then (NV, NV) may be the equilibrium outcome

- e.g., MMR vaccination, EU stopping the Astra Zeneca Covishield vaccine till more information

If benefits are high enough, (V, V) would be the outcome

- Covid vaccination being given free of cost
- Food and other incentives when getting vaccinated
- Small-pox vaccine having high benefits – one shot, effective for lifetime

Discussion on the Vaccination Example

If a person wants to benefit from the other persons taking the vaccination, then it is called ‘free-riding’

Specifically,

<u>Free rider problem</u>

- When individuals can benefit without paying for it
- Common in public health
- Can be partially resolved with some coordination, penalty, increased benefit - policy

Free Rider Problem

- A swamp is located between two villages Rampur and Sitapur, with high density of mosquitos contributing to malaria, dengue, chikungunya and other mosquito-related diseases
- A permanent solution would be to fill up the swamp
- Each village wants the other to take the first step - this arises due to the ‘free rider’ problem
- Needs government action or coordination between the groups to help achieve the preferred outcome

Free Rider Problem

		Sitapur	
		Contribute	Don't Contribute
Rampur	Contribute	1, 1	-1, 2
	Don't Contribute	2, -1	0, 0

- The equilibrium is (Don't contribute, Don't contribute) with a payoff (0, 0)
- To achieve the (1, 1) payoff some coordination either by themselves or by a central authority is necessary
- Taxes for public goods, military spending, road improvement….

Tragedy of the Commons

Tragedy of the Commons:

- Consider forest, fisheries, grazing land etc.
- These are non-private goods and examples of common pool resources (CPR)
- Consumption by one group affects the availability of these resources for the other group (subject to congestion)
- Leads to overconsumption and ultimately depletion
- Emission standards and clean air

Specifically, rivalrous consumption and non-excludability (swamp example) create incentives for personal gain leading to the inefficient outcomes

Emission Standards: Top down Approach

Payoffs - Original game

		Region 2	
		Lower emissions	Do not lower emmisions
Region 1	Lower emissions	10, 10	2, 15
	Do not lower emmisions	15, 2	3, 3

Payoffs including Fine

		Region 2	
		Lower emissions	Do not lower emmisions
Region 1	Lower emissions	10, 10	2 , (15-8)
	Do not lower emmisions	(15-8), 2	(3-8), (3-8)

- Suppose the violator when caught is fined $F, and is caught with probability m. Then, expected fine f = mF+(1-m)*0 = mF (=8, say)
- The payoffs change as shown above
- With the fine the equilibrium outcome is (LE, LE) with (10,10) as the payoffs – no longer a PDG

Emission Standards: Top down Approach

Payoffs - Original game

		Region 2	
		Lower emissions	Do not lower emmisions
Region 1	Lower emissions	10, 10	2, 15
	Do not lower emmisions	15, 2	3, 3

Payoffs including a reward

		Region 2	
		Lower emissions	Do not lower emmisions
Region 1	Lower emissions	(10+10), (10 + 10)	(2 + 10), 15
	Do not lower emmisions	15, (2 + 10)	3, 3

- Suppose the region that adheres to the emission standard gets a 'reward' for the good behavior (=10, say)
- The payoffs change as shown above
- With the reward the equilibrium outcome is (LE, LE) with (20,20) as payoffs – no longer a PD game

Emission Standards: Self Governance

- Major issue with top-down is monitoring – too costly
- Elinor Ostrom observed an alternate structure wherein communities devise ways to govern themselves so that future sustainability is ensured – this is self governance based on local information
- This could well involve the hiring a ‘police/ sheriff’ and sharing the cost of enforcement

Emission Standards: Self-governance

		Region 2	
		Lower emissions	Do not lower emmisions
Region 1	Lower emissions	10,10	2,15
	Do not lower emmisions	15, 2	3,3

		Region 2	
		Lower emissions	Do not lower emmisions
Region 1	Lower emissions	(10- 2.5), (10-2.5)	2 ,(15-8)
	Do not lower emmisions	(15-8), 2	(3-8),(3-8)

- Let the cost of self-enforcement/monitoring = e (contingent upon lowering the emissions, e = 5), shared equally among the regions and f (=8) is the expected fine
- The game is as represented above
- If e (= 5) and f (= 8) go to zero, it is the original PD game with (DNL, DNL) as the equilibrium
- Note that e cannot be greater that 20 in this case

Other Applications to Public Health

Application to public health and development arises since actions of a group affect the health of others, or conflict between individual interest and community benefit

- Clearing of a common swamp (Malhotra 2012)
- Getting vaccinated (Malhotra 2012, Shim et al., 2009, others)
- Patient Doctor consultation (Tarrant et al., 2004)
- Global warming /Climate change (Vann R. Newkirk, 2016)
- Social distancing due to an epidemic (Reluga, 2010)
- Emission standards
- Carbon emissions
- Driving rules

Other Applications to Public Health

- Consider wearing a mask – the person not wearing the mask is affecting the other individuals due to his/her action
- Consider travel restrictions due to an epidemic
  - ✓ During the Ebola breakout in 2014 travel restrictions across regions was imposed and it seemed the best way to contain the disease and protect individuals
  - ✓ Analysis conducted later identified that such a restriction only delayed the spread of the disease to neighboring regions but stopped support staff and necessary aid from reaching the affected areas in a timely manner

Other Applications to Public Health

- Take vaccination – repeatedly shown to be safe

  For the vaccine taker: short-term negative effects (financial cost, pain from injection, a temporary reaction from the immune system).

  Long-term immunity
- Each individual will weigh the costs and benefits before deciding
- Suppose everyone gets vaccinated and I do not, I am still largely protected
- However, if everyone thinks in this manner the impact at an individual level may differ but the population as a whole will be worse off

Other Applications to Public Health

- Due to the incorrect notion that the MMR vaccine leads to autism the vaccination levels declined in the USA and Europe – this led to significant increase in the incidence of the illness, and increased deaths and permanent injuries

Reproduction Number

Let p = fraction vaccinated

For a given R0 , there is a p (critical) – the population that needs to be vaccinated so that the disease declines

From player 1 ‘s point of view

		Actual Population	
		p >= p(critial)	p < p(critial)
Player 1	Vaccination	Lower payoff	Higher Payoff
	No Vaccination	Higher payoff	Lower payoff

		Actual Population	
		p >= p(critial)	p < p(critial)
Player 1	Vaccination	8	15
	No Vaccination	10	6

One has to watch out for misinformation, rumors, fear of vaccination (link to behavior economics)

Reproduction Number

India is getting a lot of people vaccinated, but given the size of the population that needs to be vaccinated to achieve a critical mass, the progress seems low

It may be necessary to think of other ways to speed up the vaccination process

Country	R0	P (critical)	Population (cr)	# to be Vaccinated (cr)	Currently Vaccinated (cr)
India	1.35	26%	136	35.26	6.5
USA	2.5	60%	33	19.80	14.8

Conclusion

- Game theory has been applied to address public health and development issues
- There are other games that are applicable in other settings – stag hunt, centipede….
- GT helps to model trust, reputation, quality, cooperation
- Provides a framework to generate new hypothesis that can be tested empirically
- Can be integrated with mechanism design to develop alternate solutions to achieve the collectively better equilibrium

Thank you!