BUEC 311: Business Economics, Organization and Management
Strategic Behaviour Part I
Game Theory and Business Strategy

Fall 2020

Outline

1. Overview
2. Oligopoly Games
3. Nash Equilibrium
4. Information and Rationality
5. Using Game Theory to Make Business Decisions
6. Bargaining
7. Auctions

Outline

1. Strategic Interaction

- Thus far: We have primarily focused on cases where firms are not interacting strategically.
  - But we often need to understand the potential decisions of rivals.
  - We need a toolbox for understanding strategic decision making.

- Game Theory: A set of tools used to analyze strategic decision making.
  - Idea: Model strategic interactions as a game in which players interact according to a set of rules.
    - Players decide strategies based on payoffs, the level of information, and their rationality.
    - Outcome of a game is a Nash Equilibrium; depends on information and rationality.
  - Game theory can be used to understand strategic behaviour by firms, outcomes in bargaining, and auctions.

Outline

2. Oligopoly Games

- Ex. A duopoly game between American Airlines and United Airlines
  - Players and rules:
    - Two players: American and United, play a static game to decide how many passengers to fly per quarter. Each airline's objective is to maximize profit.
    - Rules: Firms announce output levels simultaneously, but cannot communicate otherwise (no side deals or coordination is allowed).
    - Complete information: Firms know all strategies and payoffs.
  - Strategies:
    - Each firm's strategy is to take one of two available actions: ether choose low output (48k passengers per quarter) or high output (64k passengers per quarter).
    - Both firms know all strategies and the corresponding payoffs for each firm.
    - We can summarize these strategies in a payoff matrix (or profit matrix).

2. Oligopoly Games

		American Airlines	
		$q_A = 64$	$q_A = 48$
United Airlines	$q_U = 64$	4.1 4.1	3.8 5.1
	$q_U = 48$	5.1 3.8	4.6 4.6

Note: Quantities are in thousands of passengers per quarter; (rounded) profits are in millions of dollars per quarter. The payoff to American Airlines is in the upper-right corner of each cell and the payoff to United Airlines is in the lower left.

Figure: The Payoffs for American and United

2. Oligopoly Games

- If one is available, a rational player always uses a dominant strategy.

Definition (Dominant Strategy)

A dominant strategy is a strategy that produces a higher payoff (profit) than any other strategy the player can use, no matter what its rivals do.

- In our airline duopoly example, high-output (64k) is the dominant strategy for both firms.
  - High output yields the highest profit *regardless of what the other firm is doing*.
  - Hence, the dominant strategy solution is $q_U = q_A = 64$.

2. Oligopoly Games

- A dominant strategy solution does not necessarily lead to the best outcome for firms.
  - In our example, United and American choose strategies that do not maximize their joint or combined profit.
    - Each firm could earn \$4.6 million if they both chose to produce a low level of output (48k).
  - Game between United and American is an example of a Prisoner's Dilemma.
    - All players have dominant strategies that lead to a profit that is inferior to what they could have achieved if they cooperated.
    - Individual incentives cause players to choose strategies that do not maximize joint profits.

2. Prisoner's Dilemma Example

- Suppose that United and American are now choosing whether or not to invest in new planes. Currently, each airline earns a profit of $25 billion using their old fleet of planes. If American upgrades to new planes and United does not, then American steals some of United's customers and increases its profits to $35 billion, while United's profits fall to $10 billion. Similarly, if United upgrades and American does not, United's profits increase to $35 billion and American's profits fall to $10 billion. If both airlines upgrade to new planes, then they each will earn $20 billion. What will each firm do? What will they earn in equilibrium?

2. Oligopoly Games

- Many games do not have a dominant strategy solution. In this case, we can use the approach of <u>best response</u> to determine the outcome of a game.

Definition (Best Response)

A best response is the strategy that maximizes a players payoff (profit) given its beliefs about the strategies of its rivals.

- A dominant strategy is a strategy that is a best response to all possible strategies a rival might use.

- In the absence of a dominant strategy, each firm can determine its best response to <u>any possible</u> strategy chosen by its rivals.

2. Oligopoly Games

- Best responses are the basis of a Nash Equilibrium.

Definition (Nash Equilibrium)

A Nash equilibrium is a set of strategies such that if, when all other players use these strategies, no player can obtain a higher profit by choosing a different strategy.

- In a Nash equilibrium, players are "best-responding" to each other.
  - This means the Nash equilibrium is self enforcing.

- Two steps to find the Nash Equilibrium:
  1. Determine each player's best response to any given strategy of the other player.
  2. Check whether pairs of strategies are best responses for both firms; these pairs are Nash equilibria.

2. Oligopoly Games

- As an example, consider a more complicated game between American and United.
  - Now both firms have 3 possible strategies:
    1. High output (96k passengers/quarter).
    2. Medium output (64k passengers/quarter).
    3. Low output (8k passengers/quarter).
  - Otherwise, the rules are the same as before:
    - Static simultaneous move game.
    - Perfect information.

2. Oligopoly Games

		American Airlines		
		$q_A = 96$	$q_A = 64$	$q_A = 48$
United Airlines	$q_U = 96$	0 0	2.0 3.1	2.3 4.6
	$q_U = 64$	3.1 2.0	4.1 4.1	3.8 5.1
	$q_U = 48$	4.6 2.3	5.1 3.8	4.6 4.6

Note: Quantities are in thousands of passengers per quarter; (rounded) profits are in millions of dollars per quarter.

2. Oligopoly Games

- Determine equilibrium via two step method:
  1. Determine best responses for United:
     - If United chooses $q_U = 96$, American's best response is $q_A = 48$.
     - If United chooses $q_U = 64$, American's best response is $q_A = 64$.
     - If United chooses $q_U = 48$, American's best response is $q_A = 64$.

     And for American:
     - If American chooses $q_A = 96$, United best response is $q_U = 48$.
     - If American chooses $q_A = 64$, United best response is $q_U = 64$.
     - If American chooses $q_A = 48$, United best response is $q_U = 64$.
  2. Determine the Nash Equilibrium
     - The Nash equilibrium is $q_A = q_U = 64$.
     - This outcome is a Nash equilibrium because neither firm wants to deviate from its strategy *given what the other firm is doing.*
     - Note: The Nash Equilibrium does not maximize joint profits.

2. Oligopoly Games

- In general, whether or not the Nash equilibrium maximizes the combined payoff to players (i.e. profits for firms) depends on the payoff matrix.
- As an example, consider a static game where firms decide to 'advertise' or 'not advertise'.
- The effects of advertising depend on whether advertising brings new customers into the market.

2. Oligopoly Games

(a) Advertising Only Takes Customers from Rivals

		Firm 1	
		Do Not Advertise	*Advertise*
Firm 2	*Do Not Advertise*	2 / 2	3 / 0
	Advertise	0 / 3	1 / 1

(b) Advertising Attracts New Customers to the Market

		Firm 1	
		Do Not Advertise	*Advertise*
Firm 2	*Do Not Advertise*	2 / 2	4 / 3
	Advertise	3 / 4	5 / 5

2. Oligopoly Games

- Example highlights a phenomenon often observed in practice:
  - In oligopolistic markets, the effect of firm advertising depends on whether it helps (increases the size of the overall market) or hurts (steals customers) rivals.
- In some industries, advertising primarily steals customers from rivals.
  - E.g. market for cola; market for erectile dysfunction drugs.
- In other industries, advertising by any firm increases the size of the market.
  - E.g. market for beer; market for cigarettes.
- It is possible to observe market size and business stealing effects simultaneously.
  - E.g. Fast food; CPUs.

Outline

3. Types of Nash Equilibria

- There are three possible outcomes for a game with Nash equilibria:
  1. Unique Nash Equilibrium: Only one combination of pure strategies is each firm's best response to a rival's strategy.
  2. Multiple Nash Equilibria: More than one possible Nash Equilibrium in pure strategies.
  3. Mixed-Strategy Nash Equilibrium: Equilibrium in which players randomize over possible pure strategies.

3. Types of Nash Equilibria

- Example: Coordination between TV networks.
  - Suppose two networks play a static game.
  - Each network chooses to schedule a reality show on Wednesday night or Thursday night.
  - Scheduling decisions are made simultaneously and independently.
  - If the networks schedule their reality shows on different days, both earn 10 million dollars. Otherwise, each network loses 10 million dollars.

3. Example: Coordination Between Networks

		Network 1	
		Wednesday	*Thursday*
Network 2	*Wednesday*	−10, −10	10, 10
	Thursday	10, 10	−10, −10

3. Types of Nash Equilibria

- Neither network has a dominant strategy; for each, the best choice depends on the choice of its rival.
  - If Network 1 opts for Wednesday, then Network 2 prefers Thursday.
  - If Network 1 chooses Thursday, then Network 2 opts for Wednesday.
- In this case there are two Nash Equilibria in pure strategies; each as a different network broadcast on a different day.
- Prediction: networks would schedule shows on different nights.
- But, we lack a basis for predicting which night each network would choose.

3. Types of Nash Equilibria

- In our example, the two Networks could potentially exploit cheap talk to try and resolve the coordination problem.

Definition (Cheap Talk)

Cheap talk is "pre-play" communication where parties communicate without affecting payoffs from the game.

- Eg. Network 1 might announce it will broadcast on Wednesday, so Network 2 chooses Thursday.
- This type of communication works if there is a clear incentive to be truthful (i.e. higher profits from coordination).

3. Types of Nash Equilibria

- If cheap talk is not allowed or not credible, then we need a different means to distinguish between potential outcomes.

- One possibility arises if there is a solution that has a higher payoff for all parties.
  - In this case, we can expect that each player will select that solution even in the absence of any pre-play communication.
  - This is known as the Pareto Criterion.

- As an example, suppose that in Network 1 plays its show on Wednesday, and Network 2 plays its show on Thursday, each firm earns $15 million.

3. Example: Coordination Between Networks

		Network 1	
		Wednesday	*Thursday*
Network 2	*Wednesday*	−10, −10	10, 10
	Thursday	15, 15	−10, −10

3. Types of Nash Equilibria

- So far, we have assumed that each player uses a pure strategy.

Definition (Pure Strategy)

A pure strategy is an action that a player takes in every possible situation in a game.

- A pure strategy is a rule telling the player, with certainty, what action to take at each decision point in a game.

3. Types of Nash Equilibria

- Players can also use a mixed strategy.

Definition (Mixed Strategy)

In a mixed strategy, the player chooses amongst pure strategies according to a probabilities that the player sets.

- A mixed strategy is a rule telling the player which method to use to randomly choose amongst possible pure strategies.

3. Contract Example

- Example: Competition for a contract.
- Suppose two design firms, *Upstart* and *Established*, compete for an architectural contract and simultaneously decide if their proposed designs are traditional or modern.

3. Contract Example

		Established Firm	
		Traditional	*Modern*
Upstart	*Traditional*	20 –2	–2 20
	Modern	–2 20	20 –2

3. Contract Example

- There is no Nash Equilibrium in pure strategies in this case:
  - Upstart's best response to Established is:
    - Modern design if Established chooses Traditional.
    - Traditional design if Established chooses Modern.
  - Established's best response to Upstart is:
    - Modern design if Upstart chooses Modern.
    - Traditional design if Upstart chooses Traditional.

3. Contract Example

- There is a Nash Equilibrium in mixed strategies.

- Each firm randomizes such that the other is indifferent between the two outcomes.
  - Let θ denote the probability that Established chooses the traditional style.
  - Upstart's expected payoff is then $[\theta \times (-2)] + [(1-\theta) \times 20] = 20 - 22 \times \theta$ if it picks the traditional style, and $[\theta \times 20] + [(1-\theta) \times (-2)] = -2 + 22 \times \theta$ if it picks the modern style.
  - Upstart will only be indifferent between these two pure strategies if the expected payoffs are equal: $20 - 22\theta = -2 + 22\theta$, or $22 - 44\theta$, or $\theta = 1/2$.
  - Hence, Established randomizes between the two outcomes with a probability of $1/2$. Similarly, Upstart randomizes between the two outcomes with a probability of $1/2$.
  - Nash equilibrium: Each firm chooses the traditional style with a probability of $1/2$.

3. Types of Nash Equilibria

- Both pure and mixed-strategy equilibria can arise in the same game.
- Example: Suppose two firms are considering opening gas stations at the same location, but only one station could operate profitably due to small demand. If both firms enter, they both lose $200k.

3. Entry Game

		Firm 1	
		Do Not Enter	*Enter*
Firm 2	*Do Not Enter*	0 0	1 0
	Enter	0 1	–2 –2

3. Entry Game

- In this case, neither firm has a dominant strategy. Each firm's best action depends on what the other firm does.

- There are three Nash equilibria in total:
  - Two Nash equilibria in pure strategies:
    - Firm 1 enters and Firm 2 does not.
    - Firm 2 enters and Firm 1 does not.
    - Note: players do not know which outcome will arise; cheap talk/Pareto criterion offer no help in this case.
  - One Nash equilibrium in mixed strategies:
    - Each firm enters with a probability of 1/3.
    - No firm could increase its expected profit by changing its mixed strategy.

Outline

4. Information and Rationality

- So far, we have assumed players have complete information.
    - Players know all strategies and associated payoffs (profits).
- In more complex settings, players may have incomplete information.
    - May occur because of private information or high transaction costs.
- We have also assumed players act rationally.
    - Players use all available information to determine their best strategies.
- However, players may have limited powers of calculation, or be unable to determine their best strategies (bounded rationality).
- When players have incomplete information or exhibit bounded rationality, the Nash equilibrium will be different from games with full information and rationality.

4. Information and Rationality

- Example: Investment Game
  - Google and Samsung decide ‘to invest’ or ‘do not invest’ in complementary products (Chrome OS and Chromebook, respectively).
  - There is a profit asymmetry from investment:
    - A Chromebook with no Chrome OS is worthless.
    - Chrome OS has value even without the Chromebook.
  - To start, suppose both firms have full information.

4. Investment Game

		Samsung	
		Do Not Invest	*Invest*
Google	*Do Not Invest*	0 0	–25 0
	Invest	0 5	20 20

4. Investment Game

- If each firm has full information, the unique Nash equilibrium is both firms investing.
  - Google's dominant strategy is 'invest'.
  - Samsung's best response is 'invest'.
- Now suppose that the payoffs (the profits from investing) are not common knowledge.

4. Investment Game

		Samsung	
		Do Not Invest	*Invest*
Google	*Do Not Invest*	0, 0	0, –25
	Invest	5, 0	20, 20

4. Investment Game

- With incomplete information, Samsung does not know Google's dominant strategy is to always 'invest'.
- Given its limited information, Samsung weighs a modest gain vs. a big loss. If it thinks Google will not invest, then Samsung does not invest.
- Likely outcome: Samsung and Google fail to coordinate their strategies.
- How could Google and Samsung overcome this problem?

4. Information and Rationality

- We normally assume that rational players consistently choose actions that are in their best interests given the information they have. That is, we assume they are able to choose their profit-maximizing strategies.
- However, complexity of strategic interactions may prevent this.
- In practice, managers may have limited powers of calculation or logical inference (bounded rationality), and may try to maximize profits subject to cognitive limitations.

4. Information and Rationality

- With bounded rationality, players often resort to rules of thumb.
- One simple rule of thumb: use a strategy that has worked in the past.
- Another common strategy: maximin
    - This approach maximizes the lowest possible payoff the player might receive.
    - Goal is to ensure the best possible profit if your rival takes the action that is worst for you.
    - Example: The maximin solution in the Investment Game is for Google to invest, and for Samsung to not invest.

Outline

5. Using Game Theory to Make Business Decisions

- In reality, many business games are too complex to analyze fully.
- However, we can exploit five key insights from game theory to aid in strategic decision making.
  1. Dominance
  2. Best response
  3. Point of view
  4. Coordination
  5. Randomize

5. Using Game Theory to Make Business Decisions

1. *Dominance*: A manager who has a dominant strategy – a strategy that is always best no matter what rivals do – should use it.

2. *Best Response*: A manager who does not have a dominant strategy should determine the best responses to the strategies that rivals might use.

3. *Point of View*: A manager should consider possible strategies from a rival's vantage point, try to predict which strategy the rival will choose, and select the best response to that strategy.

5. Using Game Theory to Make Business Decisions

4. *Coordination*: When doing so increases profit, a manager should coordinate with other firms through pre-play communication (cheap talk) or by using legal contracts.

5. *Randomize*: A manager may be able to earn a higher profit by keeping rivals guessing using a mixed strategy.

Outline

6. Bargaining

- Bargaining is common in many business situations.
  - Managers and employees bargain over working conditions.
  - Firms may bargain with suppliers or distributors.

- Game theory can be used to understand bargaining situations.
  - Bargaining game: Any situation in which two or more parties with different interests or objectives negotiate voluntarily over the terms of some interaction, such as the transfer of a good from one party to another.

  - Solution to game: Nash Bargaining solution.
    - Note: Nash Bargaining solution $\neq$ Nash equilibrium.

6. Bargaining

- A bargaining game is a *cooperative* game.
    - Parties are trying to decide how to divide profits or some other payoff.
- Nash bargaining solution determines *efficient* division of payoff.
    - No alternative outcome that would be better for both parties or strictly better for one party and no worse for the other.
- As an example, let's revisit the interaction between American and United.
    - But now, we will assume US antitrust laws have changed such that the firms can bargain over output levels and reach a binding agreement.

6. Bargaining

		American Airlines	
		$q_A = 64$	$q_A = 48$
United Airlines	$q_U = 64$	4.1 4.1	3.8 5.1
	$q_U = 48$	5.1 3.8	4.6 4.6

Note: Quantities are in thousands of passengers per quarter; (rounded) profits are in millions of dollars per quarter. The payoff to American Airlines is in the upper-right corner of each cell and the payoff to United Airlines is in the lower left.

6. Bargaining

- With Nash Bargaining, the division of payoffs depends on the outside option available to each party.
  - The value of the outside option is the disagreement point; it is the outcome that arises if no agreement is reached (call this d).
    - If United and American cannot reach an agreement they revert to the non-cooperative outcome: $d_A = d_U = 4.1$.
  - If an agreement is reached, each party receives a payoff of π, and a net surplus of $\pi - d$.

- The Nash Bargaining solution maximizes the product of the net surplus for the two firms:

$$NP = [\pi_A - d_A] \times [\pi_U - d_U]$$

6. Bargaining

- There are four possible outcomes for a bargain between United and American:
  1. Both produce 64k: $NP = 0$.
  2. American 64k, United 48k: $NP < 0$.
  3. American 64k, United 48k: $NP < 0$.
  4. Both produce 48k: $NP = [4.6 - 4.1] \times [4.6 - 4.1] = 0.25$.

- Nash bargaining predicts both American and United would fly 48 thousand passengers.

6. Bargaining

- If United and American could bargain about how they set their output levels in an oligopoly game, they could reach an efficient outcome that maximizes the Nash product.
- Such an agreement creates a cartel and raises the firms' profits.
  - Gain for firms is more than offset by loss in consumer surplus.
  - Consequently, such agreements are illegal in most developed countries under antitrust and competition laws.

6. Bargaining

- The Nash Bargaining solution presumes that the parties achieve an efficient outcome where neither party could be made better off without harming the other party.

- However, in the real world, bargaining often yields inefficient outcomes.
  - The bargaining process is often time consuming, which delays the start of the benefit flow, and therefore reduces the value of benefits overall.
    - This is common with strikes.
  - Bounded rationality and incomplete information also matter; parties do their best, but are unable to determine the best possible strategies, leading to mistakes that are costly for both parties.

Outline

7. Auctions

Definition (Auction)

A sale in which a good or service is sold to the highest bidder.

- Game theory can be used to understand behaviour in auctions.
  - An auction is a game in which players (called bidders) devise bidding strategies without knowing the payoff functions of other players.
  - Bidders need to know the rules of the game:
    - The number of units being sold.
    - The format of bidding.
    - The value that potential bidders place on the good.

7. Auctions

- Auctions are frequently used in practice:
  - Government auctions:
    - Government procurement, auctions for electricity and transport markets, auctions to concede portions of the airwaves for radio stations, mobile phones and wireless internet access; auctions for oil and gas leases.
  - Market transactions:
    - Goods commonly sold at auction are natural resource such as timber and drilling rights for oil, as well as houses, cars, agricultural products, horses, antiques and art. And of course, goods online in sites like eBay.

7. Auctions

- Elements of auctions:
  - Number of units:
    - Auctions can be used to sell one or many units of a good.
  - Format of bidding:
    - English auction: Ascending-bid auction process where the good is sold to the last bidder for the highest bid. Commonly used to sell art/antiques.
    - Dutch auction: Descending-bid auction process where the seller reduces the price until someone accepts it and buys at that price. Often used in government procurement.
    - Sealed-bid auction: Bidders submit bids simultaneously without seeing anyone else's bid and highest bidder wins. In a 1st price sealed-bid auction, the winner pays its own, highest bid. In a 2nd price sealed-bid auction, the winner pays the amount bid by the 2nd highest bidder.
  - Value:
    - Private value: Individual bidders know how much the good is worth to them, but not how much other bidders value it.

7. Second Price Sealed Bid Auctions

- Rules:
  - Each bidder has a different private value for a single indivisible good.
  - Bidders simultaneously submit sealed bids without knowledge of other bids.
- Design of auction means that amount that you bid affects whether you win, but it does not affect how much you pay if you win (which is equal to the second-highest bid).
- Best strategy: Bid your highest value.
  - This strategy weakly dominates all others.
  - Ex: Suppose that you value a folk art carving at \$100. If you bid \$100 and win, your $CS = 100 - \text{2nd price}$. If you bid less than \$100, you risk not winning. If you bid more than \$100, you risk ending up with negative CS.
  - Thus, bidding \$100 leaves you *at least as well off* as bidding any other value.

7. English Auctions

- Rules:
  - Each bidder has a different private value for a single indivisible good.
  - Ascending-bid auction process where the good is sold to the last bidder for the highest bid.

- Design of auction means that amount you bid affects whether you win and how much you pay.

- Best strategy: Raise the current highest bid as long as that value is less than the value you place on the good.
  - Ex: Again suppose that you value a folk art carving at \$100. If you bid an amount b and win, $CS = 100 - b$. CS is positive or zero for $b \leq 100$, but negative if $b > 100$. So it is best to raise bids up to \$100 and stop there.
  - If all participants bid up to their value, the winner will pay slightly more than the value of the second-highest bidder. Thus, the outcome of an English auction is essentially the same is a in a sealed-bid, second-price auction.

7. Other Auctions

- Two other common private value auctions:
  - Dutch Auction: Descending-bid auction where the seller reduces the price until someone accepts the offered price and buys at that price.
  - First-Price Sealed-Bid Auction: Bidders submit bids simultaneously without seeing other bids. Highest bidder wins and pays amount of bid.
- In both cases, the amount that you bid affects whether you win and pay.
- The best strategy in both auctions is to bid an amount that is equal to, or slightly greater than what you expect will be the second-highest bid, given that your value is the highest.
  - Bidders shade bids to less than their value to balance the effect of decreasing the probability of winning and increasing CS. Bid depends on beliefs about strategies of rivals.

7. Auctions

- Key point: Expected outcome is the same across private value auctions.
    - Winner is the person with the highest value, and the winner pays roughly the second-highest value.

- Is there any reason that a seller still might choose one format over an alternative?

7. Auctions

- Key feature of common-value auctions: the Winner's Curse.
  - Winner's bid exceeds the value of item up for bid; winner pays too much.
  - Occurs due to uncertainty about the true value of the good.
    - E.g. Timber land auctions/auctions for oil and gas leases.

- Best strategy to avoid Winner's Curse: Shade/reduce bids to below estimates of value.
  - The amount of reduction depends on number of other bidders; more bidders $\Longrightarrow$ more likely winning bid is an overestimate.

- While Winner's Curse is a well known phenomenon, there is strong empirical evidence it continues to happen in practice (e.g in the corporate acquisition market).
  - One possible explanation: Bounded rationality.

Takeaways

1. Insights from game theory can be used to improve outcomes when making strategic decisions.
2. Bargaining can lead to efficient outcomes.
3. Best strategy in most auctions is to bid your valuation, but it may be useful to shade bids to avoid the Winner's Curse.