Management the risks of outsourcing: Time, quality and correlated costs

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A B S T R A C T
Cost, quality and time to market are three main factors for outsourcing management. A game theoretic model is used to design optimal outsourcing contracts including these three factors for a buyer and a supplier under Full Information (F) case and Asymmetric Information (A) case where the buyer does not share her internal variable cost information with the supplier. Optimal outsourcing contracts are derived and results of numerical experiment are also presented. Several insights of managing the outsourcing risks due to the Asymmetric Information are given for various industries, like cost-sensitive industry, time-sensitive industry, and quality-sensitive industry.

1. Introduction

With the market becoming more competitive, many companies focus on improving the efficiency of operations and logistics management. Outsourcing is currently being used as an important strategy by many companies in the US to focus on the core competency, reduce cost and increase profit. Besides the cost savings, outsourcing has some other advantages, including decreasing the time to market and increasing the quality of work. If a company does not have skills or expertise for a certain work, outsourcing or working with a supplier is one of best strategies. The supplier can help the buyer company to reduce the product development time and logistics time, like faster start-up, development and scalability for new operations. Accenture and Procter & Gamble’s (P&G) won 'Most Innovative' Outsourcing Excellence Award in 2013. According to Accenture, Marco Ziegler, a managing director from Accenture states that Accenture "is helping P&G realize greater agility and flexibility in the front office and enabling it to meet its changing business needs more effectively, drive improved productivity and innovation, accelerate the start-up of new services and realize lower IT costs." Wang et al. (2015) point out that outsourcing is one of effective ways to improve the service supply chain management. But the outsourcing is not a trouble free solution. The outsourcing strategy has proven to be an effective way to reduce the cost and shrink the time-to-market but brings with it significant quality risks that must be recognized and properly managed.

All three important outsourcing factors of cost saving, market time reduction, and quality assurance need to be addressed simultaneously when discussing the outsourcing management. These three factors are often competing constraints. Increased quality typically means increased time and increased cost; a market time reduction constraint could mean increased costs and reduced quality; and a cost saving could mean increased market time and reduced quality. In this
research, we study that a supplier and a buyer initialize an outsourcing relationship and need to sign an outsourcing contract before establishing a long term trust outsourcing relationship. Hence, managing a new outsourcing work is like managing a new project that a set of activities need to be completed within the constraints of cost, quality, and time. Project Management Triangle model (PMI, 2013) recognizes three key constraints, cost, time, and scope (quality), for a project. Here we see the need to discuss the cost, time, and quality simultaneously in the outsourcing management.

In outsourcing, a firm is relying on a third party to run certain business functions, like producing products or offering services. The third party may hold some private information. The Asymmetric Information creates uncertainty for decision making and hence increases the supply chain risks. If not properly managed, the firm might negatively affect its performance. One of the major concerns is the quality of outsourcing work. If the outsourcers cannot get the expected quality level, the company may decide to stop outsourcing in most cases. Dell stopped routing corporate customers to a technical support call center in India because of quality issues in 2003. The quality of the particular call center was unsatisfactory leading to corporate customers’ dissatisfaction. To avoid getting hurt, Dell promptly decided to channelize those calls to a higher quality onshore center. Individual customers, on the other hand, got shifted to the lower-cost offshore centers (Hallett, 2004).

Gadde and Hulthen (2009) shows that many companies have taken outsourced functions back in-house to ensure the quality of products or services. This shows that quality of outsourcing work, in addition to outsourcing price and time-to-market, plays an important role in outsourcing decisions.

In this research, we consider a company, or a buyer, that outsources part of its works to a supplier in order to reduce the cost, time-to-market, and maintain a certain level of outsourcing quality. We use a game theoretic model to design the optimal contracts between the buyer who seeks outsourcing and the supplier under a Full and an Asymmetric Information case. Asymmetric Information is more like real business scenario where the buyer does not share her internal variable cost information with the supplier. Asymmetric Information creates decision making under information risks. We discuss the risks of outsourcing management by comparing Full Information and Asymmetric Information case. The expected loss due to Asymmetric Information could be viewed as the expected information risks that are measured by the difference of Asymmetric Information and Full Information.

2. Literature survey

Outsourcing has been widely used, from manufacturing outsourcing (Tsai et al., 2007), call center outsourcing (Gans and Zhou, 2003, 2007; Aksin et al., 2008), IT outsourcing (Gopal et al., 2003; Kalnins, 2004; King and Torkzadeh, 2008), to Business Process Outsourcing (Kenion, 2005). Researchers study outsourcing from various aspects. Tsai et al. (2007) study cost savings from remanufacturing outsourcing decision by integrating the Activity-Based Costing (ABC) approach. Ho and Zheng (2004) develop a market share model to study how a firm might choose a delivery-time commitment to influence its customer expectation, and delivery quality in order to maximize its market share. Li et al. (2009) develop a model for ride service outsourcing. Hsiao et al. (2010) study the logistics outsourcing focus on service benefits. Tsai et al. (2012) study the dark side of logistics outsourcing. Kouvelis and Mukhopadhyay (1999) use a duopolistic non-cooperative game theoretic framework to study the design quality competition in a durable product market. Dixit (2003) uses moral hazard model and Lizzieri (1999) focuses on adverse selection to study quality competition under Asymmetric Information.

Outsourcing increases the complexity of global supply chain. Meixell and Gargeya (2005) review decision support models for the design of global supply chains and outsourcing network, and assess the fit between the research literature and the practical issues. Zhen (2014) studies an integrated optimization problem on outsourcing and production decisions in the context of the global supply chain. Reeves et al. (2010) report on an empirical study that examined a suite of outsourcing distribution and logistics services within the automotive supplier industry.

Outsourcing can be used to reduce the product deliver time and the logistic time. Sheu (2007) discusses an emergency logistics distribution approach for quick response to relief demand in disasters. Logistic outsourcing could be used in a quick response systems. Tsai et al. (2012) identify and empirically examine the potential risk factors and their structural relationships that can cause a logistics outsourcing relationship to fail. De Mello Bandeira et al. (2015) adopt an empirical approach using qualitative and quantitative techniques to propose a set of factors that affects the logistics outsourcing decision-making process in the Brazilian context, as well as the level of importance attributed to each decision factor.

Supply Chain Risks Management became one of important research topics for many years. Many different types of supply chain have been studied. Nagurney and Toyasaki (2005) study the reverse supply chain. Sheu and Talley (2011) review the green supply chain. Nagurney and Matsypura (2005) study the risks in global supply chain. Yue et al. (2010) study a make-to-order manufacturer in the sourcing selection process. Their research provides a decision model to develop a portfolio allows the manufacturer to make trade-offs between cost and reliability to finish the job on time. Dong and Tomlin (2012) discuss how to manage the disruption risk by study the interplay between operations and insurance. Researchers use various approaches to mitigate or manage the supply chain risks. Chiu and Choi (2013) give an extensive review of using mean–variance models to manage the supply chain risks. Sheu (2010) uses a dynamic relief-demand management model to study emergency logistics operations under imperfect information conditions in large-scale natural disasters. Mishra et al. (2009) propose to share the demand forecast information to improve the supply chains. Choi (2011) uses a new technology RFID (Radio-frequency identification) to reduce the risks in VMI (Vendor-managed inventory) and hence to coordinate the whole supply chain. Zeng and Xia (2015) study a purchasing firm work with its backup supplier in cases of primary supply
disruptions. They use a decision-tree approach to find the Nash equilibrium contract parameters, and identify the critical conditions under which such a contractual partnership will be valuable and hence reduce the supply risks.

Asymmetric information increases the supply chain risks and complexity in contract design. Asymmetric information exists in many different types of supply chain. Sheu (2011) uses asymmetrical Nash bargaining game to study a problem of negotiations between producers and reverse-logistics (RL) suppliers for cooperative agreements under government intervention. Mukhopadhyay et al. (2008) study the Asymmetric Information issue in a mixed channel setting. Kong et al. (2013) investigate information leaking under a one supplier–two reseller setting. Li et al. (2014) study the impact of Asymmetric Information on the supplier’s and the retailer’s performance when the supplier launch its direct sale channel. Ye et al. (2013) explore the impact of Asymmetric Information on the capacity decision. Zhu and Mukhopadhyay (2009) study the quality management for outsourcing contract with buyer’s cost Asymmetric Information. Several researchers study the information sharing problem in Asymmetric Information. Xu et al. (2015) examine the timing of information sharing of supply chain demand collaboration between a manufacturer and a retailer. This research indicates that early collaboration as in the ‘Too Little’ mechanism leads to a stable production schedule and whereas a late collaboration as in the ‘Too Late’ mechanism enhances the flexibility of production adjustment when demand information warrants it. Ha et al. (2011) study the incentives of sharing Asymmetric Information within two competing supply chains.

Though outsourcing risk has been extensively researched in literature, relatively few have studied multiple factors simultaneously in outsourcing. Most research mainly focus on one of the aspects of outsourcing, either cost reduction (Tsai et al., 2007; Kenion, 2005), time saving (Zhu et al., 2014), or quality management (Zhu and Mukhopadhyay, 2009; Ye et al., 2014). As we have discussed earlier in section one, these three factors are competitive constraints. Changing one of the factors will affect the other two factors. We see the need to study these three factors simultaneously in the outsourcing management. In contrast to any of the above research streams, our paper discusses the outsourcing risks management from three major factors of cost, quality and time that simultaneously impact the decision making in outsourcing contract design. This is one of the contributions of this research to the existing literature.

3. The model

The outsourcing model we consider in this paper consists of a buyer company who is the outsourcer and a supplier to whom the outsourcing firm outsource her works. Fig. 1 shows a representation of this model. We consider a Stackelberg game where the supplier acts as a leader and the buyer acts as a follower. First, the supplier decides the unit outsourcing price $s$, the launch time of outsourcing product/service $t$, and the quality of outsourcing product/service $Q$. Then the buyer announces the retail price $p$ to the final customers. The decision variables in our model are outsourcing price $s$, launch time $t$, and outsourcing quality $Q$ for the supplier and retail price $p$ for the buyer, each maximizing his or her own profit functions. We will focus on studying the relationships among the competitive outsourcing factors, including the prices, the launch time, and the outsourcing quality. This paper attempts to develop an outsourcing contract which can be used for decision making under Asymmetric Information and managing the information risks in outsourcing management. Table 1 gives a summary table of all the parameters and variables used in this research.

3.1. Demand function

$$d = a - bp - rt + eQ$$

where $a > 0$, $b > 0$, $r > 0$, and $e > 0$ are known parameters. As we see that the demand $d$ is decreasing in retail price $p$ and time to market (outsourcing time) $t$, and increasing in the quality of outsourcing product/service $Q$. $a$ is the base demand. $b$ is the retail price elasticity. $r$ is the sensitivity of outsourced work with respect to the time to market. $e$ is the sensitivity parameter of outsourced work with respect to the quality of outsourcing work. From the demand function, we can see that the demand

![Fig. 1. Outsourcing system.](http://dx.doi.org/10.1016/j.tre.2015.06.005)
Table 1
A summary of all the parameters and variables used in this research.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(d)</td>
<td>Market demand function</td>
</tr>
<tr>
<td>(a)</td>
<td>Base demand, known parameter</td>
</tr>
<tr>
<td>(b)</td>
<td>Retail price elasticity, known parameter</td>
</tr>
<tr>
<td>(p)</td>
<td>Retail price, Buyer's decision variable</td>
</tr>
<tr>
<td>(r)</td>
<td>Sensitivity of outsourced work with respect to the time to market, known parameter</td>
</tr>
<tr>
<td>(t)</td>
<td>Time to market (outsourcing time), Supplier's decision variable</td>
</tr>
<tr>
<td>(e)</td>
<td>Sensitivity of outsourced work with respect to the quality of outsourcing work, known parameter</td>
</tr>
<tr>
<td>(Q)</td>
<td>Quality of outsourcing product/service (Q), Supplier's decision variable</td>
</tr>
<tr>
<td>(\pi_s)</td>
<td>Supplier's profit function</td>
</tr>
<tr>
<td>(\pi_s, \pi_s)</td>
<td>Supplier's reserved profit value, known parameter</td>
</tr>
<tr>
<td>(s)</td>
<td>Outsourcing price, Supplier's decision variable</td>
</tr>
<tr>
<td>(c)</td>
<td>Supplier's variable cost, known parameter</td>
</tr>
<tr>
<td>(L)</td>
<td>Measure the outsourcing cost regarding to outsourcing time, known parameter</td>
</tr>
<tr>
<td>(T)</td>
<td>Pessimistic estimate outsourcing time, known parameter</td>
</tr>
<tr>
<td>(t)</td>
<td>Outsourcing time, Supplier's decision variable</td>
</tr>
<tr>
<td>(K)</td>
<td>Measure the outsourcing cost regarding to outsourcing quality, known parameter</td>
</tr>
<tr>
<td>(\pi_b)</td>
<td>Buyer's profit function</td>
</tr>
<tr>
<td>(\pi_b)</td>
<td>Buyer's reserved profit value, known parameter</td>
</tr>
<tr>
<td>(m)</td>
<td>Buyer's variable cost, unknown to the supplier under (A) asymmetric case</td>
</tr>
<tr>
<td>(f(m), F(m))</td>
<td>Prior density function of (m) and cumulative distribution of (m)</td>
</tr>
<tr>
<td>([m, M])</td>
<td>The range of (m), known parameters</td>
</tr>
</tbody>
</table>

\(d\) will decrease with retail price \(p\) and time to market \(t\) but increase with quality of outsourcing work \(Q\). We can also see that the retail price \(p\) is decreasing with time to market and increasing with quality of outsourcing work \(Q\). Similar linear demand functions can be found in Banker et al. (1998) and Gavious and Lowengart (2012). Time to market and quality are important factors to impact the retail price, market share and revenue. Taking time and quality simultaneously into consideration of the demand function is the one of the major contributions for this research.

### 3.2. Profit functions

The supplier’s profit function is:

\[
\pi_s = (s - c)d - \frac{L}{2} \left( \frac{T - t}{T} \right)^2 - \frac{K}{2} Q^2 \quad \text{or} \quad \pi_{S_m}
\]  

(2)

The supplier receives \(s\) from the buyer for each unit of outsourcing work. The costs for offering outsourcing work include variable cost \(c\) per unit, fixed cost \(\frac{L}{2} \left( \frac{T - t}{T} \right)^2\) on launch time, and fixed cost \(\frac{K}{2} Q^2\) on quality. The fixed cost includes the wage for the supplier’s employees, cost of utilities and equipment, cost of training of employees, and other costs. \(T\), pessimistic estimate outsourcing time, is the maximum time required for completing outsourcing work under adverse conditions. \(t\), the span of completing outsourcing work or outsourcing time, is the decision variable for the supplier. \(T - t\) is the time saving. \(t/L\) is the ratio of time saving. \(L\) is a parameter to measure the outsourcing cost regarding to outsourcing time. We assume that the fixed cost decreasing in time of completing outsourcing work. The faster the supplier completes the outsourcing work, the higher the fixed cost is. We also assume that the quality cost is increasing in the level of quality offered represented by a quadratic function given by \(\frac{K}{2} Q^2\). \(K\) is a parameter to measure the outsourcing cost regarding to outsourcing quality. \(c, T, L, \) and \(K\) are common knowledge. We assume quadratic fixed cost functions for the launch time and quality. Note that we have defined \(\frac{K}{2} Q^2\) as per unit quadratic cost to capture the phenomenon that adding a large quantum of quality \(Q\) are proportionately more costly than adding minimal amount of quality \(Q\). Same reasoning can be applied to quadratic cost function on launch time, \(\frac{L}{2} \left( \frac{T - t}{T} \right)^2\). Similar quadratic cost functions are extensively used in the existing literature, including Kouvelis and Mukhopadhyay (1999), Mukhopadhyay et al. (2008), Zhu and Mukhopadhyay (2009) and etc.

The buyer’s profit function is:

\[
\pi_b = (p - s - m)d \quad \text{or} \quad \pi_{B_m}
\]

(3)

The profit margin for each outsourcing work is decided by using retail price \(p\) subtracted by outsourcing price \(s\) and buyer's internal variable cost \(m\). We assume that \(p - s - m > 0\). \(m\) is a private information of the buyer. In general, the supplier does not know \(m\). The buyer assumes the supplier holds a prior cumulative distribution \(F(m)\) with density function \(f(m)\), defined on \([m, M]\), where \(0 \leq m \leq M \leq \infty\). We will further discuss this Asymmetric Information scenario in the later section of “Contracts under Asymmetric Information (A)”.

The supplier and the buyer will maximize his or her function. Both of the supplier and the buyer have a reservation profit level which they intend to achieve in order for a trade to take place. A reservation profit level of a party is defined as the minimum level of profit the party needs to accept any contract. The reservation profit levels of the supplier and the buyer...
are \( \pi_s \) and \( \pi_b \), respectively. Buyer's profit \( \pi_b \) will drop to her reservation profit \( \pi_{br} \) for a certain value of \( m \) called \( M \), the cut-off point. At this point, the buyer will stop trading with the buyer. The supplier will refuse to trade with the buyer if his profit is below \( \pi_c \). Ha (2001) shows that including the cut-off point in the contract is indeed optimal.

4. The contracts

We model this outsourcing problem using Stackelberg game, which is typically played in two stages. In the first stage, the supplier, as the game leader, announces the outsourcing price, outsourcing time, and outsourcing quality. In the second stage, the buyer, the game follower, announces the retail price. We will study two kinds of contract: contract under Full Information (F), and under Asymmetric Information (A). Under (F), the supplier knows the buyer’s internal cost \( m \) and designs the contract taking \( m \) as common knowledge to maximize his own profit. Under (A), the supplier does not know the buyer’s \( m \) and designs the contract using prior density function \( f(m) \) and cumulative distribution \( F(m) \) defined on \([m, \infty)\).

4.1. Contracts under Full Information (F)

In this scenario, the buyer agrees to share her private variable cost information \( m \) to the supplier. The moves of buyer and supplier follow a Stackelberg type game. The supplier acts as the leader, announcing the \( s, t \) and \( Q \) first; the buyer acts as the follower, announcing the \( p \) after that. The solution of this game follows.

Before the first stage of the game where the supplier announces the values of his decision variables, the buyer’s best response function, as functions of the supplier’s variables, needs to be determined. This is done by maximizing her profit \( \pi_b \) with respect to her decision variable \( p \). Lemma 1 gives the buyer’s best response function, as functions of \( s, t \) and \( Q \). Proofs of Proposition 1.1 and Proposition 2.1 are shown in the Appendix A.

**Lemma 1.** Buyer’s best response function in terms of the Supplier’s parameters is given as: \( p^{BR} = -\frac{-a + tr - eQ - bsL}{\theta_0} \)

Next, in stage 1 of the game, the supplier derives the optimal \( s, t \) and \( Q \) by maximizing his own profit \( \pi_s \), given in Eq. (2), and substituting the optimum values of \( p \) with \( p^{BR} \) thus making it a function of \( s, t \) and \( Q \) alone. Using the first order conditions, we obtain the supplier’s optimal policies \( s_F, t_F \) and \( Q_F \) in Proposition 1.

In Stage 2 of the game, the buyer uses the supplier’s policy announcement of \( s_F, t_F \) and \( Q_F \), and maximizes her own profit function to obtain the optimal policies \( p_F \) in Proposition 1.

The supplier acts as a leader and announces his decision variables the unit outsourcing price \( s \), the launch time of outsourcing product/service \( t \), and the quality of outsourcing product/service \( Q \) first. Then the follower buyer will decide her decision variable after he knows the supplier’s decision variables’ values. The game follower buyer actually has an information advantage of knowing the supplier’s decision before she makes her decision. The buyer also has a power to decide who makes the decision first and who makes the decision next. Since the buyer has the advantages from making the decision after the supplier, she can let the supplier make his decision first (being a Stackelberg leader) and herself being a Stackelberg follower.

**Proposition 1.**

(a) The supplier gets the following equilibrium outsourcing price \( c \), outsourcing time, and outsourcing quality level \( Q \), and buyer gets the equilibrium retail price \( p \) as follows:

\[
\begin{align*}
\text{s}_F &= \frac{-2aLK + T^2r^2Kc + 2TrLK + 2bmlK - 2bLK + e^2L}{4bKL - T^2r^2K - e^2L} \\
\text{t}_F &= \frac{T(-TrK + TrbKm + TrcKb + 4bLK - e^2L)}{4bKL - T^2r^2K - e^2L} \\
\text{Q}_F &= \frac{-L(-a + Tr + bm + bc)e}{4bKL - T^2r^2K - e^2L} \\
p_F &= \frac{-3Kal + r^2T^2Km + r^2T^2Kc + 3TrKL + e^2Lm + e^2Lc - bKmL - bKcl}{4bKL - T^2r^2K - e^2L}
\end{align*}
\]

(b) The profits of the buyer and the supplier are:

\[
\begin{align*}
\pi_{BF} &= \frac{K^2L^2(-a + Tr + bm + bc)^2b}{(4bKL - T^2r^2K - e^2L)^2} \\
\pi_{SF} &= \frac{KL(-a + Tr + bm + bc)^2}{2(4bKL - T^2r^2K - e^2L)}
\end{align*}
\]

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4.2. Contracts under Asymmetric Information (A)

In this scenario, the supplier typically does not know the buyer’s internal variable cost m. As noted earlier, we assume that the supplier only knows the prior density function f(m) and cumulative distribution F(m). f(m) and F(m) are defined on [m, M]. The supplier acts as a leader, proposing outsourcing unit price s, finish time t, and quality of outsourcing level Q without knowledge of m. The buyer acts as the follower, announcing retail price p after that. The supplier offers a contract to the buyer which is a menu of (s, t, Q) meaning that it offers a number of alternative values for this contract. The buyer has a choice of not accepting the contracts but earning her reserved profit π_A, if none of the alternatives are attractive enough to her. Or she may select one alternative from the menu and decides to accept that. In the next proposition, we derive the equilibrium outsourcing price, outsourcing time, outsourcing quality level, and retail price for the buyer and supplier under Asymmetric Information in the next proposition.

**Proposition 2.** The optimal contract under Asymmetric Information can be found as follows. Find a contract menu (s_A, t_A, Q_A) that satisfies the following equations:

\[
\left( \frac{x^2 - b + \frac{eQ}{2}}{2} \right) + \left( \frac{M f(m) dm}{F(m)} \right) - \left( \frac{m f(m) dm}{F(m)} \right) = \left[ (s - c) - \left( \frac{a - b}{2b} \right) \left( \frac{\text{er} + \frac{b + \frac{eQ}{2}}{2}}{2} \right) \right] - \left( \frac{\text{er} + \frac{b + \frac{eQ}{2}}{2}}{2} \right) \left( \frac{\text{er} + \frac{b + \frac{eQ}{2}}{2}}{2} \right) = \left( \frac{\text{er} + \frac{b + \frac{eQ}{2}}{2}}{2} \right) \left( \frac{\text{er} + \frac{b + \frac{eQ}{2}}{2}}{2} \right)
\]

**Proposition 2** gives a general form of outsourcing contract under Asymmetric Information about the buyer’s internal cost. There is no closed form solution for the general case of contract. So in **Proposition 3**, we give a closed form solution for a special case at cut off point M, where \( \pi_A(M) = \pi_S \).

**Proposition 3.** When the supplier comes to his reservation profit \( \pi_S \), at the cut-off point M, \( \pi_S(M) = \pi_S \) binding.

(a) The supplier gets the following equilibrium outsourcing price, time and quality level, the buyer gets the equilibrium retail price, and cut-off point under Asymmetric Information as following:

\[
s_A = - \frac{-2aKL + T^2 r^2 Kc + 2T r K + 2b \frac{m f(m) dm}{F(m)}}{4bKL - T^2 r^2 K - e^2 L}
\]

\[
t_A = \frac{-(2aKL + T^2 r^2 K + 2Tr r K + 2b \frac{m f(m) dm}{F(m)})}{4bKL - T^2 r^2 K - e^2 L}
\]

\[
Q_A = - \frac{L \left( -a + Tr + \frac{b \frac{m f(m) dm}{F(m)}}{F(m)} + bc \right)}{4bKL - T^2 r^2 K - e^2 L}
\]

\[
p_A = \frac{a - t_A r + +eQ_A + bs_A + bm}{2b}
\]

M satisfies \( s_A - c \left( a - b \right) \left( \frac{\text{er} + \frac{b + \frac{eQ}{2}}{2}}{2} \right) + t_A - \frac{1}{2} \left( \frac{T - T_A}{T} \right)^2 - \frac{KQ_A^2}{2} = \pi_S \).

(b) The profits of the buyer and the supplier are:

\[
\pi_{SA} = (s_A - c)d - \frac{L}{2} \left( \frac{T - T_A}{T} \right)^2 - \frac{KQ_A^2}{2}
\]

\[
\pi_{BA} = (p_A - s_A - m)d
\]

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5. Outsourcing risks due to the lack of information

In this section, we will compare the cases of Full Information and Asymmetric Information. The differences between these two cases are caused by lack of information or Asymmetric Information. Full Information case can be served as benchmark case where each part makes optimal decision (price, quality, or time) without the lack of information. In the Asymmetric Information, the supplier does not know the buyer's internal cost information. The lack of information puts the supplier into a disadvantage position. For the supplier, the expected loss without information could be viewed as the expected information risks, that can be measured by \( \Delta \pi = \pi_{\text{FS}} - \pi_{\text{KL}} \), the difference of supplier's profit under Full Information case and Asymmetric Information case.

Only the supplier accurately predicts the buyer's internal cost information, both the supplier and the buyer can develop a win–win solution (like the Full Information case). In the most cases, the supplier could over-estimate or under-estimate the true value of the buyer's internal cost. The buyer can easily observe the supplier's estimate mistake by looking at supplier's announced value of decision variables. Then the buyer might have a motivation to share her private internal cost information with the supplier if the buyer can get a higher profit, a higher retail price, a lower outsourcing price, or a shorter time-to-market. In this case, the buyer turns the outsourcing game from Asymmetric Information into Full Information. In some cases, the buyer might want to keep the outsourcing game under Asymmetric Information if she realizes that she can play a better game, like earning a higher profit, a higher retail price, a lower outsourcing price, or a shorter time-to-market, by taking advantage of Asymmetric Information and/or the supplier's estimate mistake. On the other hand, the supplier can get some feedback from the buyer’s reaction, including voluntarily disclose her private internal cost or still keep the internal cost information as private information. The outsourcing game under Asymmetric information increases the risks of decision making and makes the game more complicating. We will discuss the supplier and the buyer’s reactions in details for Asymmetric Information case. We also give guidelines based on different industries, like time sensitive industry, quality sensitive industry, and others.

We will use mathematical analysis and numerical experiment approaches to explore the risks of lack information in outsourcing management.

5.1. Mathematical analysis

**Proposition 4.1.** In the Full Information case or a benchmark case,

- i. With the base demand \( a \) increasing, the optimal outsourcing unit price \( s_F \), outsourcing quality \( Q_F \), and retail price \( p_F \) are all increasing; but the optimal outsourcing time \( t_F \) is decreasing.
- ii. With the supplier’s internal cost \( c \) increasing, the optimal outsourcing time \( t_F \) is increasing, but his optimal outsourcing quality \( Q_F \) is decreasing.
- iii. With the buyer’s internal cost \( m \) increasing, the optimal outsourcing unit price \( s_F \) is decreasing, the optimal outsourcing time \( t_F \) is increasing.
- iv. The buyer’s profit \( \pi_{\text{BS}} \) is bigger than or equal to the supplier’s profit \( \pi_{\text{FS}} \) if

\[
\frac{2KLb}{4bKL - T^2\epsilon^2K - \epsilon^2L} > 1
\]

From **Proposition 4.1.i**, we see that outsourcing price \( s_F \), retail price \( p_F \), and outsourcing quality \( Q_F \) are all increasing in base demand \( a \). It follows intuition. It is interesting to see that outsourcing time is decreasing in \( a \). If the market demand \( a \) is high, the supplier need to speed up time-to-market of outsourcing work. Increased demand market and shortened time-to-market will help the supplier and buyer get higher profits. Similar finding is also applied to the Asymmetric Information case.

From **Proposition 4.1.ii**, it is interesting to see how the impact of supplier’s internal unit cost \( c \) does on his outsourcing time and outsourcing quality. From Eq. (2), we find that the supplier’s gross profit \( (s - c)’d \) will decrease with unit cost \( c \). So a high cost (or inefficient) supplier will lower the quality related cost and prolong time-to-market to get higher profit. It will cause low quality of outsourcing work and delayed time-to-market. The managerial insight we get here is that the buyer should choose a cost efficient (or low internal cost) supplier who is more likely to invest more on outsourcing work and hence gets higher quality and shorter time-to-market. Similar finding is also applied to the Asymmetric Information case.

**Proposition 4.1.iii** shows that outsourcing price \( s_F \) is decreasing with the buyer’s internal cost \( m \). If the buyer is cost inefficient (or with higher inner cost \( m \)), she tends to increase her profit by cutting the outsourcing price \( s_F \) that she pays to the supplier for each outsourced product. A useful finding for the supplier here is that the supplier will benefit from higher outsourcing price by working with a cost efficient buyer.
Proposition 4.2. In the Asymmetric Information case (at the cut-off point $M$),

i. With the buyer’s internal cost $\frac{\int m f(m|m)}{\int m f(m|m)}$ increasing, the optimal outsourcing unit price $s_A$ is decreasing; the optimal outsourcing time $t_A$ is increasing.

ii. If the distribution of $m$ satisfies the condition $\frac{\int m f(m|m)}{\int m f(m|m)} > m$, then the outsourcing price in the asymmetric case will be lower than that in the Full Information case, i.e., $s_A < s_F$; the outsourcing time in the asymmetric case will be lower than that in the Full Information case, i.e., $t_A > t_f$; the outsourcing quality in the asymmetric case will be lower than that in the Full Information case, i.e., $Q_A < Q_F$.

In Proposition 4.2. i, $\frac{\int m f(m|m)}{\int m f(m|m)}$ is the supplier’s estimate of buyer’s internal cost. This Asymmetric Information creates the risks in outsourcing management. If the supplier overestimates the buyer’s internal cost, the supplier will charge a lower unit outsourcing price and set a longer outsourcing time. From this finding, the buyer knows how to take the advantage of Asymmetric Information in the outsourcing contract. If the buyer is mainly focus on cost control of outsourcing work, she need to give the supplier some “hints” or “message” to let him (the supplier) overestimate her (the buyer’s) internal cost. In the other case, if the buyer is mainly focus on the time-to-market, she need to give the supplier some “hints” or “message” to let him (the supplier) underestimate her (the buyer)’s internal cost. We see that the Asymmetric Information from the buyer’s internal cost creates risks or uncertainty in decision making. The buyer can take the advantage of information to play a win-lose game. The supplier could suffer from the Asymmetric Information if he cannot estimate the buyer’s internal cost accurately.

In Proposition 4.2. ii, condition of $\frac{\int m f(m|m)}{\int m f(m|m)} > m$ means that the supplier over-estimates the buyer’s internal cost $m$. The supplier and buyer’s performance are depending on how close the supplier estimates the buyer’s internal cost $m$. We see that the Asymmetric Information is increasing the whole supply chain’s risks. Proposition 4.2. ii states that if the supplier overestimates $m$ in the Asymmetric Information, he will set a lower outsourcing price, a longer outsourcing time, and a lower outsourcing quality. For the outsourcing product or service, the buyer can use Asymmetric Information case (do not share her internal cost with the supplier) and induce the supplier to overestimate her internal cost if the end customers are sensitive to the price but not sensitive to the time-to-market and quality. For some industries, like pharmaceutics and high-tech company, customers are very sensitive to the time-to-market and quality but not much to the cost or price, the buyer can use Asymmetric Information case (do not share her internal cost with the supplier) and induce the supplier to underestimate her internal cost. Proposition 4.2.ii provides a strategy for companies in different industries, either focus on the costs, the time-to-market, or the quality, to make an outsourcing contract.

5.2. Numerical experiments

In this section, we take the analysis further using extensive numerical experimentation and gain more insights into the optimal policies and profits of the two parties. We assume a Uniform distribution for $m$ with $f(m) = \frac{1}{m-M}$ and $F(m) = \frac{m-m}{M-m}$ over the interval $[m, M]$, for the Asymmetric Information case. The numerical values used in this experiment are as following Table 2.

<table>
<thead>
<tr>
<th>$a$</th>
<th>$b$</th>
<th>$c$</th>
<th>$e$</th>
<th>$r$</th>
<th>$L$</th>
<th>$T$</th>
<th>$K$</th>
<th>$m$</th>
<th>$M$</th>
<th>$m$</th>
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<td>0.1</td>
<td>0.2</td>
<td>1</td>
<td>0.1</td>
<td>5</td>
<td>1</td>
<td>11</td>
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</tbody>
</table>

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the supplier sets a relatively high outsourcing price \( s_A \) (higher than \( s_F \)) under Asymmetric Information case, she can conclude that the supplier underestimates her internal cost. In this case, the buyer has an incentive to share her actual internal cost information with the supplier to get a lower outsourcing price. On the other side, if the buyer does not want to share her actual internal cost with the supplier, the supplier can infer that he might overestimate the buyer’s internal cost and set a relatively low outsourcing price \( s_A \) (lower than \( s_F \)) under Asymmetric Information case. The above analysis is a guideline for the buyer and the supplier how to play a better “game” under uncertainty or information risk.

Fig. 2(b) illustrates the changes of retail price \( p \) with various \( \eta \) under Full Information (F) and Asymmetric Information (A) case. We note that the retail price is increasing with her internal cost \( m \). The buyer needs to keep her profit margin by setting a higher retail price \( p \) if her internal cost \( m \) is high. It is interesting to see that the retail prices under Full Information (F) and Asymmetric Information (A) are so close to each other.

The next Fig. 2(c) shows the change of buyer’s unit profit margin with his internal cost \( m \). It is interesting to see that the buyer’s unit profit margin \( p - s - m \) is increasing with her inner cost \( m \). The buyer prefers Asymmetric Information (A) to get a higher unit profit margin, like \( p - s - m \). She would like to keep her private cost information \( m \) as a secrete and does not want to share it with the supplier. But the supplier prefers Full Information (F) to get a higher unit profit margin, like \( s - c \), as shown in Fig. 2(a). The supplier might offer an incentive to the buyer to let her to share her information, or moving from Asymmetric Information (A) case to Full Information (F) case.

After studying the price change with the buyer’s internal cost, we will discuss the outsourcing time and quality in the next set of figures.

From Fig. 3(a), we see that the outsourcing time \( t_A \) and \( t_F \) are both increasing with the buyer’s internal cost \( m \). It is also interesting to find that the outsourcing time \( t \) is shorter under Asymmetric Information (A) than Full Information (F) case. So it is beneficial for the buyer to disclose her internal cost information \( m \) to the supplier, moving from the Asymmetric Information case to the Full Information case and decreasing the time to market. This finding also proves the supplier with disadvantage of information. Due to the lack of the buyer’s internal cost information, the supplier sets a shorter outsourcing time with increased costs \( \frac{1}{2}(\frac{Q}{T})^2 \), as shown in Eq. (2).

Fig. 3(b) illustrates that the outsourcing quality \( Q_A \) and \( Q_F \) are both decreasing with the buyer’s internal cost \( m \). We also find that the outsourcing quality \( Q \) is higher under Full Information (F) than Asymmetric Information (A) case. The managerial insight we gain here is that the outsourcing quality can be increased (like moving from \( Q_A \) to \( Q_F \)) if the buyer can share her internal cost \( m \) with the supplier.

The next set of figures is about the buyer’s and supplier’s profits under different buyer’s internal cost \( m \), labeled as Fig. 4(a) and (b). We find that \( \pi_{BF} \), \( \pi_{BA} \), \( \pi_{SF} \), and \( \pi_{SA} \) are all decreasing with \( m \). This result is expected. We see that the profits for the buyer and supplier are always higher under Full Information (F) than those of under Asymmetric Information (A), like \( \pi_{BF} > \pi_{BA} \) in Fig. 4(a) and \( \pi_{SF} \geq \pi_{SA} \) in Fig. 4(b). Both of the buyer and supplier can perform better (or getting a higher profit) in Full Information (F) case, or without Asymmetric Information existing. Recall that we use \( \Delta \pi = \pi_{SF} - \pi_{SA} \) to measure the expected loss for the supplier without the buyer’s internal cost information. From Fig. 4(b), we see that \( \Delta \pi \) is increasing with \( m \). It means that the supplier gets more profit loss if the buyer’s internal cost \( m \) is higher. If a supplier works with a cost inefficient buyer (with high \( m \)), it is more important for the supplier to predict the buyer’s internal cost accurately or persuade the buyer to share her private cost information, switching from Asymmetric Information case to Full Information case.

We also find that \( \pi_{BF} + \pi_{SF} > \pi_{BA} + \pi_{SA} \) (the graph is omitted). The profit realized under Full Information (F), is always higher than the sum of the retailer’s and the manufacturer’s profits under Asymmetric Information (A). This is generally
the same result found in most supply chain coordination literature and information sharing literature. Information asymmetry and information uncertainty cause inefficiency for the whole supply chain.

5.2.2. Effect of varying cost efficient factors L and K

From Fig. 5, we see that with the cost efficient factor $L$ increasing, the supplier profit $p_{SF}$ under Full Information (F), supplier profit $p_{SA}$ under Asymmetric Information (A), the buyer profit $p_{BF}$ under (F), and the buyer’s profit $p_{BA}$ under (A) are all decreasing. It means that the supplier and buyer’s profits will decrease if the supplier becomes more cost inefficient. If the
buyer can work with a cost efficient supplier, both firms’ profits will increase. We get a similar result when we plot varying cost efficient factor $K$ vs. profits. We skip the figure here.

6. Managerial implications and conclusion

In this paper, we consider an outsourcing scenario where a buyer outsources product or service to a supplier. There is Asymmetric Information in this outsourcing supply chain where the buyer holds her private internal cost information that is unknown to the supplier. This Asymmetric Information increases the risks of supply chain management and makes the decision making more complicated. Game theory was used to design the contracts between the buyer and the supplier. We derived the equilibrium outsourcing price, outsourcing time, retail price, quality level, cut-off point, and profits under two information scenarios, including Full Information and Asymmetric Information. We also analyzed the effect on the optimal policies of any changes in the values of market parameters and private information, by conducting sensitivity analyses, both analytically and numerically.

This research focuses on the value of information or information risk on outsourcing management. We extensively discuss how the Asymmetric Information impacts the firm performance. Several suggestions are developed about how the supplier and the buyer can play a better “game” under Asymmetric Information and reduce information risks (see discussion after Figs. 2(a)–(c) and 3(a) and (b)). From the figures and our discussion in sections 4 and 5, we see that the supplier has information disadvantage due to the lack of the buyer’s private internal cost. We also discuss that the game based on Asymmetric Information can be played in many different ways (see discussion after Proposition 4.2) for different industry or using business strategy. The outsourcing management under Asymmetric Information can be very complex based on each part’s announced value of decision variables and each player’s reactions. The buyer might have a motivation of voluntarily disclosing her private information (moving from Asymmetric Information to Full Information case) or continue to keep her private information as a secret (staying on Asymmetric Information case). We identify the conditions when the buyer wants to disclose her private information. Our findings also consistent with the existing literature, like the total supply chain gets higher profit under (F) than under (A), and each firm’s profit increases with base demand $a$.

Our model can be extended in many different directions. We can study an outsourcing supply chain that includes one buyer and multiple suppliers. Contract designed under duopoly setting will be very interesting. The game can be modified also. We can let the buyer be the game leader and supplier be the game follower. The other extension or modification of current research could be the source of Asymmetric Information. The supplier could hold his internal cost information as private information. The buyer needs to decide her optional decision variable under Asymmetric Information from the supplier. Our current research and proposed future research will help industry practitioner to understand how to play a “better” game under Asymmetric Information and reduce the risks of supply chain due to the Asymmetric Information.
Appendix A. Proof of Proposition 1.1

As in Lemma 1: The supplier can derive the buyer’s best response function as:

\[ p_{BR}^* = a - tr + bs + bm \]

In the stage 1 of the game, the supplier maximizes his own profit by cooperating the buyer’s best response function to derive the optimal outsourcing price \( s_i \), time \( t_i \), and quality \( Q_i \).

In the stage 2 of the game, the buyer derives the optimal retail price \( p_b \) by bring the supplier’s announced values of decision variables into Lemma 1.

Appendix B. Proof of Proposition 2.1

The Lagrangian for the supplier’s problem for follows. Assume \( \pi_s \) is decreasing function in \( m \).

\[ L = \int \pi_s f(m) dm + \int \pi_b f(m) dm + \lambda (\pi_b - \pi_s) \quad (a) \]

where \( \lambda \) is the Lagrangian variable. Substituting \( d = a - bp - rt + eQ \) and \( p_{BR}^* = a - tr + bs + bm \) (Lemma 1),

\[ L = \int \left( s - c \right) \left( a - b \left( a - tr + bs + bm \right) - rt + eQ \right) \frac{L}{2} \left( \frac{2}{T - t} \right)^2 - \frac{K}{2} Q^2 \right) f(m) dm + \int \pi_s f(m) dm \]

Using KKT-condition, we set \( \frac{\partial L}{\partial m} - 0 = \frac{\partial L}{\partial s} = 0 \) and \( \frac{\partial L}{\partial e} = 0 \).

By using Leibniz Integral Rule and set the supplier’s profit equals \( \pi_s \) at the cut-off point, the supplier can get the optimal value of \( s_i, t_i \), and \( Q_i \).

The buyer derives the optimal retail price \( p_b^* \) by bringing the supplier’s announced values of decision variables into Lemma 1.

References


