IM 7011: Information Economics (Fall 2014)

Value of Information: the More, the Better?

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Introduction

- In a typical principal-agent relationship:
  - The agent have private information.
  - Hidden information creates the **screening** problem for the principal.
  - A hidden action creates the **moral hazard** problem for the principal.
- Many possibilities:
  - What if the agent has **both** hidden information and a hidden action?
  - What if the principal may obtain **some** (but not all) information?
  - What if there are two **cascaded** principal-agent relationship?
- We will address these issues by discussing Kung and Chen (2014).[1]

[1] Ling-Chieh Kung and Ying-Ju Chen, 2014, "Impact of reseller's and sales agent's forecasting accuracy in a multilayer supply chain," *Naval Research Logistics* **61**(3) 207-222.

Road map

- **The story**.
- Model.
- Optimal contracts.
- Findings.
- Extensions and conclusions.

This is a story of a salesperson

http://www.cartoonstock.com/

Different supply chains in practice

- Some manufacturers hire salespeople directly.

http://img.autonet.com.tw/news/img/2005/12/

http://static.ettoday.net/images/85/d85813.jpg

- Some manufacturers let retailers manage salespeople.
- Why?

When a manufacturer hires a salesperson

- The salesperson needs to put **efforts** in promoting the product.
  - The efforts are costly: No one wants to work for free.
  - The efforts are hidden.
- The manufacturer will pay **commissions** to the salesperson.
  - The salesperson's payoff is based on the sales outcome.
- However, the outcome is **uncertain**.
  - What if a salesperson is diligent (resp., lazy) in promoting an unpopular (resp., popular) product?
  - What if the **market condition** is just bad?
- The market condition is also **hidden** to the manufacturer.
  - Is a high sales volume due to the salesperson's hard work or a good market condition?
  - If a salesperson is rewarded or punished by luck, will he work hard?

When a retailer hires a salesperson

- The market condition and sales effort introduce **information asymmetry** between manufacturers and salespeople.
- How to collect more information? Find a retailer!
  - The retailer is closer to the market and to the salespeople.
  - She knows more about the market condition and sales efforts.
- We will focus on the **informational impact** of including a retailer.
  - The retailer simply **resell** the product.
  - It is called a **reseller** in this study.

Demand forecasting

- Different retailers have different **demand forecasting** capabilities.
  - Manufacturers care about resellers' forecasting capabilities.
  - Sony (Stoller, 2004), HP (Newswire, 2000), CPFR (Fraser, 2003).
- When a reseller can do better demand forecasting, its screening problem (with respect to salespeople) is alleviated.
- In estimating the random market condition:
  - Salespeople are the best.
  - Retailers are second best.
  - Manufacturers are the worst.
- We study the impact of **forecasting accuracy** on supply chain performance and profit splitting.
  - How should the manufacturer choose the supply chain structure?
  - How should the retailer choose her forecasting accuracy?

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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.
- $\theta \in \{\theta_\text{L}, \theta_\text{H}\}$ where $0 < \theta_\text{L} < \theta_\text{H} < 1$.
- $\Pr(\theta = \theta_\text{L}) = \Pr(\theta = \theta_\text{H}) = \frac{1}{2}$.
- Cost of a is $\frac{1}{2}a^2$.

Demand forecasting

- R and A estimate θ independently.
- R obtains **signal** $s_\text{R} \in \{G, B\}$ with forecasting **accuracy** λ_R.
  - G = Good, B = Gad.
  - $\Pr(B|\theta_\text{L}) = \Pr(G|\theta_\text{H}) = \lambda_\text{R} = 1 - \Pr(G|\theta_\text{L}) = 1 - \Pr(B|\theta_\text{H})$.
- A obtains **signal** $s_\text{A} \in \{F, U\}$ with forecasting **accuracy** λ_A.
  - F = Favorable, U = Unfavorable.
  - $\Pr(U|\theta_\text{L}) = \Pr(F|\theta_\text{H}) = \lambda_\text{A} = 1 - \Pr(F|\theta_\text{L}) = 1 - \Pr(U|\theta_\text{H})$.
- $\lambda_\text{R} \in [\frac{1}{2}, 1]$ and $\lambda_\text{A} \in [\frac{1}{2}, 1]$.
- 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 consists of a **fixed payment** α and a **sales bonus** β:

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

- Because A privately observes s_{A}, it is **optimal** for R to offer a **menu of contracts** $\{(\alpha_{\mathrm{F}}, \beta_{\mathrm{F}}), (\alpha_{\mathrm{U}}, \beta_{\mathrm{U}})\}$.
- Similarly, M offers $\{(u_{\mathrm{G}}, v_{\mathrm{G}}), (u_{\mathrm{B}}, v_{\mathrm{B}})\}$ 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.

Road map

- The story.
- Model.
- **Optimal contracts**.
- Findings.
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Sales agent's effort level

- Suppose the sales agent has observed $(s_{\mathrm{A}}, s_{\mathrm{R}}) = (j, k)$ and chosen the contract (α, β).
- The sales agent solves

$$\begin{aligned} \mathcal{A}_{jk}(t) &\equiv \max_{a \geq 0} \; \mathbb{E}\left[\alpha + \beta x - \frac{1}{2}a^2 \middle| s_{\mathrm{A}} = j, s_{\mathrm{R}} = k\right] \\ &= \max_{a \geq 0} \; \alpha + \beta N_{jk} a - \frac{1}{2}a^2. \end{aligned}$$

  - Let $N_{jk} \equiv \mathbb{E}[\theta | s_{\mathrm{A}} = j, s_{\mathrm{R}} = k]$.
- The optimal service level is $a^*_{jk}(t) = N_{jk}\beta$.

Reseller's optimal menu

- In expectation, the sales agent earns

$$\alpha + \frac{1}{2}\beta^2 N_{jk}^2$$

  if he observes $(s_{\mathrm{A}}, s_{\mathrm{R}}) = (j, k)$ and selects (α, β).
- For the reseller (seeing $s_{\mathrm{R}} = k$) to induce **truth-telling**:
  - To make an agent observing $s_{\mathrm{A}} = F$ prefer $(\alpha_{\mathrm{F}}, \beta_{\mathrm{F}})$:

$$\alpha_{\mathrm{F}} + \frac{1}{2}\beta_{\mathrm{F}}^2 N_{Fk}^2 \geq \alpha_{\mathrm{U}} + \frac{1}{2}\beta_{\mathrm{U}}^2 N_{Fk}^2.$$

  - To make an agent observing $s_{\mathrm{A}} = U$ prefer $(\alpha_{\mathrm{U}}, \beta_{\mathrm{U}})$:

$$\alpha_{\mathrm{U}} + \frac{1}{2}\beta_{\mathrm{U}}^2 N_{Uk}^2 \geq \alpha_{\mathrm{F}} + \frac{1}{2}\beta_{\mathrm{F}}^2 N_{Uk}^2.$$

  - These are the **incentive compatibility** constraints.

Reseller's optimal menu

- In expectation, the sales agent earns

$$\alpha + \frac{1}{2}\beta^2 N_{jk}^2$$

  if he observes $(s_{\mathrm{A}}, s_{\mathrm{R}}) = (j, k)$ and selects (α, β).
- For the reseller (seeing $s_{\mathrm{R}} = k$) to induce **participation**:
  - To allow an agent observing $s_{\mathrm{A}} = F$ to earn something:

$$\alpha_{\mathrm{F}} + \frac{1}{2}\beta_{\mathrm{F}}^2 N_{Fk}^2 \geq 0.$$

  - To make an agent observing $s_{\mathrm{A}} = U$ select $(\alpha_{\mathrm{U}}, \beta_{\mathrm{U}})$:

$$\alpha_{\mathrm{U}} + \frac{1}{2}\beta_{\mathrm{U}}^2 N_{Uk}^2 \geq 0.$$

  - These are the **individual rationality** constraints.

Reseller's optimal menu

- Suppose the reseller has observed $s_{\mathrm{R}} = k$ and chosen (u, v):

$$\mathcal{R}_k(t) \equiv \max_{\substack{\alpha_{\mathrm{F}} \text{ urs.}, \beta_{\mathrm{F}} \geq 0, \\ \alpha_{\mathrm{U}} \text{ urs.}, \beta_{\mathrm{U}} \geq 0}} \sum_{j \in \{F, U\}} \bar{P}_{jk} \Big[u_t - \alpha_j + (v_t - \beta_j) N_{jk}^2 \beta_j \Big]$$

$$\begin{aligned} \text{s.t.} \quad & \alpha_{\mathrm{F}} + \frac{1}{2}\beta_{\mathrm{F}}^2 N_{Fk}^2 \geq 0 \\ & \alpha_{\mathrm{U}} + \frac{1}{2}\beta_{\mathrm{U}}^2 N_{Uk}^2 \geq 0 \\ & \alpha_{\mathrm{F}} + \frac{1}{2}\beta_{\mathrm{F}}^2 N_{Fk}^2 \geq \alpha_{\mathrm{U}} + \frac{1}{2}\beta_{\mathrm{U}}^2 N_{Fk}^2 \\ & \alpha_{\mathrm{U}} + \frac{1}{2}\beta_{\mathrm{U}}^2 N_{Uk}^2 \geq \alpha_{\mathrm{F}} + \frac{1}{2}\beta_{\mathrm{F}}^2 N_{Uk}^2. \end{aligned}$$

  - $\bar{P}_{jk} \equiv \Pr(s_{\mathrm{A}} = j | s_{\mathrm{R}} = k)$.
  - $\mathbb{E}[x | s_{\mathrm{A}} = j, s_{\mathrm{R}} = k] = N_{jk} a_{jk}^* = N_{jk}^2 \beta_j$.

Reseller's optimal contract

Lemma 1

With $s_{\mathrm{R}} = k \in \{G, B\}$ and (u_t, v_t), the reseller offers

$$\beta_F^* = v_t \text{ and } \beta_U^* = \frac{\bar{P}_{Uk}}{\bar{P}_{Uk} + \bar{P}_{Fk}(N_{Fk}^2 / N_{Uk}^2 - 1)} v_t$$

and earns $\mathcal{R}_k(t) = u_t + \frac{1}{2} Z_k v_t^2$ in expectation, where

$$Z_k \equiv \bar{P}_{Fk} N_{Fk}^2 + \frac{\bar{P}_{Uk}^2 N_{Uk}^4}{\bar{P}_{Uk} + \bar{P}_{Fk}(N_{Fk}^2 / N_{Uk}^2 - 1)}.$$

- Downward distortion for the pessimistic sales agent.

Manufacturer's optimal contract

- Let $\mathcal{R}_k \equiv \mathcal{R}_k(k)$.
- The manufacturer solves

$$\begin{aligned}\mathcal{M} = \max_{\substack{u_G \text{ urs., } v_G \geq 0, \\ u_B \text{ urs., } v_B \geq 0}} \quad & \sum_{k \in \{G,B\}} \frac{1}{2}\Big[(1-v_k)Z_k v_k - u_k\Big] \\ \text{s.t.} \quad & \mathcal{R}_G \geq 0, \quad \mathcal{R}_B \geq 0, \\ & \mathcal{R}_G \geq \mathcal{R}_G(B), \quad \mathcal{R}_B \geq \mathcal{R}_B(G).\end{aligned}$$

  - $\mathbb{E}[x|s_R = k] = \sum_{j \in \{F,U\}} \bar{P}_{jk} N_{jk}^2 \beta_{jk} = Z_k v_k$.

Manufacturer's optimal contract

Lemma 2

The manufacturer offers

$$v_G^* = 1 \text{ and } v_B^* = \frac{Z_B}{Z_G}$$

and earns $\mathcal{M} = \frac{1}{4}\left[Z_G + \frac{Z_B^2}{Z_G}\right]$ *in expectation. We also have* $\mathcal{R}_B = 0$, $\mathcal{R}_G = \frac{1}{2}(Z_G - Z_B)(\frac{Z_B}{Z_G})^2$, *and* $\mathcal{R} = \frac{1}{2}(\mathcal{R}_G + \mathcal{R}_B)$.

- Downward distortion for the pessimistic reseller.

Road map

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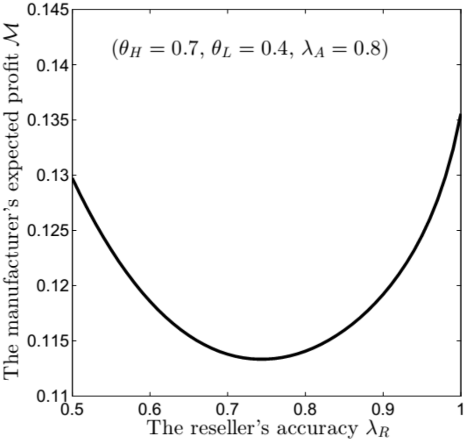
Manufacturer's profitability

- How does the reseller's accuracy affect the manufacturer's expected profit $\mathcal{M}$?

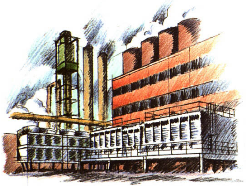
Proposition 1

- *$\mathcal{M}$ is* **convex** *on $\lambda_R \in [\frac{1}{2}, 1]$.*
- *$\mathcal{M}$ may first decrease and then increase.*



Impact of reseller's accuracy

- If there should be a retailer, which one?
  - Huge upstream information asymmetry:



http://servagya.com

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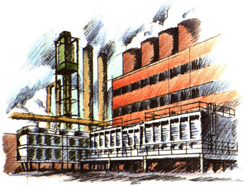
  - Huge downstream information asymmetry:



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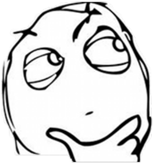

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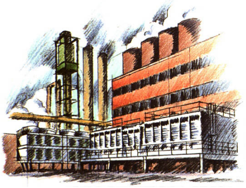
Two driving forces when the reseller improves

- **Better-monitoring** effect.
  - Mitigating the R-A information asymmetry.
  - Strong when λ_{R} is large.
- **Rent-extraction** effect.
  - Aggravating the M-R information asymmetry.
  - Strong when λ_{R} is small.
- The better-monitoring effect eventually dominates the rent-extraction effect when λ_R is large enough.

Supply chain structure

- Which supply chain structure is optimal?
  - One huge level of information asymmetry:



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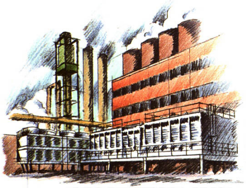
  - Two small levels of information asymmetry:



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Supply chain structure

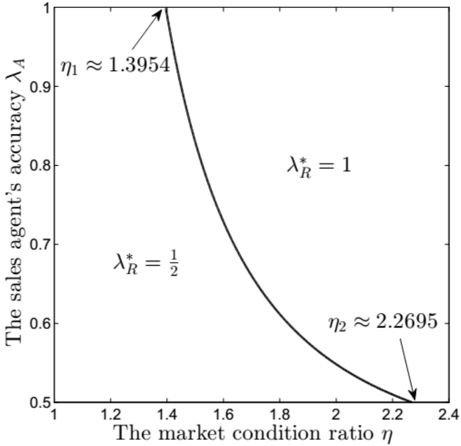
- The manufacturer prefers R to be **uninformed or precise**.
- Supply chain structure selection: M-R-A v.s. M-A.
- Let λ_{R}^* maximize $\mathcal{M}$. Let $\eta \equiv \frac{\theta_{\mathrm{H}}}{\theta_{\mathrm{L}}}$.

Proposition 2

There exists two cutoffs η_1 and η_2 such that

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

Supply chain structure



- Reseller's accuracy λ_{R}^* maximizes $\mathcal{M}$.
- $\lambda_R^* = 1$ for large η and λ_{A}.
- $\lambda_R^* = \frac{1}{2}$ for small η and λ_{A}.

Road map

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An extension: General levels of pessimism

- The random market condition follows a general Bernoulli distribution:

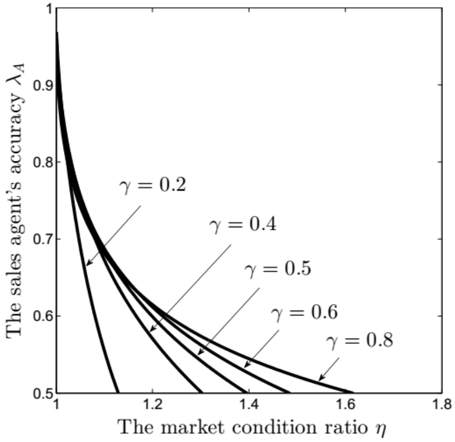
$$\Pr(\theta = \theta_{\mathrm{L}}) = \gamma = 1 - \Pr(\theta = \theta_{\mathrm{H}})$$

  for any $\gamma \in (0, 1)$.
- Too complicated to prove our main results!
- We may use **numerical studies** to confirm our main insights.

Nonmonotonicity

Observation 1

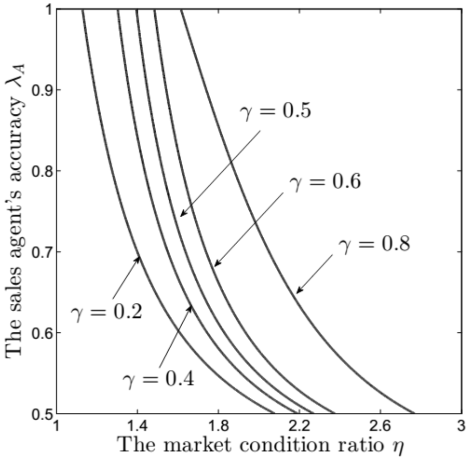
For any $\gamma \in (0,1)$, $\mathcal{M}$ either first decreases and then increases or monotonically decreases in $\lambda_R \in [\frac{1}{2}, 1]$. In particular, $\mathcal{M}$ tends to be nonmonotone when γ is low but monotonically decreasing when γ is high.



Manufacturer-optimal reseller's accuracy

Observation 2

For any $\gamma \in (0,1)$, $\mathcal{M}$ is maximized at $\lambda_R^* = \frac{1}{2}$ (respectively, $\lambda_R^* = 1$) if η and λ_A are both small (respectively, large) enough. Moreover, it is more likely that $\lambda_R^* = \frac{1}{2}$ (respectively, $\lambda_R^* = 1$) when γ increases (respectively, decreases).



Other extensions

- A is protected by limited liability.
  - $\alpha_j \geq 0$ for $j \in \{F, U\}$.
- A does not observe R's signal s_{R}.
  - Informed principal.
  - R offers different menus upon observing different s_{R}.

Conclusions

- A manufacturer may benefit from having a reseller **indirectly collect information** for it.
  - However, "more" information may **hurt** a principal!
- Once a reseller is included in the supply chain, she should be either **precise or uninformed**.
- The manufacturer prefers:
  - The reseller to be uninformed when the market is not volatile and the sales agent is not accurate.
  - The reseller to be precise when the market is volatile and the sales agent is accurate.
- Do these implications match your daily life experiences?