Information Economics

Cascade Contract Design and
Partial Monitoring

Ling-Chieh Kung

Department of Information Management
National Taiwan University

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.

Road map

▶ The story.

▶ **Model**.

▶ Optimal contracts.

▶ Findings.

▶ Extensions and conclusions.

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.
- $\theta \in \{\theta_{\mathrm{L}}, \theta_{\mathrm{H}}\}$ where $0 < \theta_{\mathrm{L}} < \theta_{\mathrm{H}} < 1$.
- $\Pr(\theta = \theta_{\mathrm{L}}) = \Pr(\theta = \theta_{\mathrm{H}}) = \frac{1}{2}$.
- 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 = Bad.
  - $\Pr(B|\theta_L) = \Pr(G|\theta_H) = \lambda_R = 1 - \Pr(G|\theta_L) = 1 - \Pr(B|\theta_H)$.
- 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 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** $\{(\alpha_F, \beta_F), (\alpha_U, \beta_U)\}$.

▶ 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}.

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

A decides a.

θ is realized;
s_{R} and s_{A}
are observed.

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

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

Solution: Backward induction.

Road map

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

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

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

▶ Let $N_{jk} \equiv \mathbb{E}[\theta | s_{\mathrm{A}} = j, s_{\mathrm{R}} = k]$.

▶ 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 $(s_A, s_R) = (j, k)$ and selects (α, β).

▶ For the reseller (seeing $s_R = k$) to induce **truth-telling**:

▶ To make an agent observing $s_A = F$ prefer (α_F, β_F):

$$\alpha_F + \frac{1}{2}\beta_F^2 N_{Fk}^2 \geq \alpha_U + \frac{1}{2}\beta_U^2 N_{Fk}^2.$$

▶ To make an agent observing $s_A = U$ prefer (α_U, β_U):

$$\alpha_U + \frac{1}{2}\beta_U^2 N_{Uk}^2 \geq \alpha_F + \frac{1}{2}\beta_F^2 N_{Uk}^2.$$

▶ 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 $(s_A, s_R) = (j, k)$ and selects (α, β).

▶ For the reseller (seeing $s_R = k$) to induce **participation**:

▶ To allow an agent observing $s_A = F$ to earn something:

$$\alpha_F + \frac{1}{2}\beta_F^2 N_{Fk}^2 \geq 0.$$

▶ To make an agent observing $s_A = U$ select (α_U, β_U):

$$\alpha_U + \frac{1}{2}\beta_U^2 N_{Uk}^2 \geq 0.$$

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

Reseller's optimal menu

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

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

$$\text{s.t.} \quad \alpha_{\rm F} + \frac{1}{2}\beta_{\rm F}^2 N_{Fk}^2 \geq 0$$

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

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

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

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

Reseller's optimal contract

Lemma 1

With $s_R = k \in \{G, B\}$ 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

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

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

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

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

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.
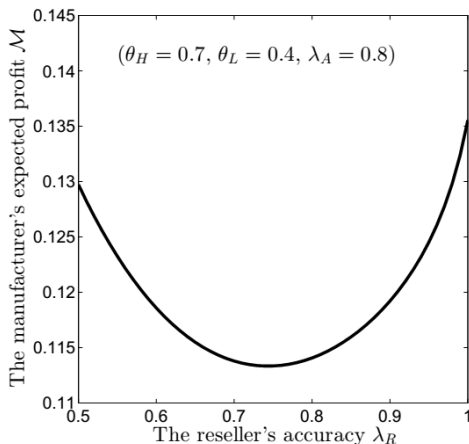
Road map

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

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.*

$(\theta_H = 0.7, \theta_L = 0.4, \lambda_A = 0.8)$

The manufacturer's expected profit $\mathcal{M}$

The reseller's accuracy λ_R

Impact of reseller's accuracy

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

    Manufacturer   →→→→→   Reseller   →   Salesperson

  - ▶ Huge downstream information asymmetry:

    Manufacturer   →   Reseller   →→→→→   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 $\rightarrow\rightarrow\rightarrow\rightarrow\rightarrow\rightarrow\rightarrow\rightarrow\rightarrow\rightarrow\rightarrow$ Salesperson

  ► Two small levels of information asymmetry:

    Manufacturer $\rightarrow\rightarrow\rightarrow$ Reseller $\rightarrow\rightarrow\rightarrow$ Salesperson
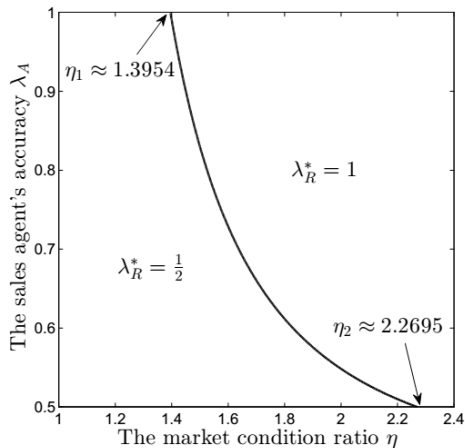
Supply chain structure

▶ 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.

Road map

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

An extension: General levels of pessimism

▶ The random market condition follows a general Bernoulli distribution:

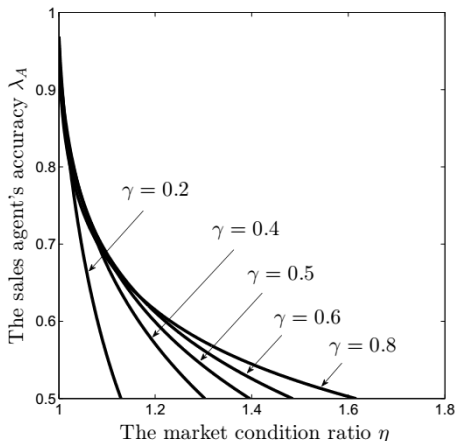$$\Pr(\theta = \theta_{\mathrm{L}}) = \gamma = 1 - \Pr(\theta = \theta_{\mathrm{H}})$$

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).
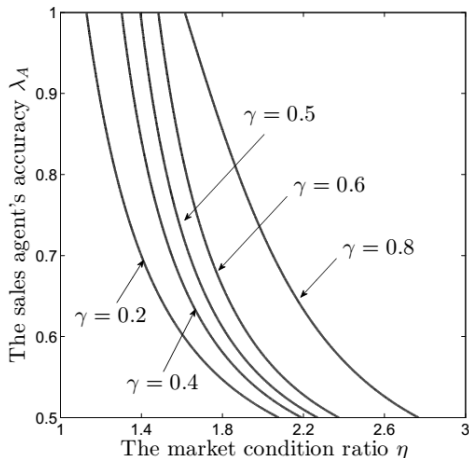
Other extensions

- ▶ 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?