Introduction to Industrial Organization

Dynamic Oligopoly

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Outline

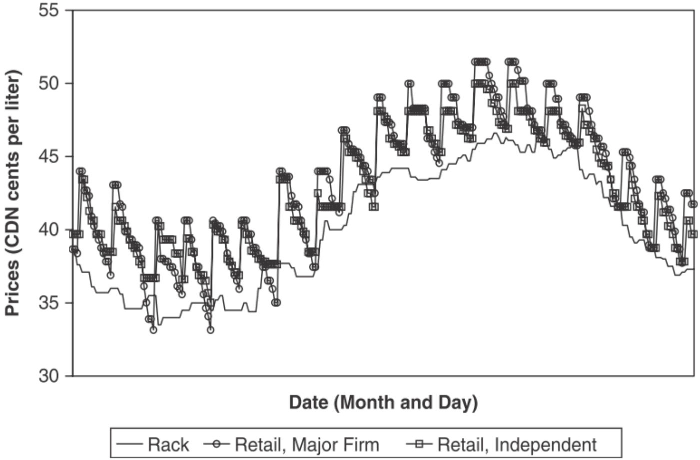
- Edgeworth Cycle
- Multiple-Period Oligopoly Model
  - Review: Subgame perfect equilibrium
  - Stackelberg model
  - Finite-period repeated games
  - Infinite-period repeated games

Edgeworth Cycle

Edgeworth Cycle

- Edgeworth cycle: firms repeatedly undercut one another to steal the market, until price reaches marginal cost.
- A typical example: gasoline retailing market
- Castanias and Johnson (1993):
  - retail prices in Los Angeles during the period from 1968 to 1972
  - They find an asymmetry in retail price movements: retail gasoline prices would rise quickly during a single week by large amounts, declining slowly to the original level over several weeks, in an asymmetric cycle not observed in the relevant wholesale price.
- Great summary: Eckert (2013), section 3.2.

Example from Noel (2007)



Theory of Edgeworth Cycle (I)

- Theoretical "Edgeworth Cycles" is introduced by Edgeworth (1925) and formalized by Maskin and Tirole (1988).
- Eckert (2003) extends the Maskin & Tirole analysis to allow for firms of different size.
- Model settings:
  - Two firms with infinitely periods
  - They compete in a dynamic pricing game by alternatively setting prices.
  - Firm i's profits at period t:

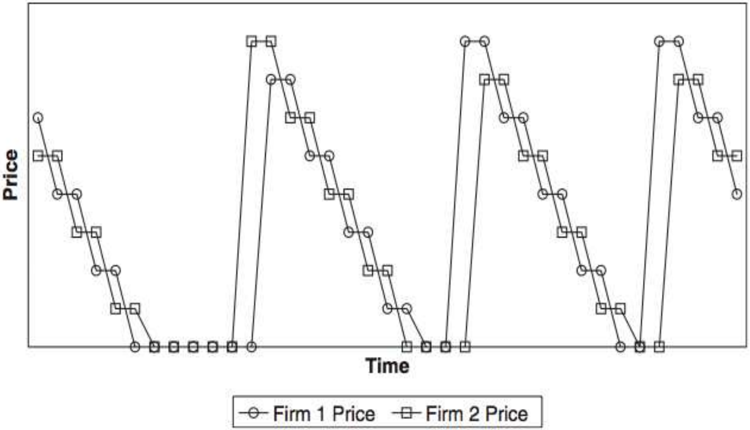
    $$\pi_t^i(p_t^1, p_t^2, c_t) = D^i(p_t^1, p_t^2) \times (p_t^i - c_t),$$

    where D^i is the demand for firm i, and c_t is a marginal cost.
  - Maskin and Tirole (1988) assume the constant marginal cost $c_t = c$ for all t, and D^i is the standard homogeneous Bertrand demand function.

Theory of Edgeworth Cycle (II)

- Two different types of equilibria are shown:
  - Focal price equilibria
  - Edgeworth Cycle equilibria:
    - Undercutting phase (U): Firms repeatedly undercut one another to steal the market, until price reaches marginal costs.
    - Relenting Phase (R): Each firm has a mixed strategy between raising price and remaining at marginal cost.
- The length of the undercutting phase is not certain, but the length of the relenting phase is. So the model predicts a clear asymmetric shape and extremely fast but not simultaneous reactions.
- The amplitudes are not clearly predicted, so the top of the cycle price may be above or below the monopoly price.

Theoretical Prediction from Noel (2007)



Theory of Edgeworth Cycle (III)

- Eckert (2003) extends the Maskin & Tirole analysis to allow for firms of different size.
- He shows that
  - Small firm (with lower equal-price market share) has a greater incentive to undercut from equal prices.
  - The large firm is more likely than the small firm to increase price back to the top of the cycle.

Empirical Studies of Edgeworth Cycle (I)

- A primary contribution of the empirical literature has been to document that asymmetric cycles in prices, not related to observable upstream costs, exist in gasoline markets.
- Also, empirical literature has focused on the following questions:

1. In what market settings are such asymmetric cycles most likely to be observed?
   - Eckert (2003) and Noel (2007): lower market concentration (Canadian cities)
   - Doyle et al. (2010): intermediate levels of concentration, and markets with more independent stations with convenient stores. (US cities)
   - Zimmerman et al. (2010): higher concentration of vertically integrated stations. (US cities)

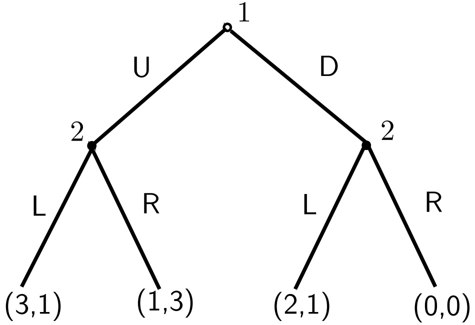
Empirical Studies of Edgeworth Cycle (II)

2. How do market characteristics change the nature of the cycle?
   - Noel (2007) finds that in markets with more firms, the undercutting phases are shorter.
   - An increase in the number of small firms is also associated with an increase in the amplitude of the cycle.
   - Faster cycles with less asymmetry are found in larger markets.
3. How do Edgeworth cycles affect the passthrough of upstream cost shocks to retail gasoline prices?
   - Noel (2009) decomposes the asymmetric passthrough into the component that is explainable by the existence of Edgeworth cycles.
   - Lewis and Noel (2011) examine daily price data for cities in the USA, and conclude that upstream price changes are passed through more quickly into retail prices in cities with cycles than in cities without Edgeworth cycles.

Multiple-Period Oligopoly Model

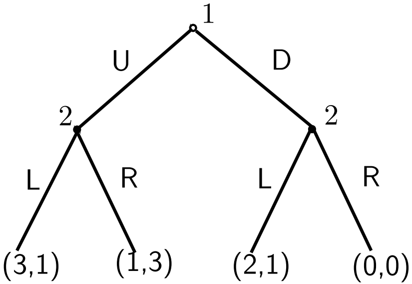
Review of Game Theory

- Subgame Perfect Equilibrium (SPE), also called Subgame Perfect Nash Equilibrium (SPNE)
  - Definition: If it represents a Nash equilibrium **in each subgame**, then it is called SPE.
- Example:



Review of Game Theory

- players: player 1, 2
- strategies: $s_1 = \{\text{U}, \text{D}\}$, $s_2 = \{\text{LL}, \text{LR}, \text{RL}, \text{RR}\}$
- payoffs: as figures.
- What is Nash equilibrium?



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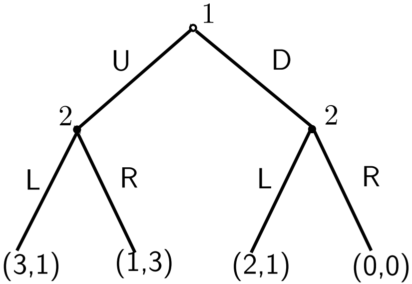

player 2

		LL	LR	RL	RR
player 1	U	(3,1)	(3,1)	(1,3)	(1,3)
	D	(2,1)	(0,0)	(2,1)	(0,0)

- players: player 1, 2
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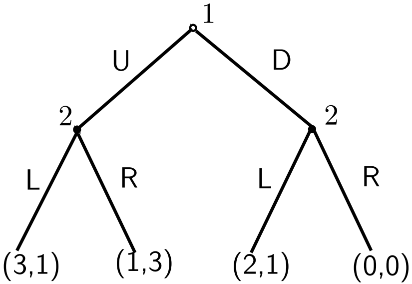

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player 1		LL	LR	RL	RR
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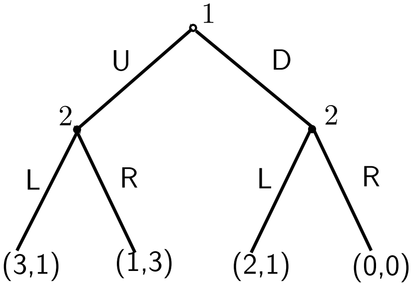
- players: player 1, 2
- strategies: $s_1 = \{\text{U}, \text{D}\}$, $s_2 = \{\text{LL}, \text{LR}, \text{RL}, \text{RR}\}$
- payoffs: as figures.
- What is Nash equilibrium?
- $\{\text{U}, \text{RR}\}$ and $\{\text{D}, \text{RL}\}$ are N.E.



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Review of Game Theory

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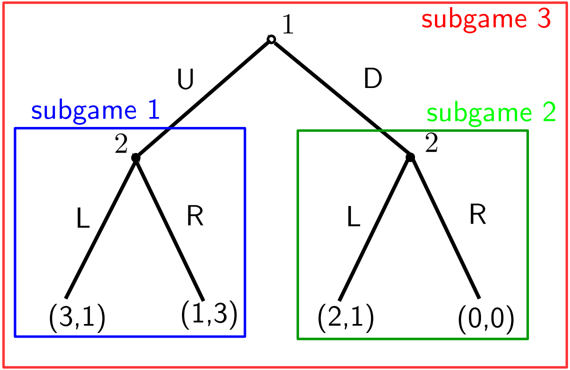
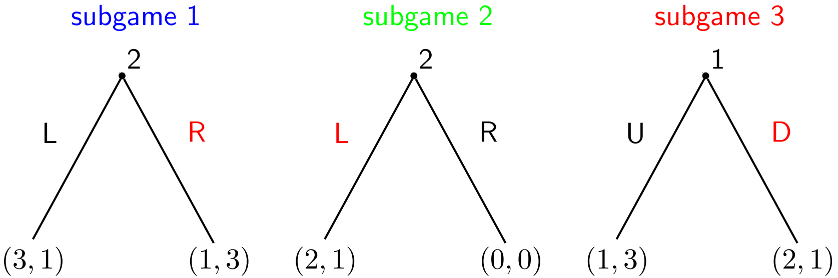


Review of Game Theory

- What is SPE?



- $\{\text{D}, \text{RL}\}$ is SPE.
- Remove all non-credible threats.
- All SPE are NE, but not all NE are SPE.

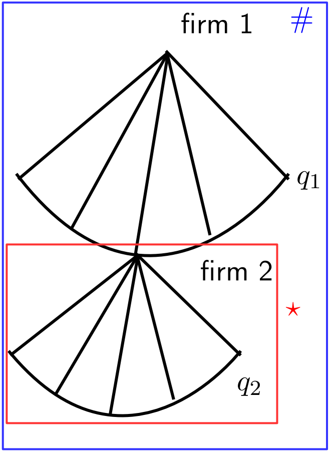
Stackelberg Model (Leader and Follower)

- Model settings:
  - Players: firm 1 (leader), firm 2 (follower)
  - Strategies: q_1 by firm 1 (decide first). q_2 by firm 1 (decide later)
  - Inverse demand function: $P = a - bQ$.
  - Payoffs:

$$\pi(q_1, q_2) = q_1(a - b(q_1 + q_2)) - c(q_1),$$
$$\pi_2(q_1, q_2) = q_2(a - b(q_1 + q_2)) - c(q_2)$$

  - Constant marginal costs for two firms. $c(q) = c \cdot q$.
- What is subgame perfect equilibrium?

Stackelberg Model (Leader and Follower)



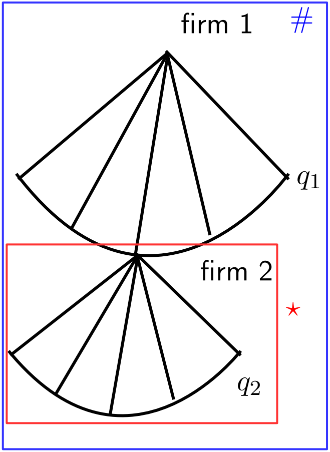
- Subgame(⋆): given q_1,

$$\max_{q_2} \; q_2(a - b(q_1 + q_2)) - c \cdot q_2$$

- First-order condition: (Best response function)

$$q_2 = (\frac{a-c}{2b}) - \frac{1}{2}q_1$$

Stackelberg Model (Leader and Follower)



- Subgame(#): the profits maximization problem:

$$\max_{q_1} q_1(a - b(q_1 + \frac{a-c}{2b} - \frac{1}{2}q_1)) - c \cdot q_1$$

- First-order condition:

$$q_1 = \frac{a-c}{2b}$$

- $q_2 = \frac{a-c}{4b}$, and $q_1 > q_2$. (first-mover advantage!)

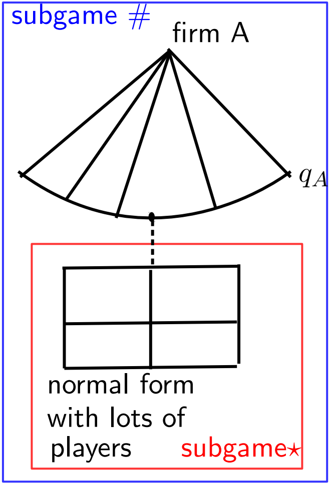
Comparison Between Stackelberg and Cournot Model

- Cournot model (duopoly):
  - $q_1 = \frac{a-c}{3b}$, $q_2 = \frac{a-c}{3b}$.
  - Equilibrium total quantity: $q_1 + q_2 = Q_c = \frac{2(a-c)}{3b}$.
  - Equilibrium price: $P_c = \frac{a+2c}{3}$.
- Stackelberg model (one leader and one follower):
  - $q_1 = \frac{a-c}{2b}$ (leader), $q_2 = \frac{a-c}{4b}$ (follower).
  - Equilibrium total quantity: $q_1 + q_2 = Q_s = \frac{3(a-c)}{4b} > Q_c$.
  - Equilibrium price: $P_s = \frac{a+3c}{4} < P_c$.
- Welfare increases in Stackelberg model.

Stackelberg Model (1 Leader with $n-1$ followers)

- Model settings:
  - players:
    - firm A (leader)
    - firm i (followers), $i = 1, 2, \cdots, n-1$
  - strategies:
    - q_A by firm A (decide first),
    - $q_1, q_2, \cdots, q_{n-1}$ by followers (decide simultaneously)
  - payoffs: $\pi_A(q_A, q_1, q_2, \cdots, q_{n-1})$, $\pi_i(q_A, q_{-i})$ $\forall i$

Stackelberg Model(1 Leader with $n-1$ followers)



- Subgame(⋆): given q_A, for follower i,

$$\max_{q_i}(a - b(q_A + \sum_{j \neq i} q_j + q_i))q_i - cq_i$$

- First-order conditions:

$$a - bQ - bq_i - c = 0, \quad \forall i$$

where $Q = q_A + \sum_{j \neq i} q_j + q_i$.

- By symmetric condition:
  $q_1 = q_2 = \cdots = q_{n-1} = q_i^*$.
- Then

$$q_i^* = \frac{a-c}{bn} - \frac{1}{n} q_A$$

Stackelberg Model(1 Leader with $n-1$ followers)

- subgame(#):

$$\max_{q_A} q_A \left(a - b \left(q_A + \underbrace{(\frac{n-1}{n})(\frac{a-c}{b}) - (\frac{n-1}{n})q_A}_{(n-1)q_i^*} \right) \right) q_A - cq_A$$

- By first-order condition:

$$q_A = (\frac{a-c}{2b})$$
$$q_i = (\frac{a-c}{2bn})$$

- If $n = 2$, then $q_i = \frac{a-c}{4b}$. (Stackelberg model)

Stackelberg Model(1 Leader with $n-1$ followers)

- Total equilibrium quantity:

$$Q^* = q_A^* + (n-1)q^* = (\frac{2n-1}{n})(\frac{a-c}{2b})$$

- Equilibrium price:

$$P^* = a - (\frac{2n-1}{n})(\frac{a-c}{2}).$$

- As $n \to \infty$. $P^* \to a - 2(\frac{a-c}{2}) = c$ (Competitive market!)

Summary

- Inverse demand function: $P = a - bQ$; marginal Cost: c

	Quantity	Price	Profits
Monopoly:	$Q = \frac{a-c}{2b}$	$\frac{a+c}{2}$	$\pi = \frac{(a-c)^2}{4b}$
Cournot (duopoly):	$q_i = \frac{a-c}{3b}$	$\frac{a+2c}{3}$	$\pi_i = \frac{(a-c)^2}{9b}$
Cournot (n firms):	$q_i = \frac{1}{n+1}(\frac{a-c}{b})$	$\frac{a+nc}{n+1}$	
	$Q = \frac{n}{n+1}(\frac{a-c}{b})$		
Competition:	$Q = \frac{a-c}{b}$	c	

Cournot Model with Two Periods (Finite Periods)

- Back to the static Cournot model
- Model settings:
  - Players: 2 identical firms with constant marginal cost c.
  - Strategies:
    - Firm 1 decides {Cooperate, Not Cooperate};
    - Firm 2 decides {Cooperate, Not Cooperate}.
  - Inverse demand function: $P = a - bQ = a - b(q_1 + q_2)$.
  - Payoffs:

		firm 2	
		Cooperate	Not Cooperate
firm 1	Cooperate	$\left(\frac{(a-c)^2}{8b}, \frac{(a-c)^2}{8b}\right)$	$\left(\frac{3(a-c)^2}{32b}, \frac{9(a-c)^2}{64b}\right)$
	Not Cooperate	$\left(\frac{9(a-c)^2}{64b}, \frac{3(a-c)^2}{32b}\right)$	$\left(\frac{(a-c)^2}{9b}, \frac{(a-c)^2}{9b}\right)$

Cournot Model with Two Periods (Finite Periods)

- {Cooperate, Cooperate}: Two firms act as monopoly.
- {Not Cooperate, Not Cooperate}: Nash equilibrium.
- {Not Cooperate, Cooperate}: Given the cooperation decision by firm 2, the non-cooperation decision by firm 1:
  - Profits maximization problem:

$$\max_{q_1} \left(a - b(\frac{a-c}{4b} + q_1) \right) q_1 - c \cdot q_1$$

  - First-order condition:

$$a - b(\frac{a-c}{4b} + q_1) - bq_1 - c = 0 \;\Rightarrow\; q_1^* = \frac{3(a-c)}{8b} > \frac{a-c}{4b}$$

  - Profits:

$$\pi_1^* = \frac{9(a-c)^2}{64b};\; \pi_2^* = \frac{3(a-c)^2}{32b}.$$

Cournot Model with Two Periods (Finite Periods)

- Best response function:

		firm 2	
		Cooperate	Not Cooperate
firm 1	Cooperate	$\left(\frac{(a-c)^2}{8b}, \frac{(a-c)^2}{8b}\right)$	$\left(\frac{3(a-c)^2}{32b}, \frac{9(a-c)^2}{64b}\right)$
	Not Cooperate	$\left(\frac{9(a-c)^2}{64b}, \frac{3(a-c)^2}{32b}\right)$	$\left(\frac{(a-c)^2}{9b}, \frac{(a-c)^2}{9b}\right)$

- C: Cooperate; NC: Not Cooperate.
- $\{$NC,NC$\}$ is Nash equilibrium.
- Simplify the problem: $a = 1, b = 1$, and $c = 0$.

Discount Factor

- The role of discount factor $\delta \in [0, 1]$.
- Finite period:

Period 1	Period 2	period 3
\$ 10	\$ 10	\$ 10

Current value at period 1: $\$10 + \delta\$10 + \delta^2\$10$.

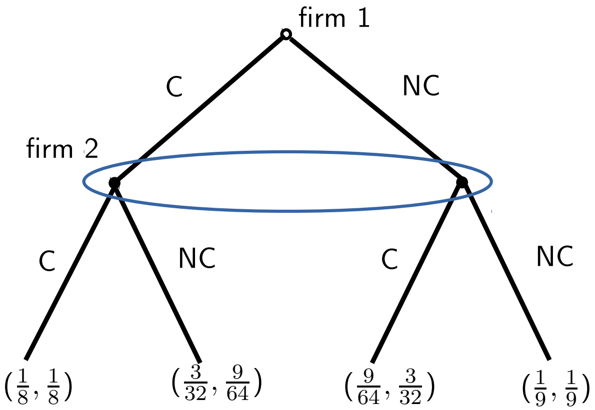
- Infinite period:

Period 1	Period 2	period 3	...
\$ 10	\$ 10	\$ 10	...

Current value at period 1: $\$10 + \delta\$10 + \delta^2\$10 + ... = \frac{1}{1-\delta}\$10$.

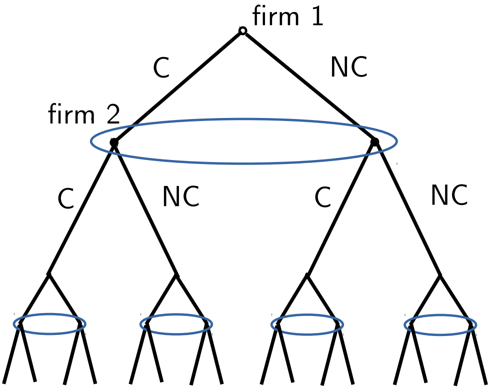
Cournot Model with Two Periods (Finite Periods)

- Extensive form:



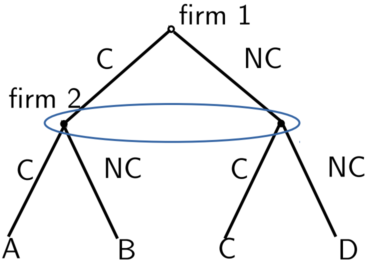
Cournot Model with Two Periods (Finite Periods)

- How about two-period model?
- Extensive form:



Cournot Model with Two Periods (Finite Periods)

- In period 2, for all the subgames: {NC, NC} is N.E., and payoff $\{\frac{1}{9}, \frac{1}{9}\}$
- In period 1, the subgame can be updated as:
- Extensive form:



- A: $(\frac{1}{8} + \delta\frac{1}{9}, \frac{1}{8} + \delta\frac{1}{9})$; B: $(\frac{3}{32} + \delta\frac{1}{9}, \frac{9}{6} + \delta\frac{1}{9})$; C: $(\frac{9}{64} + \delta\frac{1}{9}, \frac{3}{32} + \delta\frac{1}{9})$; D: $(\frac{1}{9} + \delta\frac{1}{9}, \frac{1}{9} + \delta\frac{1}{9})$.

Cournot Model with Two Periods (Finite Periods)

- In period 1, $\{$NC, NC$\}$ is N.E.
- Subgame perfect equilibrium:

$$\{\{NC, NC\}, \{NC, NC\}\}.$$

- In the finite-period cournot competition:

$$\{\{NC, NC, ...\}, \{NC, NC, ...\}\} \text{ is SPE.}$$

- In each period, two firms play N.E. as static model.

Cournot Model with Infinite Periods

- In infinite periods, $t = 1, 2, ..., \infty$.
- Model settings:
  - Players: firm 1 and firm 2
  - Strategies:
    - $\{q_{11}, q_{12}, ..., q_{1\infty}\}$ by firm 1;
    - $\{q_{21}, q_{22}, ..., q_{2\infty}\}$ by firm 2.
    - Assume $q_{it} = q^j \Rightarrow$ Cooperation; $q_{it} = q^* \Rightarrow$ Not Cooperation.
  - Payoffs:
    - $\pi_1 = \pi_{11} + \delta\pi_{12} + \delta^2\pi_{13} + ... + \delta^n\pi_{1n+1} + ...$
    - $\pi_2 = \pi_{21} + \delta\pi_{22} + \delta^2\pi_{23} + ... + \delta^n\pi_{2n+1} + ...$
  - Inverse demand function: $P = 1 - Q$.
  - Constant marginal cost $c = 0$.
  - Two firms simultaneously decide the quantity in each period.

Cournot Model with Infinite Periods

- How to check SPE in infinite periods?
- Theorem (Single-Deviation Principle)

  In a multistage game that is continuous at infinity, a strategy profile is called a subgame-perfect Nash equilibrium if and only if it passes the single-deviation test at **every stage** for **every player**.
- What is single-deviation test?

  Consider a strategy profile s^*, pick any stage, any player i. Fixing all the other players' moves as prescribed by the strategy profile s^* (current period and future periods), and fixing all the future moves for player i, s^* fails the single-deviation test if we can find a strategy which get a higher payoff than strategy s^*. If we can not find any better strategy, then s^* passes the single deviation test for player i at that stage.

Cournot Model with Infinite Periods

- Proposition (for Cournot in infinite periods)

  If the discount rate is higher enough, then the following strategies can constitute a SPE of this infinite-period Cournot game:

  strategy s^*:

  - In period t, firm 1 plays $q_{1t} = q^j$ if $q_{2t-1} = q^j$.
  - In period t, firm 1 plays $q_{1t} = q^*$ if $q_{2t-1} \neq q^j$.

Cournot Model with Infinite Periods

- Check Single-deviation principle: let's consider firm 1 (symmetric for firm 2)
  (1) After a period of not cooperation, "q^* forever" is the best response to firm 2 playing "q^* forever".

$$\begin{array}{lllll} \text{firm 1} & q_{1t} =??, & q_{1t+1} = q^*, & ... & q_{nt+1} = q^*, & ... \\ \text{firm 2} & q_{1t} = q^*, & q_{2t+1} = q^*, & ... & q_{nt+1} = q^*, & ... \end{array}$$

  - Any possible strategies other than $q_{1t} = q^*$ to increase the profits? No!

- Check Single-deviation principle: let's consider firm 1 (symmetric for firm 2)
  (2) After a period of cooperation, which one is better? (payoff)

$$\begin{array}{llllll} \text{firm 1} & q_{1t} = q^* \ (\frac{9}{64}), & q_{1t+1} = q^* \ (\frac{1}{9}), & \ldots & q_{1t+n} = q^* \ (\frac{1}{9}), & \ldots \\ \text{firm 2} & q_{1t} = q^j \ (\frac{3}{32}), & q_{2t+1} = q^* \ (\frac{1}{9}), & \ldots & q_{2t+n} = q^* \ (\frac{1}{9}), & \ldots \end{array}$$

$$\begin{array}{llllll} \text{firm 1} & q_{1t} = q^j \ (\frac{1}{8}), & q_{1t+1} = q^j \ (\frac{1}{8}), & \ldots & q_{1t+n} = q^j \ (\frac{1}{8}), & \ldots \\ \text{firm 2} & q_{1t} = q^j \ (\frac{1}{8}), & q_{2t+1} = q^j \ (\frac{1}{8}), & \ldots & q_{2t+n} = q^j \ (\frac{1}{8}), & \ldots \end{array}$$

  - If $\frac{9}{64} + \delta\frac{1}{9} + \ldots < \frac{1}{8} + \delta\frac{1}{8} + \ldots$, then the firm 1 will choose cooperation! (not deviation).
  - That is $\delta > \frac{9}{17}$. (δ is large enough!)

Cournot Model with Infinite Periods

- Summary: if $\delta > \frac{9}{17}$, then s^* is a subgame perfect equilibrium for Cournot infinite-period game.
- Note:
  - Punishment forever is not necessary for SPE. We only need enough severe punishment. For instance, punish opponent for several periods to avoid not cooperation.
  - In general, **Folk Theorem** says that, if δ is high enough, an infinite number of SPE exist for infinite-horizon repeated games. Payoffs are higher than all NE in each period.

Bertrand Model with Infinite Periods

- In two-period Bertrand model without capacity constraints, two firms decide the price equal to the marginal cost for each period.
- In finite-period Bertrand model without capacity constraints, two firms play NE in each period. (SPE)
- In infinite-period Bertrand model without capacity constraints,
  - If the discount rate is higher enough, then the strategies s^* can be a SPE:

    strategy s^*:

    - Firm 1 plays $P_{1t} = \tilde{P}_M$ if $P_{2t-1} = \tilde{P}_M$.
    - Firm 1 plays $P_{1t} = c$ if $P_{2t-1} \neq \tilde{P}_M$,

    where $\tilde{P}_M$ is the monopoly price.

Bertrand Model with Infinite Periods

- What's the range for δ? after a period of cooperation, which one is better?

$$\begin{array}{llll} \text{firm 1} & P_{1t} = \tilde{P}_M - \epsilon \ (\Pi^M), & P_{1t+1} = c \ (0), & P_{1t+2} = c \ (0), \quad ... \\ \text{firm 2} & P_{2t} = \tilde{P}_M \ (0), & P_{2t+1} = c \ (0), & P_{2t+2} = c \ (0), \quad ... \end{array}$$

$$\begin{array}{llll} \text{firm 1} & P_{1t} = \tilde{P}_M \ (\frac{\Pi^M}{2}), & P_{1t+1} = \tilde{P}_M \ (\frac{\Pi^M}{2}), & P_{1t+2} = \tilde{P}_M \ (\frac{\Pi^M}{2}), \\ \text{firm 2} & P_{2t} = \tilde{P}_M \ (\frac{\Pi^M}{2}), & P_{2t+1} = \tilde{P}_M \ (\frac{\Pi^M}{2}), & P_{2t+2} = \tilde{P}_M \ (\frac{\Pi^M}{2}), \end{array}$$

- If $\frac{\Pi^M}{2} + \delta \frac{\Pi^M}{2} + \delta^2 \frac{\Pi^M}{2} + ... > \Pi^M$, then the firm 1 will choose cooperation! (not deviation).
- That is $\delta > \frac{1}{2}$. (δ is large enough!)

Empirical Example

- Clark and Houde (2013, AEJ Micro) point out a fundamental difficulty of successfully colluding in retail markets with heterogeneous firms, and characterize the mechanism recent gasoline cartels in Canada used to sustain collusion.
- They characterize empirically the strategy and transfer mechanism using court documents containing summaries and extracts of conversations between participants.
- The mechanism implements transfers based on adjustment delays during price changes.
  - The cartel leaders systematically allow the most cost-effective firms to move last during price-increase episodes.
  - In addition to this delay period, one of these firms is allowed to initiate price cuts, while the rest of the players moved subsequently to match the new price.

Organization of the Cartel

TABLE 1—DISTRIBUTION OF STATIONS SUSPECTED OF PRICE-FIXING IN THE THREE MARKETS

Key players	Characteristics	Sherbrooke/ Magog	Thetford Mines	Victoriaville	Total
Bilodeau—Shell	Organizer	0	4	4	8
Bourassa—Olco	Organizer	9	0	0	9
Canadian Tire	Hardware store	3	0	1	4
Christian Goulet	Informant	0	0	1	1
Couche-Tard	Convenience store	13	2	3	18
Maxi	Grocery store	0	0	1	1
Petro-T	Wholesaler	5	2	1	8
Ultramar	Vertically integrated	18	3	2	23
Other	Independent	32	12	12	56
Total		80	23	25	128

- Cartel leaders:
  - Bilodeau (Shell): Victoriaville and Thetford Mines
  - Bourassa (Olco): Sherbrooke

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- Other key players:
  - Ultramar: vertically integrated company
  - Cauche-Tard: the largest chain of convenience stores.
  - Canadian Tire/Maxi: a large hardware store/supermarket chain (stations serve as loss-leaders)

Transfer Mechanism: Coordinated Order of Play (I)

- The cartels coordinate on an asymmetric pricing cycle. Prices adjust faster upwards than downwards.
- Price increase delays:
  - The leader first communicates with Couche-Tard and a group of active cartel members (followers).
  - They determine a new target price for the market and a time t_0 at which the leader and most followers first raise their prices.
  - Once an agreement is reached, the leader communicates with Ultramar and the big-box retailers to propose a time $t_1 (\geq t_0)$ at which they are supposed to increase their price.

Transfer Mechanism: Coordinated Order of Play (II)

- Price decrease delays:
  - Price decreases are much less coordinated than increases, and involve less communication.
  - Only Ultramar stations are allowed to cut prices without warning.
  - The chain becomes a price leader during price decrease periods.
- The value of delay:
  - The particular order of play favors firms that are able to lower prices first, and increase prices last.
  - This paper quantifies the volumes transferred to show that the transfer mechanism lowers the probability of deviation.

Homework 3

- Please provide and describe a (suspected) cartel example in the real world. (Hint: You can search the news articles from the internet, and pick up an interesting one to understand it in detail. Please not OPEC.)
- The following questions may be useful to bear in mind:
  - What are the relevant characteristics of the industry?
  - What was the scope of the cartel?
  - How was the cartel enforced?
  - What were the effects of the cartels?