A Game Theoretic Economics Framework to understanding the Information Security outsourcing Market

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February 1, 2008

Abstract
On information security outsourcing market, an important reason that firms do not want to let outside firms (usually called MSSPs-Managed Security Service Providers) to take care of their security need is that they worry about service quality MSSPs provide because they cannot monitor effort of the MSSPs. Since MSSPs action is unobservable to buyers, MSSPs can lower cost by working less hard than required in the contract and get higher profit. In the asymmetric information literature, this possible secret shirking behavior is termed as moral hazard problem. This paper considers a game theoretic economic framework to show that under information asymmetry, an optimal contract can be designed so that MSSPs will stick to their promised effort level. We also show that the optimal contract should be performance-based, i.e., payment to MSSP should base on performance of MSSP’s security service period by period. For comparison, we also showed that if the moral hazard problem does not exist, the optimal contract does not depend on MSSP’s performance. A contract that specifies constant payment to MSSP will be optimal. Besides these, we show that for no matter under perfect information scenario or imperfect information scenario, the higher the transaction cost is, the lower payment to MSSPs will be.

Keywords: outsourcing, information security, managed security service providers, economics of information security

1 Introduction
Security outsourcing market where firms contract with outside information security vendors to meet their organizational demands has been growing at a double digit rate for the past 3 years, and experts predict that this growth rate will continue through 2008[7]. Compared with the booming of the business, theory of security outsourcing is less developed. In view of this both buyers and MSSPs need to strategically understand the nature of this market.
Information security outsourcing is different from traditional outsourcing because information security is different from durable goods and other services outsourced such as payroll and accounting. As more and more firms automate processes, servers and the networks work like the brains and vessels of a firm. If any core system go down, the cost may be large due to lost data and lost revenue. What makes it worse is that security breaches are irreversible. While defects in manufacturing can be returned or wrong paychecks can be reissued, monetary loss due to down time is gone forever, and lost customer confidence may be hard to gain back. Therefore, while most industries put cost saving as the primary reason they outsource business processes other than security, firms that outsource information security state service quality is their primary motivation. This is supported by a survey by Jeffrey Kaplan published in Business Communication Review (2003)\[10\]. It is reported that 40.6% of the firms outsource network operations based on concerns for service quality.

Information asymmetry is another reason that firms have concerns outsourcing their security. Since buyers cannot observe and monitor MSSPs’ action, MSSPs, as profit maximizing companies, have an incentive to lower their effort level to reduce cost.

The model we present is a model where buyers and MSSPs engage in a repeated game with infinite horizon where MSSPs’ effort level in not observable to buyers. We show that under this information asymmetry, moral hazard problem will occur. Performance based contracts are recommended to avoid such moral hazard problem.

For comparison, we also provide results under perfect information, where buyers can have all information they need and shirking is not an option for MSSPs. Under the scenario of perfect information, the optimal solution (in terms how the contact is written) is a price-only contract. This solution is called first best because no deadweight loss is incurred under perfect information assumption.

Besides the optimal contract form, we are particularly interested in the effect of transaction cost on market equilibrium price. Transaction cost includes all cost spent on searching for, arguing and executing contracts with MSSPs\[4\]. We argue in section (3.2) transaction cost can be very high in outsourcing non traditional services such as security because standard rules and procedures have not been established yet. We show that when transaction cost increases, price of security outsourcing will be lowered.

There is a large body of literature on IT outsourcing, including information security outsourcing as a sub-category. Ang and Straub (1998)\[1\] did an empirical study on the U.S. banking industry and showed IT outsourcing is strongly influenced by the production cost advantage offered by IT service vendors. Transaction cost also influences outsourcing decisions with a much smaller effect. Though their result is based on data of US banking system, this result is probably true in a lot of areas outside the banking system. Based on their result, we will assume decrease in production cost out-weight increase in transaction cost throughout this paper. Lacity and Wilcocks’ (1998)\[11\] use US and UK organizations survey data and provide empirical evidence that the following practices are recommended to achieve cost saving expected: selective outsourcing, senior executives and IT manager make decisions together, invite both internal and external bids, short-term contract, detailed fee-for-service contract. This paper will provide theoretical support for the last practice. Mieghem (1999)\[12\] builds a game theoretic model on production outsourcing where investment decision has to be made before market demand is revealed. After market demand is revealed, the firm’s production is limited to its investment level, and will use outside production(outsource) to meet excess demand. His paper studies three kinds of contracts 1), price-only contract, 2), incom-
plete contract and 3), state-dependent contract. He shows that only state-dependent contract is optimal in the sense that it eliminates all decentralizing cost. His paper is related to security outsourcing because in security outsourcing, an implicit assumption of centralized economy is that all participants will work diligently. Therefore, with moral hazard problem, decentralization cost is caused by the possibility that MSSPs may shirk. This paper will investigate why state-contingent contract is preferred to non state-contingent contract from an information economics point of view. We argue that state-contingent contract is the optimal contract form when there is moral hazard problem.

The rest of this paper is organized as follows: In Section 2 and 3, we contrast information security outsourcing with other types of outsourcing. Next we set up an outsourcing model with perfect and imperfect information to discuss what optimal contract look like and what is the effect of transaction cost on prices in Section 4. In Section 5, related work on this topic is summarized. We end with a summary and conclusions in Section 6.

2 Outsourceing Theory

Outsourcing is defined as ‘all the subcontracting relationships between firms and the hiring of workers in non-traditional jobs’ (Heshmati 2003). Business Process Outsourcing (BPO), which includes outsourcing of human resources, finance and accounting, procurement, shared services, billing, customer care and so on, is estimated to grow at a 9.5% compound annual rate through 2007 reaching $173 billion by Gartner. IT Outsourcing (ITO) is expected to grow at a compound rate of 7.2% through 2008 reaching $253.1 billion in 2008. Furthermore, Information security outsourcing is predicted to grow from $4.1 billion in 2001 to $9.0 billion in 2006, a compound growth rate of double digits.

Behind this booming of outsourcing, the basic force is ‘cost efficiency’. As markets become more competitive, outsourcing is an essential way firms may reduce costs. By using information security outsourcing, firm only need to pay a fraction of their in-housing cost for outsourced security. Outsourcing can reduce cost either because suppliers has lower input costs and/or larger scale of production as in the case of offshore manufacturing outsourcing; or because the suppliers have expertise or more advanced technology as in payroll and IT outsourcing. However, at the same time of reducing production cost, buyers incur transaction costs searching for, signing, and executing contracts with suppliers. The case of total outsourcing, when firms keeps no in-house production, firms also lose sunk costs, which can be machines and plants that can only be used to produce the outsourced product or can be money spent on training technicians.

If cost reduction is the only concern for firms, firms will outsource when reduction in production cost exceeds increase in transaction cost. In standardized outsourcing procedures such as payroll and manufacture goods, transaction cost has been reduced as Coase predicted ‘this(transaction) cost may be reduced but it will not be eliminated by emergence of specialist...’. It is argued that transaction cost is some percentage of the contract value since the larger the project, the greater ef-

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1Centralized economy system assumes there is a social planner who make decision by pooling all available resources from different firms. Decentralized economy system is one where firms make their own decision using individual resources. It can be shown that outcome of centralized economy weakly dominates outcome of decentralized economy. Difference between the two is decentralization cost.

2Firm’s investment specific to the outsourced process
fort firms will spent on searching for a proper MSSP and the more coordination is needed between firm and MSSP after signing the contract.

The second outsourcing incentive is firms will be able to concentrate on their core competence by outsourcing support/routine functions. For example, although a lot computer companies are based in the U.S., most keyboards are produced in Asia. By outsourcing labor intensive processes to areas that are abundant in labor, firms achieve cost reduction and become more focused on core competence.

Yet another key reason for outsourcing is to obtain higher quality. Outside companies accumulate more experience by specializing in certain processes. They can afford larger investment on R&D to get updated technology and skills and better trained expertise. A large client base also contributes to the quality of goods and services of outside producers and service providers. They gain experience and knowledge by serving varied clients. Consulting, for example, the service providers have professional knowledge that a non-consulting firm can never afford to build by itself.

Argument against production outsourcing concerns unemployment issue as in off-shore outsourcing: while argument against security outsourcing focus on transaction cost control and service quality monitoring. We will analyze these two concerns on information security outsourcing in detail in the following section.

3 Security Outsourcing: What is Special?

In spite of all the advantages outsourcing may bring, some people think security should not be outsourced, or firms should be really careful when doing so.

3.1 Quality Measurement Difficulty

Security management is an art rather than science where we know how to achieve a best solution; here we do not even know what the best solutions are, nor do MSSPs. A security system can be a very complicated project. People may think that they are safe with firewalls and IDSs. Even so, firms have to decide which firewalls and IDSs to buy, how to allocate limited budget on combination of these devices to reach maximum level of security and how to manage these devices and tune them so that they secure your system enough and do not give too many alerts on harmless behaviors. The bright side is MSSPs are gaining experience on these issues quickly by their devotion and specialization in this area.

However, people argue that it is hard to evaluate products and services of MSSPs both ex ante and ex post. As security outsourcing market becoming prominent over the last few years; a large number of MSSPs emerged from diversified backgrounds. The largest ones include firms formed solely to solve internet security problems such as Counterpane, firms from research and computer production such as IBM, anti virus companies such as Symantec, firms from internet providers such as AT&T and so on. This diversification in background reflects on their diversified product and services making it really hard for the firms to compare and choose from them. (See appendix I for major MSSPs and their products.)

Also, evaluating MSSPs’ products by performance of their products is tricky because the outcome is highly random and can even be misleading. A better secured system may be down because
of intensive attacks; systems that ignore patching notices from time to time may go well for a long time. On the other hand, it is not true that the more money spent on security, the fewer bleaches a system will have. Sophisticated hackers are more attracted to systems that are hard to break into.

However, a ‘better’ secured system should be less vulnerable in statistical sense in the long run. This paper will use expected performance to evaluate a security system. We assume buyers have access to historical data of MSSP’s service performance, and can generate a distribution of benefit from using security outsourcing.

3.2 Effective Cost Reduction?

Based on a survey on IT managers, directors and other decision makers from both firms that outsourced security and those who did not, cost reduction remains their focus[10].

There is evidence that security outsourcing will reduce production cost. Device management for example, which tunes and monitors firewalls, IDSs and runs vulnerability testing, a security personnel cost $8,000 to $16,000 per month. And to get 24*7 support, this figure may need to be more than tripled. For the same functions, MSSPs charge between $600 and $4,000. For network monitoring, Counterpane, one of the most successful MSSPs, claims that it only charges a fraction of the money for net management a firm need to spend to do the security in house: ‘From an annualized basis, its going to cost you $1 million to $1.2 million just to look at the same information we monitor, and our average contract ranges from $40,000 to $150,000 a year — between 4% and 10% of what it would cost to do yourself . . . ’[13].

However, although security vendors’ may provide huge reduction in production cost, transaction cost may be quite high. Since standard measure for security services has not been established and each MSSP uses their featured (different) technology, most of the time it is very hard to do comparison across different MSSPs. This quality measurement difficulty may increase transaction cost potentially[15].

Also, writing up the contract and decide who is responsible for what kind of losses due to security breaches can be painful. Firms would feel more comfortable if security vendors can take responsibility if losses occur. But it is not always the security vendor’s fault because no matter how well security devices are designed and tuned, there is always probability that the system is broken into. More tricky things can be if security vendors take responsibility for the losses, firms may not play due diligence as they should. Therefore, although this paper is devoted to discussion of MSSPs’ moral hazard behavior, the optimal contract needs to guard against firms’ moral hazard behavior as well, which may increase transaction cost significantly. Therefore although we will assume that transaction cost is lower than reduction in production cost, effect of transaction cost needs to be further explored.

4 The Model

Based on above observation of how security outsourcing is special, We set up the model in the following way.

There are two sides on the security outsourcing market: potential security service buyers (“buyers” for short), and security vendors(MSSPs). Vendors and buyers all seek to maximize their individual profit.
Basic assumptions are:

- A1: Vendors are more cost efficient than firms; transaction cost is lower than production cost advantage.
- A2: Services provided by different security vendors are imperfect substitutes.
- A3: Buyers do not have moral hazard problem.

In the following three subsections, we show that:

1. With imperfect information, we have moral hazard problem on MSSP side. Optimal contract depends non-trivially on MSSPs performance.
2. With perfect information, optimal contract is a price-only contract.
3. With either perfect information or imperfect information, price is decreasing on transaction cost.

### 4.1 Optimal contract with imperfect information

#### Performance based contract

Due to imperfect information, actions of the players are not directly observable. Both MSSPs and security buyers can disobey their promises secretly. In this paper, we focus on how to avoid moral hazard behavior of MSSPs, and assume buyers will always follow the contract as it is. The optimal contract will be such that following the contract is the best choice for both players. We temporarily assume transaction cost is zero in this section.

Our analysis is based on principal-agent problem with infinite horizon following Spear and Srivastava[18], where agent’s action is not observable to principal. Principal is assumed to be risk neutral and agent risk averse. Here, MSSP is agent to principal buyer. We are allowed to assume security buyer is risk neutral because security buyers have access to insurance market and can buy insurance to mitigate risks that MSSPs cannot eliminate. However, the risk neutral assumption is not essential to the result. We can discuss risk averse buyers but it only make the mathematics more complicated without accomplishing anything. So we just keep the simple assumption that buyers are risk neutral.

Denote buyer’s period t benefit(before payment to MSSP) from security outsourcing as $y_t$. Because of the random nature of cyber attacks, $y_t$ is a random variable. Denote MSSP’s effort level in period t as $a_t$, $a_t \in [\underline{a}, \overline{a}]$. Then distribution of security service performance $y_t$ is conditional on MSSP’s effort $a_t$. Denote the distribution as $f(y, a_t)$. $P_t$ denotes buyer’s compensation(price) to MSSP in period t. History up to period t is denoted as: $h_t = \{y_t, y_{t-1}, \ldots, y_0\}$.

A price contract is composed of MSSP’s effort level and price buyer pays to MSSP: $\{a_t(h_{t-1}), P_t(h_t)\}$. Notice that MSSP’s period t effort level $a_t$ depends only on history up to period t-1, since MSSP has to choose his effort level at beginning of period t before period t benefit $y_t$ is realized. Payment to MSSP in period t however depends on the whole performance history.

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3 Imperfect substitutes are goods that are not identical but have similar functions, e.g. lap-top and desk-tops.

4 A risk neutral player only cares about average payoff.

5 A risk averse player gets lower utility if variance of his payoff increase.
Let \( u(P_t) - \phi(a_t) \) be net payoff to MSSP under contract \( \{a_t(h_{t-1}), P_t(h_t)\} \), where \( u(P_t) \) is MSSP’s utility from payment \( P_t \) and \( \phi(a_t) \) measures cost of working at effort level \( a_t \). We assume \( u' > 0, u'' < 0^6 \) and \( \phi' > 0 \). History \( h_t \) evolve recursively by the following probability rule:

\[
\pi(h_t|h_{t-1}) = f(y_t, a_t(h_{t-1}))\pi(h_{t-1})
\]  

(1)

Assume buyers and MSSP discount future payoff at same rate \( \rho, \rho \in [0,1] \), then buyer and MSSP’s period \( t \) expected payoff are \( \int(y_t - P_t) f(y_t|a_t)dy_t \) and \( u(P_t) - \phi(a_t) \):

Discount all future payoff to period 0, we have buyer and MSSP’s period 0 discounted payoff as:

\[
B_t(P_t, a_t) = \sum_{j=0}^{\infty} \rho^j \left[ \int (y_t - P_t) f(y_t, a_t)dy_t \right] \pi(h_{t+j}, a_{t+j}|h_t)
\]

(2)

\[
M_t(P_t, a_t) = \sum_{j=0}^{\infty} \rho^j \left[ u(P_t) - \phi(a_t) \right] \pi(h_{t+j}, a_{t+j}|h_t)
\]

(3)

Therefore, the maximization problem for security buyer is to choose a sequence of contracts \( \{P_t(y), a_t\}_{t=0}^{\infty} \) to maximize discounted expected utility subject to the constraint that MSSP cannot benefit from deviating from the contract:

\[
\max_{\{P_t(y), a_t\}_{t=0}^{\infty}} \quad B_t(P_t(y), a_t) \\
\text{st} \quad M_t(P_t(y), a_t) \geq M_t(P_t(y), \tilde{a}_t) \quad \forall \tilde{a}_t \in [a, \bar{a}]
\]

(4)

where, constraint in above maximization problem is called the incentive compatibility(IC) constraint. It show that the effort level \( a_t \) is optimal for MSSP compared to any other possible effort level \( \tilde{a}_t \).

Since the above problem has infinitely unknown variables, it is impossible to solve it directly. Instead, we rewrite it in the recursive form.

In the recursive form, principal maximize current period’s payoff assuming he will behave optimally from next period on. Let \( v \) denote payoff buyer promised to MSSP this period and \( w(y) \) denote the promised payoff to MSSP next period. \( K(v) \) be maximized payoff to buyer when MSSP gets \( v \) as promised expected payoff. Hence, \( K(w(y)) \) is buyer’s best possible payoff next period. Then the maximization problem in recursive form is:

\[
K(v) = \max_{P(y), w(y), a} \quad \int [y - P(y) + \rho K(w(y))] f(y, a)dy \\
\text{st} \quad \int [u(P(y)) + \rho w(y)] f(y, a)dy - \phi(a) \geq v \quad \text{(PK)}
\]

\[
a \in \arg \max \int [u(P(y)) + \rho w(y)] f(y, a)dy - \phi(a) \quad \text{(IC)}
\]

(5)

The optimal contract should contain \( \{P(y), w(y), a\} \). (PK) is short for “promise keeping”. It requires that if buyer promised MSSP payoff \( v \), the contract should guarantee expected payoff to MSSP is at least \( v \)(equal to \( v \) in equilibrium). (IC) constraint is same as in [4].

\(^6u'' < 0 \) comes from risk averse assumption.
The (IC) constraint implies the solution \( a \) should satisfy both the following first order condition and second order condition:

\[
(FOC) \quad \int [u(P(y)) + \rho w(y)] f_a(y, a) dy - \phi'(a) = 0 \quad (6)
\]

\[
(SOC) \quad \int [u(P(y)) + \rho w(y)] f_{aa}(y, a) dy - \phi''(a) \leq 0 \quad \forall w(y) \quad (7)
\]

Assumption:

• Convexity of distribution function condition (COFC):

\[ F_{aa} \geq 0 \quad (8) \]

where \( F(x, a) = \int_{-\infty}^{x} f(y, a) dy \)

Rogerson (1985)\[16\] shows that when COFC is satisfied, (SOC) is guaranteed. We can use (FOC) to substitute (IC) constraint and get rid of the (SOC).

Let \( \lambda \) be Lagrangian multiplier on (PK) constraint and \( \mu \) be the multiplier on (IC)-(FOC) constraint. We have the Lagrangian equation:

\[
L = \int [y - P(y) + \rho K(w(y))] f(y, a) dy \\
+ \lambda \left( \int [u(P(y)) + \rho w(y)] f(y, a) dy - \phi(a) - v \right) \\
+ \mu \left( \int [u(P(y)) + \rho w(y)] f_a(y, a) dy - \phi'(a) \right) \quad (9)
\]

Take first order conditions w.r.t \( P(y), w(y) \) and \( a \), we get the following first order conditions and the envelope condition:

\[
\{ P(y) \} \quad -1 + \lambda u'(P(y)) + \mu u'(P(y)) \frac{f_a(y, a)}{f(y, a)} = 0 \quad (10)
\]

\[
\{ w(y) \} \quad \rho K'(w(y)) + \rho \lambda + \mu \rho \frac{f_a(y, a)}{f(y, a)} = 0 \quad (11)
\]

\[
\{ a \} \quad \int [y - P(y) + \rho P(w(y))] f_a(y, a) dy \\
+ \mu \left[ \int [u(P(x)) + \rho w(y)] f_{aa}(y, a) dy - \phi''(a) \right] = 0 \quad (12)
\]

\[
\{ ENV \} \quad K'(v) = -\lambda \quad (13)
\]

First order conditions (10) and (11) implies:

\[
\frac{1}{w'(P(y))} = -K'(w(y)) = \lambda + \mu \frac{f_a(y, a)}{f(y, a)} \quad (14)
\]

Definition: MLRP (monotone likelihood ratio property)
- Likelihood ratio $\frac{f\alpha(y,a)}{f(y,a)}$ is monotone in $y$ or $\frac{dy}{dy} \frac{f\alpha(y,a)}{f(y,a)} \geq 0$. This also implies: $\forall a > \tilde{a}, y > \tilde{y}, f(y,a) \leq f(\tilde{y},a)$. Intuitively, this means at a higher effort level $a$, it is more probable to get a higher benefit $y$ than at a lower effort level $\tilde{a}$.

Rogerson(1085)[16] shows that when the density function $f(y,a)$ has monotone likelihood ratio property, $\mu$ the multiplier on (IC) constraint is positive.

When MLRP holds, $\mu > 0$, equation (14) implies the following results:

**Result 1** $y \uparrow \Rightarrow \frac{1}{w'(P(y))] \uparrow \Rightarrow P(y) \uparrow$.
Reason: $u''(P(y)] \leq 0$

This result suggests contacts should be performance-based, i.e. payment to MSSP should be higher when benefit from security outsourcing increases and vice versa. And this supports empirical result of Lacity and Willcock(1998)[11].

**Result 2** $y \uparrow \Rightarrow K'(w(y)) \downarrow \Rightarrow w(y) \uparrow$
Reason: $K(w(y))$ is best possible payoff of buyer next period when MSSP’s expected payoff is $w(y)$. Since MSSP’s payoff comes from compensation $P(y)$ from buyer, the higher MSSP’s payoff $w(y)$ is, the lower buyer’s payoff $K(w(y))$ will be.

This result suggests buyer should reward MSSP with higher expected payoff for next period if buyer gets high benefit this period.

**Result 3** $v \uparrow \Rightarrow \lambda \uparrow \Rightarrow P(y), w(y) \uparrow$
Reason: $v \uparrow \Rightarrow \lambda \uparrow$ from the envelope condition (ENV). $\lambda \uparrow \Rightarrow P(y), w(y) \uparrow$ follows from equation (14).

This result shows that if buyer promise MSSP a higher current expected payoff, buyer should increase both current period compensation and next period promised expected payoff.

To sum up, from Result 1 - 3, we suggest that optimal contract under moral hazard should depend on performance in a non-trivial way. And effect of performance is persistently on future compensations. The effect is carried over by promised value $v$ and $w(y)$ as shown in Result 2 and 3.

**4.2 Optimal contract with perfect information  — price only contract**

With perfect information, buyer can monitor MSSP’s behavior very well. Then MSSP is not able to shirk and moral hazard problem does not exist. In this scenario, Maximization problem of buyer[5] reduces to:

$$K(v) = \max_{P(y),w(y),a} \int [y - P(y) + \rho K(w(y))] f(y,a) dy$$
$$\text{st} \int [u(P(y)) + \rho w(y)] f(y,a) dy - \phi(a) \geq v$$  \hspace{1cm} (PK) (15)

Corresponding first order conditions are:

$$\{P(y)\} -1 + \lambda u'(P(y)) = 0$$  \hspace{1cm} (16)
\{w(y)\} \quad \rho K'(w(y)) + \rho \lambda = 0 \quad (17)

\{a\} \quad \int [y - P(y) + \rho P(w(y))] f_a(y, a) dy = 0 \quad (18)

\{ENV\} \quad K'(v) = -\lambda \quad (19)

Equation 16 and 17 imply:

\[ \frac{1}{u'(P(y))} = -K'(w(y)) = \lambda \quad (20) \]

This suggests that without moral hazard problem, optimal compensation and next period promised value does not depend on this period’s outcome \( y \). Constant compensation and promised value would be optimal.

4.3 Effect of transaction cost

4.3.1 Effect from game between buyer and MSSP

In this section, we will study how transaction cost affects equilibrium market price. No matter whether buyer has perfect information about MSSP’s effort level or not, existence of transaction cost reduces buyer’s compensation to MSSP.

As in section 4.1, we use \( P(y) \) to denote buyer’s compensation to MSSP. Since buyers will also need to pay transaction cost on top of service price, the actual out of pocket price buyers of MSSP face is \( (1 + \alpha) P(y) \), where \( \alpha P(y) \) is the transaction cost.

With transaction cost, we modify the maximization problem of buyer as:

\[
K(v) = \max_{P(y), w(y), a} \int [y - (1 + \alpha) P(y) + \rho K(w(y))] f(y, a) dy \\
\text{st} \quad \int [u(P(y)) + \rho w(y)] f(y, a) dy - \phi(a) \geq v \quad \text{(PK)} \\
a \in \arg \max \int [u(P(y)) + \rho w(y)] f(y, a) dy - \phi(a) \quad \text{(IC)} \quad (21)
\]

Corresponding first order conditions are:

\{P(y)\} \quad -(1 + \alpha) + \lambda u'(P(y)) + \mu u'(P(y)) \frac{f_a(y, a)}{f(y, a)} = 0 \quad (22)

\{w(y)\} \quad \rho K'(w(y)) + \rho \lambda + \mu \rho \frac{f_a(y, a)}{f(y, a)} = 0 \quad (23)

\{a\} \quad \int [y - P(y) + \rho P(w(y))] f_a(y, a) dy \\
+ \mu \int [u(P(x)) + \rho w(y)] f_{aa}(y, a) dy - \phi''(a) = 0 \quad (24)

\{ENV\} \quad K'(v) = -\lambda \quad (25)

\footnote{transaction cost is modelled as a percentage of contract value because as the project gets larger, buyer and vendor need to spend more time and money on the negotiation and coordination part \cite{Barthelemy(2001)2}. A Survey done by Barthelemy(2001)\cite{Barthelemy(2001)2} shows that transaction cost is up to 6\% for contracts lower than $10 million value}
From first order conditions (22) we have
\[ \frac{1 + \alpha}{u'(P(y))} = \lambda + \mu \frac{f_a(y, a)}{f(y, a)} \] (26)

Similarly, under perfect information, we have:
\[ \frac{1 + \alpha}{u'(P(y))} = \lambda \] (27)

Compare with equation (14) and equation (20), it can be implied that all other things same, compensation \( P(y) \) is smaller with transaction cost.

4.3.2 Effect from game among MSSPs

Another effect of transaction cost on market price comes from competition among MSSPs. This effect also suggests when transaction cost increase, nominal market price will decrease.

- A3: Vendors engage in a price competition against each other.

We will derive the Nash Equilibrium\(^8\) price under the assumption A1-A3. For this section, to see effect of MSSPs’ competitions, we ignore effect of buyers, and assume perfect information(as shown in section 4.2), optimal contract specifies a non-performance-dependent price, \( P(y) \) is replaced with \( P \). We will show that MSSPs will lower price to bear part of the transaction cost due to competition with other MSSPs. Division of the transaction cost between buyers and vendors depends on demand elasticity for security products.

A price competition is where every MSSP uses price as a strategic variable, and is free to choose a price that maximizes their profit given price of other vendors. Explicitly, profit maximization problem for vendor i is:
\[
\max_{P^i} \{ P^i \cdot N^i((1 + \alpha)P) - C^i(N^i((1 + \alpha)P)) \}
\]

\( P \) denotes the price vector \( \{P^i, i = 1, \ldots, V\} = \{P^i, P^{-i}\} \), where \( P^i \) is market price MSSP\( i \) charges. \( P^{-i} \) is the price vector of prices of all other MSSPs except MSSP\( i \) charges. \( N^i \) is demand for MSSP\( i \)'s service, which depends on market prices. It also depends on service quality MSSPs provide implicitly. \( C^i \) is MSSP\( i \)'s total cost of servicing \( N^i \) customers. Then the above maximization problem shows how MSSP\( i \) maximize its net profit(revenue minus cost) by choosing \( P^i \) when other vendors charge price \( P^{-i} \).

\( C^i \) includes both fixed cost(\( FC \)) which does not change with number of customers and variable cost(\( VC \)) which does. Explicitly,
\[ C^i(N^i(\cdot)) = FC + VC(N^i(\cdot)) \] (28)

\( C(\cdot) \) increases with number of customers.

\(^8\)A strategy vector \( x \) with payoff vector \( \pi \) is called a Nash Equilibrium if \( \pi_i(x_i, x_{-i}) \geq \pi_i(\tilde{x}_i, x_{-i}), \forall \tilde{x}_i \in X_i, \forall i \). \( X_i \) is set of all possible actions player \( i \) can take. This condition means that Nash Equilibrium is such that no player can benefit from unilateral deviations.
Optimal price MSSP\textsubscript{i} should charge solves the following first order condition of the maximization problem w.r.t \(P\):

\[
N^i(\cdot) + P^i \frac{\partial N^i(\cdot)}{\partial P^i} (1 + \alpha) = C'(N^i(\cdot)) \frac{\partial N^i(\cdot)}{\partial P^i} (1 + \alpha)
\]

(29)

Divide both sides of equation (29) with \(\frac{\partial N^i(\cdot)}{\partial P^i} (1 + \alpha)\) and rearrange terms, we get:

\[
P^i (1 - \frac{1}{\eta^i (1 + \alpha)}) = C'(N^i(\cdot)) \quad i = 1, \ldots, V
\]

(30)

where \(\eta^i = -\frac{(\partial N^i(\cdot)/N^i)/(\partial P^i/P^i)}{\partial P^i/P^i}\), which represents percentage change in demand due to percentage change in price, the price elasticity of vendor i’s demand. It measures how sensitive market demand changes with price. Because \(\frac{\partial d(\cdot)}{\partial (P)} < 0\) (demand and price move in opposite directions), a negative sign is added so that \(\eta > 0\).

solving \(P^i\) from optimizing condition (30), \(P^i\) is a function of \(P^{−i}\), \(\alpha\) and \(\eta\):

\[
P^i = r(P^{−i}, \alpha, \eta)
\]

(31)

Equation (31) can be viewed as response function of MSSP \(i\) on prices of other security MSSPs \(P^{−i}\). Therefore, for all MSSPs on the market, \(i = 1, \ldots, V\), we can form a equation system:

\[
P^1 = r(P^{−1}, \alpha, \eta),
P^2 = r(P^{−2}, \alpha, \eta),
\ldots
P^V = r(P^{−V}, \alpha, \eta)
\]

(32)

The Nash Equilibrium of this price competition is a price vector (strategies) that solves the above equation system and a corresponding vector of profit (payoffs). Under regularity conditions, this equilibrium price vector exists and is unique\textsuperscript{14}.

To give an idea how this Nash Equilibrium price look like, we present a graphic solution for the simplified case when \(V = 2\). Then optimization conditions (32) reduce to the following:

\[
P^1 = r(P^2, \alpha, \eta)
P^2 = r(P^1, \alpha, \eta)
\]

(33)

To make things easier, we make two more assumptions:

\begin{itemize}
  \item A4. Marginal cost \(C'_i(\cdot)\) is constant, i.e. it costs MSSP \(i\) same amount of money to serve one additional buyer.
  \item A5. \(\frac{\partial \eta^i}{\partial (P^i/P^{−i})} > 0\), meaning, as MSSP \(i\)’s service becomes more expensive relative to services of other MSSPs, demand for MSSP \(i\)’s service become more elastic. In other word, a same percentage increase in \(P^i\) will induce greater percentage reduction in \(N^i\) for higher \(P^i/P^{−i}\) then lower.
\end{itemize}
Two response curves $P^i = r(P^{-i}, \alpha, \eta), i = 1, 2$ are plotted in figure 1 where the horizontal axe represent MSSP 1’s price and the vertical axe represent MSSP 2’s price. Under A4 and A5, Feenstra[8] showed that both reaction curves have positive slopes. Then slope of MSSP 1’s response curve is larger than slope of that of MSSP 2’s as shown in Fig 1(a).

Because response curve is the locus of MSSP’s best responses given the other MSSP’s action, the intersection point E is the equilibrium point where both MSSPs are choosing optimally and simultaneously. By definition, they are the Nash Equilibrium prices. Observe that this Nash Equilibrium is a stable equilibrium in the sense that no matter what price the MSSPs start off with, they will eventually arrive at point E, as shown by the arrows in Fig 1(a).

Denote price vendor $i$ would charge by $P^i_0$ when there is no transaction cost($\alpha = 0$), from equation system (33),

$$P^i_0 = r(P^{-i}, \alpha = 0, \eta), i = 1, 2$$

(34)

Totally differentiate optimization condition (30),

$$dP^i(1 - \frac{1}{\eta^i(1 + \alpha)}) + P^i \frac{d\eta^i}{\eta^i(1 + \alpha)^2} + P^i \frac{d\alpha}{\eta^i(1 + \alpha)^2} = C''(N(\cdot))$$

(35)

By A4

$$C''(N(\cdot)) = 0$$

(36)

Equation (35) implies:

$$dP^i(1 - \frac{1}{\eta^i(1 + \alpha)}) + \frac{d\eta^i/P^i}{\eta^i(1 + \alpha)^2} = -P^i \frac{d\alpha}{\eta^i(1 + \alpha)}$$

(37)

Assume:
• A6. \( \frac{d\eta^i}{dP^i/P^i} > 1 - \eta^i(1 + \alpha) \)

Under assumption (4.3.2),

\[
1 - \frac{1}{\eta^i(1 + \alpha)} + \frac{d\eta^i}{dP^i/P^i} > 0
\]

Equation (38) implies

\( d\alpha > 0 \Rightarrow dP^i < 0 \) (39)

This shows that when transaction cost increases, MSSPs reduce their prices correspondingly. Graphically, the reaction curve \( P^1 = r(P^2, \alpha, \eta) \) shifts to the left and \( P^2 = r(P^1, \alpha, \eta) \) shifts down, therefore, compare with the reaction curves when there is no transaction cost. As shown in Figure 1(b), reaction curves with transaction cost intersect at lower price level for both MSSPs. Remember that the intersection of reaction curves is the Nash Equilibrium of the game.

As shown above, under assumptions 1-6, existence of transaction cost reduces prices charged by MSSPs. The extend of reduction depends on how sensitive market demand is to prices.

5 Related Work

5.1 Empirical Work

Empirical works on this issue were mostly done with surveys. Ang and Straub (1998) performed a well designed survey on banks of different sizes with items measuring degree of IT outsourcing, production cost advantage, transaction cost, financial slack (archive data also used here) outsourcing degree and firm size. And they found that production cost advantage is the main driving force of IT outsourcing, transaction cost dampens outsourcing intention, but has a much smaller effect. They also reported evidence that degree of IT outsourcing decreases with firm size. They argued that this is because large firms are more likely to generate economies of scale in their IT department, therefore are more likely to produce IT services in-house. Lacity and Willcocks (1998) measures success or failure of a IT outsourcing based on seven factors, and found that outsourcing scope, length of contract term, contract type are among the most important factors that decides how successful an IT outsourcing is. Poppo and Zenger (1998) includes technological uncertainty, measurement difficult and quality satisfaction in their model, and showed that when it is harder to measure performances, firm become less satisfied with costs. Ang and Cummings (1997) found empirical evidence that in hyper-competitive environments, not only firms act strategically, but security vendors also.

5.2 Analytical Work

Analytical papers on the other hand have a strong game theoretic flavor. Mieghem (1999) built a multivariate, multidimensional competitive model, and investigated effect of subcontracting complexity on coordination.

Ang and Cummings argued that organizations respond strategically under hyper-competitive environments. Whang employed a game theoretical approach to explain asymmetric information and incentive compatible issue in software development.
6 Conclusion

Security outsourcing market benefits both vendors and buyers if it works properly. In the first place, security outsourcing offers cost reduction for buyers. We showed that for security outsourcing, optimal form of contract should be performance-based. Also, we showed that with transaction cost, price paid to MSSPs are lower than otherwise. MSSPs take part of the transaction cost to stimulate demand.

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