Information Economics

Cascade Contract Design and Partial Monitoring

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Road map

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

Different supply chains in practice

- Some manufacturers hire salespeople directly.
  - A car manufacturer lets its salespeople work at a car dealer's store.
  - A beer manufacturer lets its salespeople work at a restaurant.
- 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?

Learning objectives

- 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.

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

Demand forecasting

- R and A estimate θ independently.
- R obtains **signal** $s_{\text{R}} \in \{G, B\}$ with forecasting **accuracy** λ_{R}.
  - G = Good, B = Bad.
  - $\Pr(B|\theta_{\text{L}}) = \Pr(G|\theta_{\text{H}}) = \lambda_{\text{R}} = 1 - \Pr(G|\theta_{\text{L}}) = 1 - \Pr(B|\theta_{\text{H}})$.
- 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.

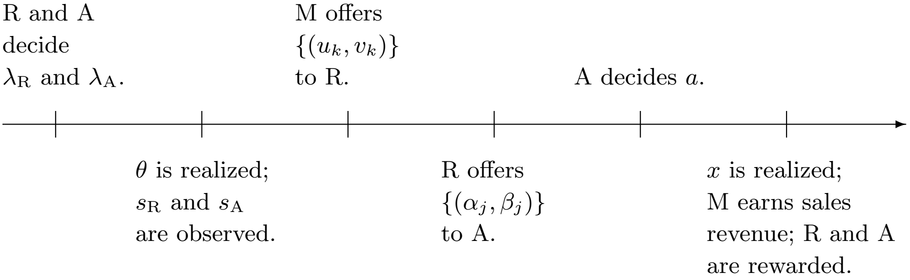
Contract forms

- 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 $s_{\rm A}$, it is **optimal** for R to offer a **menu of contracts** $\{(\alpha_{\rm F}, \beta_{\rm F}), (\alpha_{\rm U}, \beta_{\rm U})\}$.
- Similarly, M offers $\{(u_{\rm G}, v_{\rm G}), (u_{\rm B}, v_{\rm B})\}$ to R.
- Each player acts to maximize her own expected profit.

Timing and backward induction



Solution: Backward induction.

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Sales agent's effort level

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

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

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

Reseller's optimal menu

- In expectation, the sales agent earns

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

if he observes $(s_\text{A}, s_\text{R}) = (j, k)$ and selects (α, β).

- For the reseller (seeing $s_\text{R} = k$) to induce **truth-telling**:
  - To make an agent observing $s_\text{A} = F$ prefer $(\alpha_\text{F}, \beta_\text{F})$:

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

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

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

  - 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 $s_{\text{R}} = k$ and chosen (u, v):

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

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

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

Reseller's optimal contract

Lemma 1

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

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

and earns $\mathcal{R}_k(t) = u + \frac{1}{2} Z_k v^2$ *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 the retailer's expected profit be $\mathcal{R}_k(t)$ if she observes signal $s_R = k$ but selects (u_t, v_t).
- Let $\mathcal{R}_k \equiv \mathcal{R}_k(k)$.
- The manufacturer solves

$$\mathcal{M} = \max_{\substack{u_G \text{ urs., } v_G \geq 0, \\ u_B \text{ urs., } v_B \geq 0}} \sum_{k \in \{G,B\}} \frac{1}{2}\Big[(1 - v_k) Z_k v_k - u_k\Big]$$

$$\text{s.t.} \quad \mathcal{R}_G \geq 0, \quad \mathcal{R}_B \geq 0,$$

$$\mathcal{R}_G \geq \mathcal{R}_G(B), \quad \mathcal{R}_B \geq \mathcal{R}_B(G).$$

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

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.

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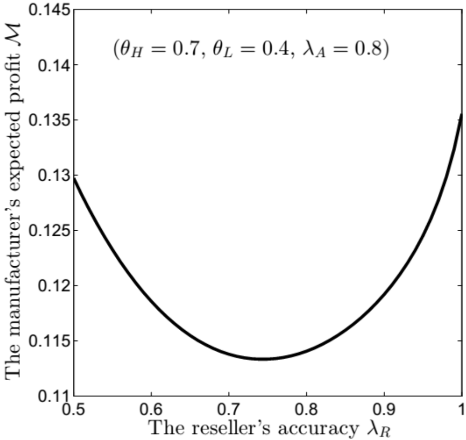
Manufacturer's profitability

- 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:

$$\text{Manufacturer} \quad \rightarrow\rightarrow\rightarrow\rightarrow\rightarrow \quad \text{Reseller} \quad \rightarrow \quad \text{Salesperson}$$

  - Huge downstream information asymmetry:

$$\text{Manufacturer} \quad \rightarrow \quad \text{Reseller} \quad \rightarrow\rightarrow\rightarrow\rightarrow\rightarrow \quad \text{Salesperson}$$

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:

    Manufacturer →→→→→→→→→→→→ Salesperson

  - Two small levels of information asymmetry:

    Manufacturer →→→ Reseller →→→ Salesperson

Supply chain structure

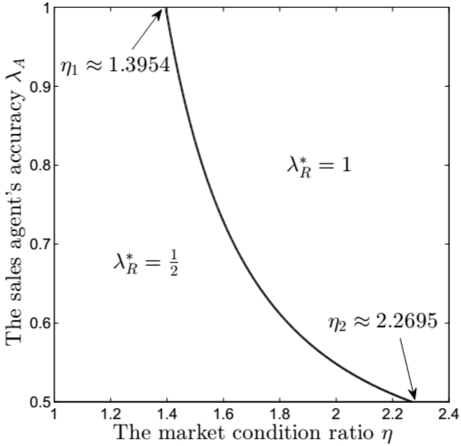
- The manufacturer prefers R to be **uninformed or precise**.
- Supply chain structure selection: M-R-A v.s. M-A.
- Let λ_R^* maximize $\mathcal{M}$. Let $\eta \equiv \frac{\theta_H}{\theta_L}$.

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 $\eta \in [\eta_2, \infty)$, $\lambda_R^* = 1$.*

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}.

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An extension: General levels of pessimism

- The random market condition follows a general Bernoulli distribution:

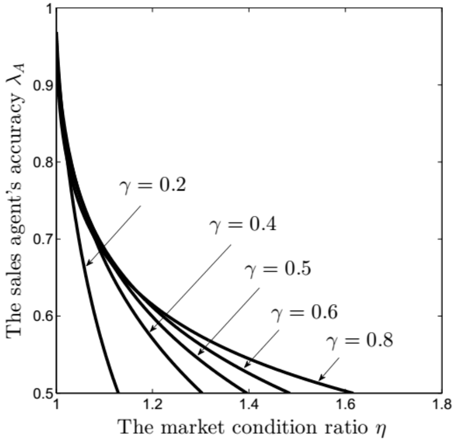
$$\Pr(\theta = \theta_{\mathrm{L}}) = \gamma = 1 - \Pr(\theta = \theta_{\mathrm{H}})$$

  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

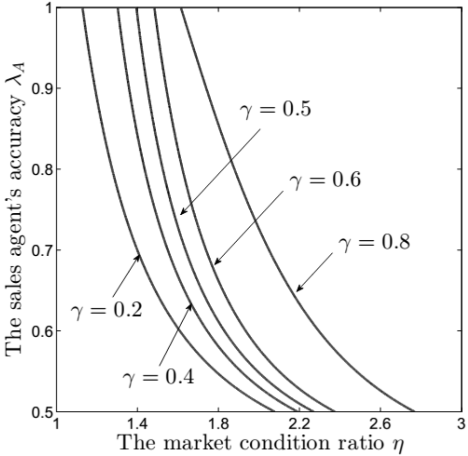
For any $\gamma \in (0,1)$, $\mathcal{M}$ either first decreases and then increases or monotonically decreases in $\lambda_R \in [\frac{1}{2}, 1]$. In particular, $\mathcal{M}$ tends to be nonmonotone when γ is low but monotonically decreasing when γ is high.



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?