Mechanism Design and Information Economics

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It was the New Year's eve in 2011

- Shilin night market, 2010/12/31.
- Seller: "NT $290 each!"

(Figure source: http://www.morningtaiwan.tw/2011/2011scarf/index.php)

It was the New Year's eve in 2011

- I: Oh OK ... (looking for money)
- My friend: No!! How about \$200?
- Seller: ...
- Seller: **The cost of this scarf is \$220**. Selling at \$290 only gives me \$70 as profit. \$200? No way!!
- Is it true???

It's time for meeting again

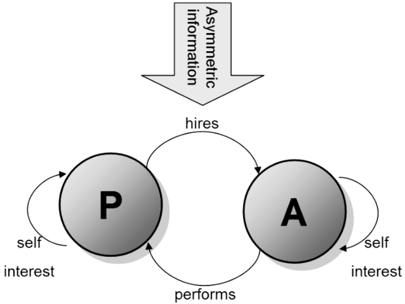
- One week has past and it's time for meeting again.
- Professor: Why there is no update?
- I: (Because I went to play volleyball for the whole weekend)
- I: Because **the problem is so hard**!
- Is it true???

Private information

- A consumer has no idea about the true cost.
- A teacher has no idea about what the student did.
- They are **private information**.
  - The cost is a piece of **hidden information**.
  - The effort is a **hidden action**.
- Private information brings **bargaining power**.
  - What if we know that the true cost is only $80?
  - What if the professor saw that I was playing volleyball?

Mechanism design

- A branch of **game theory**.
- Specifically discuss **information asymmetry**.
- Adopting the **principal-agent model**:
  - The consumer "delegates" the procurement to the seller.
  - the teacher "delegates" the problem solving to the student.



(Figure source: http://en.wikipedia.org/wiki/Principal-agent_problem)

Mechanism design

- They agree on a **contract** that rewards the agent's work.
  - The price of the scarf.
  - Graduation?
- Related fields or other names:
  - Contract theory.
  - Agency theory.
  - Incentive theory.
  - Auction theory.
  - Information economics.
- The main issues:
  - Decentralized decision making.
  - Incentives.
  - Information asymmetry.

Road map

- Introduction to mechanism design.
  - No information asymmetry.
  - Moral hazard (hidden actions).
  - Adverse selection (hidden information).
- A study: the economics of demand forecasting.
- Applications on Information Management.

Game theory

- When there is **one** decision maker, we want to know what she will do.
  - This requires solving for the **optimal decision**.
- When there is **multiple** decision makers, we want to know what they will do.
  - This requires solving for their **equilibrium decisions**:
  - “My decision is optimal, given all others’ decisions.”

Game theory

- Let's start with the following question in marketing: In operating a **retail store**, what do you consider first?
- Let's see what "he" says:

In operating a retail store

(Figure source: http://bbs.hupu.com/751370.html)

In operating a retail store

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In operating a retail store

- Many researchers agree that the most important thing is:
  - **Location**!
- So let's study how companies make their retail location decisions.

Retailers' location decisions

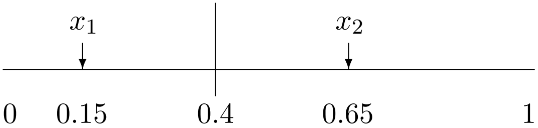
- Suppose there are two retailers.
- Suppose consumers spread **uniformly** along a line $[0, 1]$.

0 1

- Suppose the retail price is fixed. So each retailer wants to maximize her **market share**.
- All consumers are the same: They go to **the closer store** and buy one unit.

Retailers' location decisions

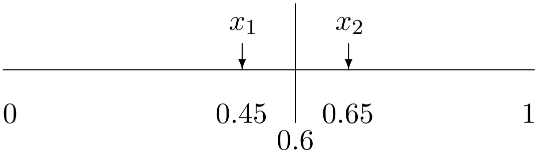
- Let x_1 and x_2 be the locations decided by retailers 1 and 2.
  - For example, suppose initially $x_1 = 0.15$ and $x_2 = 0.65$:



- Market shares?
  - Retailer 1's market share is 0.4 and retailer 2's is 0.6.
- If you are retailer 1, what will you do?

Retailers' location decisions

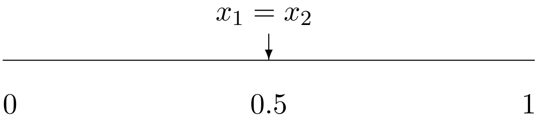
- Retailer 1 can move to the **right**, e.g., to $x_2 = 0.45$.



  - Retailer 1's market share is now 0.6.
- If you are retailer 2, how will you react?

Retailers' location decisions

- The **unique** equilibrium is $x_1 = x_2 = 0.5$.



  - Both players' market share are 0.5.
- This is not the only case that they share the market equally.
- However, this is the only case that no one wants to **unilaterally deviate**.
- A situation is a **Nash equilibrium** if no player wants to deviate while all others do not.

Retailers' location decisions

- This model is called the "**Hotelling line**."
- It models more than locations:
  - Voters' preferences on different parties.
  - Consumers' preferences on different brands/designs.
- The subject of **product line design** discusses how to design product attributes to attract heterogeneous consumers.

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Salesforce compensation

(Figure source: http://www.cartoonstock.com/directory/d/door-to-door_salesperson.asp)

Salesforce compensation: observations

- How should an adviser motivate her students to work hard?
- How should a employer motivate her employee to work hard?
- But why an employee (student) does not want to work hard?
  - Because efforts are**costly**.
- Moreover, the effort level is a **hidden action**, i.e., **unobservable** by the manager.

Salesforce compensation: model

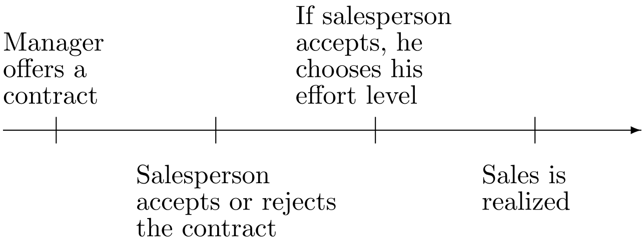
- A traditional principal-agent problem with **moral hazard**.
- Players: a manager (principal) and a salesperson (agent).
- Sales **effort**: $a \geq 0$.
- Demand $x \in \{0, 1\}$. The unit price is \$1.
  - A higher effort results in a **higher sales** in expectation:

$$P(x = 1 | a = \hat{a}) = \hat{a}.$$

- The cost of effort is $\frac{1}{2}a^2$.

Salesforce compensation: model

- Timing:



A centralized system

- Suppose the two player are centralized.
- Together they solve

$$\pi^C = \max_{a \geq 0} \ \mathbb{E}[x] - \frac{1}{2}a^2 = \max_{a \geq 0} \ a - \frac{1}{2}a^2.$$

- The optimal solution is $a^* = 1$.
- The total expected profit is $\pi^C = \frac{1}{2}$.

A decentralized system: Contract 1

- The manager offers **a fixed salary** $u \geq 0$ to the salesperson.
- The salesperson solves

$$\pi^A = \max_{a \geq 0} \; u - \frac{1}{2}a^2.$$

The optimal solution is $a' = 0$!

  - The agent will be as **lazy** as possible.

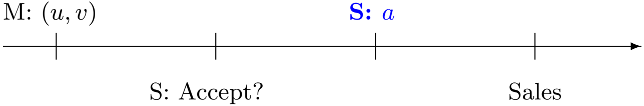
- The manager solves

$$\pi^M = \max_{u \geq 0} \; \mathbb{E}[x] - u = \max_{u \geq 0} \; -u.$$

The optimal solution is $u' = 0$. Together they earn 0.

A decentralized system: Contract 2

- The manager offers a **fixed payment** $u \geq 0$ and a **commission rate** $v \geq 0$ to the salesperson.
- The salesperson's total (random) payment is $u + vx$.

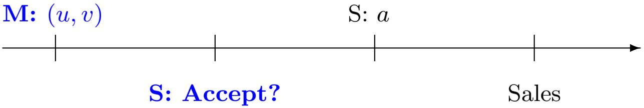


- The salesperson solves

$$\pi^A = \max_{a \geq 0} \; u + v\mathbb{E}[x] - \frac{1}{2}a^2 = \max_{a \geq 0} \; u + va - \frac{1}{2}a^2.$$

- The optimal solution is $a'' = v$. He earns $\pi^A = u + \frac{1}{2}v^2$.
  - The agent will **work harder** with a **larger bonus**.
  - Note that $a'' = v < 1 = a^*$!

A decentralized system: Contract 2



- The manager solves

$$\pi^M = \max_{u \geq 0, v \geq 0} \quad (1 - v)a - u$$
$$\text{s.t.} \quad a = v; \quad \pi^A = u + \frac{v^2}{2} \geq 0.$$

- The optimal solution is $(u'', v'') = (0, \frac{1}{2})$. She earns $\pi^M = \frac{1}{4}$.
- Moral hazard creates **efficiency loss**:

$$\pi^M + \pi^A = \frac{1}{4} + \frac{1}{8} = \frac{3}{8} < \frac{1}{2} = \pi^C!$$

Salesforce compensation: findings

- No commissions or bonus, no hard working.
- The higher the bonus, the higher the effort.
- The fixed payment does not provide any **incentive** for the agent to exert extra efforts.
- Then why do we see fixed payments in practice?
  - Agents are typically **risk-averse**.
  - Fixed payments are required for them to accept the contract.

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Procurement

(Figure source: http://www.emkt.com.cn/article/105/10546.html)

Procurement

- A problem with **adverse selection**.
- What may a buyer do when the seller has **private cost information**?
  - When a consumer buys from a retailer.
  - When a retailer buys from a manufacturer.
  - When a manufacturer buys from a material supplier.
- She may design **a menu of contract** to induce the buyer to "tell the truth".

Procurement: model

- A buyer (principal) and a seller (agent).
- The unit production cost of the product is c.
- c is **privately** observed by the seller.
- The buyer wants as many products as possible.
  - Let q be the purchasing quantity.
  - The buyer's utility $V(q)$ is increasing in q.
- However, the marginal benefit is decreasing.
  - Let's assume $V(q) = \sqrt{q}$.

Procurement: model

- A contract also specifies a **payment** p.
  - If $(p, q) = (\$5000, 20)$, the buyer gets 20 units by paying \$5000.
  - A quantity discount: $(p, q) = (\$9000, 40)$.
  - A quantity premium: $(p, q) = (\$11000, 40)$.
- The buyer's net utility is $V(q) - p$.
- The seller's net utility is $p - cq$.
- There are **2 types** of sellers: efficient/inefficient.
  - $c = c_L$ if efficient and $c = c_H$ if inefficient.
  - The proportion of efficient sellers is r.

Procurement: Revelation principle

- How should the buyer designs a menu of price-quantity pairs? How many contracts should be in the menu?

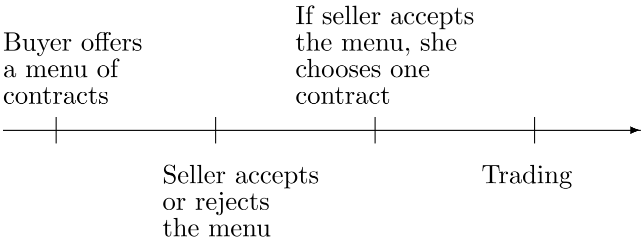
Theorem 1 (Revelation principle)

If the agent has private information, it is optimal for the principal to offer a menu of contracts to induce truth-telling.

- When there are n types of agents, the menu should contain n contracts.
- Should try to make agents with **different types** choose **different contracts**.

Procurement: model

- Timing:



Procurement: designing the menu

- How to induce truth-telling?
- The contract should be **incentive-compatible**.
  - Suppose the seller announces (p_H, q_H) and (p_L, q_L).
  - These two contracts should satisfy

    $$p_H - c_H q_H \geq p_L - c_H q_L$$

    so that the efficient seller (with $c = c_L$) will prefer (p_L, q_L).
  - Similarly, we should have

    $$p_L - c_L q_L \geq p_H - c_L q_H$$

    so that the inefficient seller (with $c = c_H$) tells the truth.

Procurement: designing the menu

- How to induce participation?
- The contract should be **individually rational**.
  - Suppose the seller announces (p_H, q_H) and (p_L, q_L).
  - These two contracts should satisfy

$$p_H - c_H q_H \geq 0$$

and

$$p_L - c_L q_L \geq 0$$

so that no seller will reject the menu.

Procurement: designing the menu

- How much does the seller earn with different sellers?
  - The buyer gets $V(q_L) - p_L$ with an efficient seller.
  - The buyer gets $V(q_H) - p_H$ with an inefficient seller.
- The seller solves

$$
\begin{aligned}
\max_{q_L, p_L, q_H, p_H} \quad & r\left[\sqrt{q_L} - p_L\right] + (1-r)\left[\sqrt{q_H} - p_H\right] \\
\text{s.t.} \quad & p_H - c_H q_H \geq p_L - c_H q_L \\
& p_L - c_L q_L \geq p_H - c_L q_H \\
& p_H - c_H q_H \geq 0 \\
& p_L - c_L q_L \geq 0.
\end{aligned}
$$

Procurement: findings

- Let $\{(p_L^*, q_L^*), (p_H^*, q_H^*)\}$ be the optimal menu of contracts.
- Some findings:
  - We always have $q_L^* \geq q_H^*$.
  - We always have $p_H^* - c_H q_H^* = 0$.
  - We always have $p_L^* - c_L q_L^* > 0$.
- **Private information** helps the seller.
- **Acquiring information** helps the buyer.

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Resellers' Demand forecasting

- **Resellers** forecast uncertain demands.
  - Reduced out-of-stocks, improved service levels, and increased sales.
- **Manufacturers** also care about resellers' forecasting capability.
  - Sony (Stoller, 2004), HP (Newswire, 2000), and more.
  - CPFR (Fraser, 2003).
- Why?

Sales agents' performance

- Another critical factor that affects a manufacturer's profitability is **sales agents**' performance.
  - A sales agent may put high **efforts** in serving consumers to enhance consumer satisfaction and increase the sales volume.
- But what will happen if a sales agent puts high efforts in promoting an **unpopular** product?
- Fortunately, sales agents typically possess valuable market knowledge by facing consumers directly.
- Fortunately?

Research questions

- How does the manufacturer's profit affected by:
  - A reseller's forecasting accuracy?
  - A sales agent's market knowledge?
- Are these effects independent, substituting, or complementary?
- If a manufacturer can "decide" a reseller's accuracy:
  - What to do when sales agents are knowledgeable?
  - What to do if their market knowledge is only marginal?

Supply chain

- Manufacturer (M) – Reseller (R) – Sales agent (A).
- Production cost is 0 and retail price is 1.
- Random market demand $x \in \{0, 1\}$ is realized according to

$$\Pr(x = 1|\theta, a) = \theta a = 1 - \Pr(x = 0|\theta, a),$$

  which depends on **market condition** θ and **sales effort** a.
- $\theta \in \{\theta_L, \theta_H\}$ where $0 < \theta_L < \theta_H < 1$.
- $P(\theta = \theta_L) = P(\theta = \theta_H) = \frac{1}{2}$.
- Cost of a is $\frac{1}{2}a^2$.

Demand forecasting

- R and A estimate θ independently.
- R obtains **signal** $s_R \in \{G, B\}$ with forecasting **accuracy** λ_R.
  - G = Good, B = Gad.
  - $\Pr(B|\theta_L) = \Pr(G|\theta_H) = \lambda_R = 1 - \Pr(G|\theta_L) = 1 - \Pr(B|\theta_H)$.
- A obtains **signal** $s_A \in \{F, U\}$ with forecasting **accuracy** λ_A.
  - F = Favorable, U = Unfavorable.
  - $\Pr(U|\theta_L) = \Pr(F|\theta_H) = \lambda_A = 1 - \Pr(F|\theta_L) = 1 - \Pr(U|\theta_H)$.
- $\lambda_R \in [\frac{1}{2}, 1]$ and $\lambda_A \in [\frac{1}{2}, 1]$.
- A sees s_A and s_R, R sees s_R, and M sees nothing.

Contract forms

- R can only compensate A based on the realized sales outcome x.
- The optimal compensation scheme is

$$\text{A's earning} = \begin{cases} \alpha & \text{if } x = 0 \\ \alpha + \beta & \text{if } x = 1 \end{cases},$$

  where α is the **fixed payment** β is the **sales bonus**.
- Because A privately observes s_A, it is optimal for R to offer a **menu of contracts** $\{(\alpha_F, \beta_F), (\alpha_U, \beta_U)\}$.
- Similarly, M offers $\{(u_G, v_G), (u_B, v_B)\}$ to R.
- Each player acts to maximize her own expected profit.

Timing and backward induction

R and A decide λ_R and λ_A.

θ is realized; s_R and s_A are observed.

M offers $\{(u_k, v_k)\}$ to R.

R offers $\{(\alpha_j, \beta_j)\}$ to A.

A decides a.

x is realized; M earns sales revenue; R and A are rewarded.

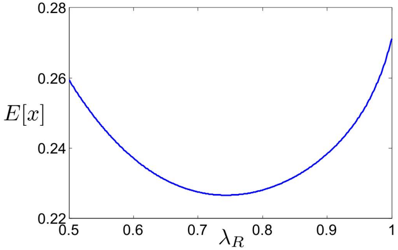
Solution: Backward induction.

Supply chain performance and R's accuracy

- Use **expected sales** $\mathbb{E}[x]$ to indicate supply chain performance.

Proposition 1

- $\mathbb{E}[x]$ *is* **convex** *on* $\lambda_R \in [\frac{1}{2}, 1]$.
- $\mathbb{E}[x]$ *may first decreases and then increases.*



Parameters:

$$\lambda_A = 0.8,$$
$$\theta_H = 0.7,$$
$$\theta_L = 0.4.$$

The reseller's forecasting accuracy

- The manufacturer faces information asymmetry between it and the sales agent.
- It must acquire information **indirectly** through the reseller.
- When the reseller improves her accuracy:
  - The indirect information acquisition is more efficient.
  - The upper-level information asymmetry is also aggravated.
  - These two opposite forces result in the nonmonotonicity.

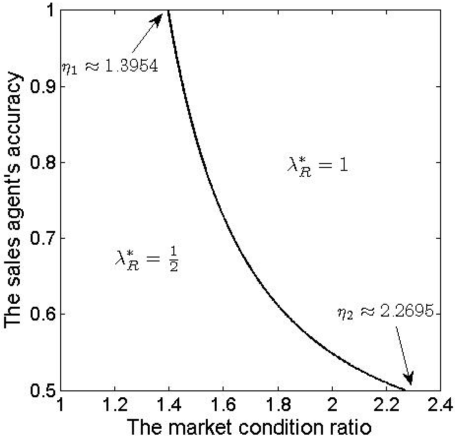
Supply chain structure

- The supply chain prefers R to be **uninformed or precise**.
- Supply chain structure selection: M-R-A v.s. M-A.
- Let λ_R^* maximize $\mathbb{E}[x]$. Let $\eta \equiv \frac{\theta_H}{\theta_L}$.

Proposition 2

There exists two cutoffs η_1 and η_2 such that

- *for $\eta \in (1, \eta_1]$, $\lambda_R^* = \frac{1}{2}$;*
- *for $\eta \in (\eta_1, \eta_2)$, $\lambda_R^* = \frac{1}{2}$ if λ_A is small and $\lambda_R^* = 1$ if λ_A is large;*
- *for $\eta \in [\eta_2, \infty)$, $\lambda_R^* = 1$.*



System-optimal reseller's accuracy λ_R^*

$\lambda_R^* = 1$ for large η and λ_A

$\lambda_R^* = \frac{1}{2}$ for small η and λ_A

Profit splitting and supply chain coordination

- M prefers the system-optimal reseller's accuracy.

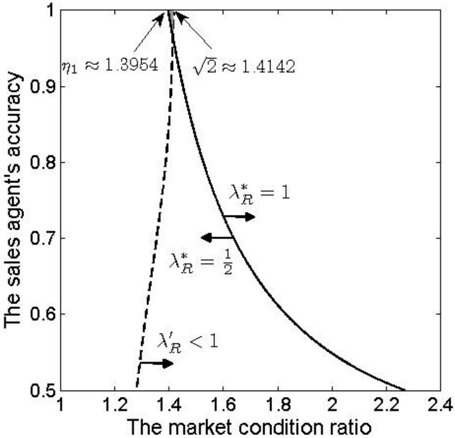
Proposition 3

M earns $\frac{1}{2}\mathbb{E}[x]$ in expectation.

- Let λ'_R maximize R's expected profit.
- The supply chain is coordinated if $\lambda'_R = \lambda^*_R$.

Proposition 4

- *Whenever $\lambda'_R = \lambda^*_R$, we have $\lambda'_R = \lambda^*_R = 1$.*
- *$\lambda'_R = \lambda^*_R$* **only if** *η is moderate and λ_A is large.*



Supply chain
coordination
is only possible
in the shaded region
for moderate η
and large λ_A

Supply chain
discoordination
for all white regions

Sales agent's forecasting accuracy

Proposition 5

$\mathbb{E}[x]$ is convex in $\lambda_A \in [\frac{1}{2}, 1]$.

Proposition 6

Let $(\lambda_R^{**}, \lambda_A^{**})$ be the joint optimizer of $\mathbb{E}[x]$, then $\lambda_A^{**} = \frac{1}{2}$.

Proposition 7

The channel is **never coordinated** *if both R and A can choose their own accuracy.*

Extensions

- A is protected by limited liability.
  - $\alpha_j \geq 0$ for $j \in \{F, U\}$.
- The random market condition follows a general Bernoulli distribution.
  - $\Pr(\theta = \theta_L) = \gamma = 1 - \Pr(\theta = \theta_H)$ for $\gamma \in (0, 1)$.
- A does not observe R's signal s_R.
  - Informed principal.
  - R offers different menus upon observing different s_R.

Conclusions

- Supply chain performance is convex in R's and A's accuracy.
- The supply chain and M prefer
  - R to be uninformed when η and λ_A are small.
  - R to be precise when η and λ_A are large.
  - A to be uninformed.
- Supply chain coordination:
  - (Only R can change) Only for moderate η and large λ_A.
  - (Both R and A can change) Never.

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Applications on Information Management

- Information acquisition:
  - The benefits of acquiring information.
  - What to acquire?
  - Better to acquire more?
- Information goods:
  - Versioning and compatibility.
  - Network externality.
  - Piracy.

Applications on Information Management

- E-business and e-commerce.
  - On-line auction design.
  - On-line display advertising.
  - Network pricing (E.g., congestion pricing).
  - Warranty and return policies.
- Distributed information systems.
  - Distributed optimization.
- Information systems:
  - Outsourcing.
  - Information security.
  - Knowledge management.