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ABSTRACT

In this dissertation, I conduct three studies on outsourcing in emerging Market under uncertainty. My first study examines a market-based gainsharing outsourcing contract. Specifically I develop an analytical model of how the client, vendor, and spot market interact and co-evolve in a complex and non-linear manner over time under a gainsharing contract. Then starting from an outsourcing contract, my second study focuses on an incentive outsourcing contract for technology adoption under uncertainty, and investigate how the client should promote the vendor to adopt a new technology when the client and vendor are already bounded with an existing outsourcing contract. Finally, taking the vendor's perspective, my third study develops a new valuation tool for the vendors to avoid the "winner's curse" based on the real option theory. By modeling these three important and fruitful topics in outsourcing, this dissertation contributes to supply chain management in general and to the outsourcing literature in particular. These three studies also generate many fruitful implications for theory and directions for future research that are suggested.

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Chapter 1

Introduction

1.1 Overview

Outsourcing has gained tremendous attention in both practice and academia in recent years due to its fast growing trend. Such trend is more profound in electronic manufacturing where the top 100 Contract Manufacturers (CMs) account for more than $100 billion in revenue. (Roberts, 2003). A survey of 238 executives from multinational companies reveals that 85% of the European and US firms are planning to increase their outsourcing levels in the near future.(FACTS & FIGURES, 2005). There are two sides to an outsourcing contract: the client (contract-granting firm) and the vendor (contract-receiving firm). Outsourcing is popular for the client because it helps reduce the client's cost and enables the client to focus on key business functions, thereby improving performance. Originally, outsourcing was mainly used in manufacturing and now it is applied in service areas such as finance and accounting. Among the outsourcing issues, there have been increasing interests pertaining to the theory and practice in outsourcing to the emerging markets. The term emerging markets refers to countries that are restructuring their economies along market-oriented lines and experiencing rapid growth in their market and economics. Emerging markets not only exist in the Asia Pacific region, but also in the Eastern Europe, South and Latin America, and most recently, Africa. Among the large emerging markets, China and India have been the most significant ones globally due to their Gross Domestic Product (GDP), market sizes and growth potential. Given the competitive labor and material costs in emerging markets, Original Equipment Manufacturers (OEMs) in many industries in developed countries have started to prefer buying finished products from CMs in emerging markets rather than producing themselves. Such outsourcing activities not only help reduce the cost for the OEMs as the CMs in emerging market can make the products more efficient but also can enable the OEMs to focus on business functions which will enhance a product's value such as R&D, design and marketing.

1.2 Research Questions

This rise of outsourcing to the emerging markets has posed new and interesting questions to the outsourcing and supply chain literature, particular with regard to operational risk, contracts, collaboration and cultural and organizational issues. However, most extant literature on outsourcing has been mainly focusing on the global strategic management on the corporate level. Only a handful studies examined outsourcing to the emerging market on the operational levels (Gray et al. 2008 and Gilbert et al. 2006),but none of them has captured the fast changing outsourcing situations. Thus, the needs to develop theory to explain the new challenges and to guide practice are urgent. I, in observing these challenges, propose to build analytical models to understand and explain the new phenomenon. Specifically, I propose to model the following topics of outsourcing in Emerging Market under uncertainty and to generate managerial insights to guide practice.

1) New contracts start to emerge as coordination mechanisms

China, one of the major emerging markets, has been one of the most attractive destinations for outsourcing in the world due to its competitive labor and material cost advantages. However, such advantages are diminishing those days due to a number of issues concerning China: high inflation since 2008, shortages of skilled workers and energy, a strengthening currency, and changing government policies (e.g., China is phasing out its practice of tax return or subsidy policy for export-oriented companies). Furthermore, the introduction of minimum wage legislation by Chinese government in January 2008 has made such cost soar even faster. All this has forced Chinese manufacturers to look for new approaches or contracts to protect cost overruns, even though that China still possesses relative cost advantages and remains the favorable outsourcing destinations to the international buyers. Current outsourcing practices in China show that a new type of contract starts to emerge and is favorable to the Chinese manufacturers than the fixed-price or cost-per-transaction contracts. This new type of contract is termed as a gainsharing contract. According to the national industry statistics, one out of four textile suppliers operating in China signed gainsharing contracts with the international buyers based on the spring session of the 2008 China Import and Export Fair.

Under a gainsharing contract, a vendor and a client originally negotiate a target price and a gainsharing ratio for a particular product. After a certain lead time, the vendor will deliver the product to the client and the client will process the payment for the vendor. However, the payment to the vendor from the client will not be the target price but a gainsharing price which is equal to the target price plus the difference between the target price and the market price at delivery. This market price might be higher than the target price due to inflation or increasing labor and energy costs. Thus, the gainsharing price is robust in a way that the vendor and the client will share the unpredictable cost-overrun or saving. While it seems that a gainsharing contract provides a risk-sharing mechanism and brings more mutual benefits to vendor and client than a fixed-price does, it has been limited applications in supply chains, due to the difficulties in determining the target price and decide the share ratio which, sometime, could bring more pain than gain (Baukney, 2000). The current literature of supply chain contracts does not provide insights of guidance on how the target should be set and how the gains/overruns should be divided between client and vendor.

In this dissertation, I propose to study spot market based gainsharing in supply chains and to provide practical guidelines to decision makers. To my best knowledge, this study represents the first step to explore the gainsharing contract's mechanisms.

2) Incentive outsourcing contracts for technology adoption

The fast technology innovation and development provide the firms not only with new innovational opportunities but also new challenges for firms as they strive to survive in the globally competitive business environment. The ability of a firm to develop and adopt new technologies has been a crucial factor for the firm's success in many industries. In the outsourcing context, a client and a vendor is usually cooperating under an outsourcing contract which specifies that the vendor manufactures certain goods for the client while the client sells the products directly to the end consumers. Within such agreements, it is crucial for both parties to adopt a new technology when it is available to remain competitive in the global business environment for both parties.

In this dissertation, I look at the problem of how to promote the green technology in the outsourcing when the client and vendor are already committing to an outsourcing contract. Green technology refers to a group of methods and materials, from techniques for generating energy to non-toxic cleaning products to achieve sustainability (http://www.green-technology.org/what.htm). By adopting the green technology adoption, the client and the vendor could generate revenues and improve the business image in the world. Failure to adopt the green technology could lead to the loss of customer and revenues. (Voigt, (2006)). This is due to the fact that the consumer's awareness of environmental problems is increasing (Boeck and Ward, 1997). Carter and Narasimhan (2000) predict that there will be a rapid increase in the consumer awareness of environmental issues in this decade. According to the 2009 Cone Consumer Environmental Survey, American consumers' interests in the environment have not been decreased given the current state of the economy. Instead, many consumers are inclined to hold companies accountable for their environmental commitments today and in the future. Many companies are aware of their environmental accountabilities. One of the ambitious goals of Wal-Mart is to sell products that sustain Wal-Mart's resources and the environment and to implement a "green" supply chain. In order to meet this goal, their new sustainability strategy would need to be deeply embedded in Wal-Mart's operations and supply chain management (Plambeck (2007)). In this global environment where many firms are sourcing their manufacturing operations overseas to take advantage of the low cost of material and labor in emerging market, the whole supply chain needs to be integrated and coordinated in order to make and sell the green products.

However, such adoption under outsourcing poses different questions than the traditional technology adoption by single firms. Specifically, how should the client promote the vendor to adopt such new technology at the right timing while they are already committing to an existing outsourcing contract? Furthermore, how to handle the adoption problem the adoption cost is usually uncertain and the vendor can exert effort to reduce the expected adoption cost?

In this dissertation, I propose an incentive outsourcing contract which is based on investment timing where agency conflicts and information asymmetries are present. This continuous-time contract provides incentives to vendors to both incur effort and truthfully disclose private cost information. To my best knowledge, this research represents the first step to investigate the incentive outsourcing contract for technology adoption under uncertainty when client and vendor are already committing to an existing outsourcing contract.

3) Valuating outsourcing contracts from vendors' perspective

Traditional outsourcing literature often focuses on performance of the outsourcing from the client's point of view by minimizing the cost of outsourcing. One of the ways to minimize the outsourcing cost for the client is to use the sealed-bid auctions. In such sealed-bid auctions, the client will invite a small pool of vendors to bid and require the vendors to submit their bid within a short period of time. Selection of a "winner" is based on a number of criteria and, not surprisingly, price is a critical component (Li & Kouvelis, 1999). Such mechanism will bring the pressures to potential vendors under intense competition. Specifically, the vendor might new know its competitors' bids and needs to provide its bid low enough to beat is competitors. This often results the vendor to leave a thin profit margin and bids aggressively which leads to the notorious "winner's curse".

In addition, when exercising the outsourcing contract, the vendor needs to face different under financial and/or operational risks, which mainly come from three aspects: competitive bidding process, uncertainty of costs, and pressure of shorter contract-duration. This will all contribute to the "winner's curse" and make the vendor suffer. These all make the standard NPV approach insufficient to evaluate the risky outsourcing contracts for the vendor. The vendors are in great needs of a new decision tool to help them evaluate such risky outsourcing contract.

In this dissertation, I propose to use the real option theory to evaluate the outsourcing contract from the vendor's point of view. I derive the decision principles form the vendor under the real option theory. In addition I also examine the differences in the decision thresholds under the NPV approach and the real option approach and explore how such differences are affected by the influential factors. Furthermore, I investigate vendors' learning effects within the context of outsourcing contract renewal. This study moves beyond the traditional decision support for the vendor and equips scholars and practitioners with a new decision tool.

1.3 A Roadmap

The remaining of this dissertation is structured as follows. In Chapter two, I investigate the market-based gainsharing contract. This section includes a continuous-time model of a market- based gainsharing contract between two risk-averse firms through a Nash bargaining process, a determination of the optimal target price and the optimal share ratio of an gainsharing contract, an extensive analysis on how the cost and price uncertainties and correlations affect the optimal gainsharing contract.

In Chapter three, I analyze how the client can promote the vendor to adopt a new technology under an outsourcing contract. I propose an incentive outsourcing contract based on investment timing where agency conflicts and information asymmetries are present in an outsourcing setting. The incentive contract could provide incentives to vendors to both incur costly efforts and truthfully disclose private information. I show how to derive the optimal parameters for such incentive outsourcing contract and the effects of agency issues.

In Chapter four, I apply the real option theory to study how to evaluate the risky outsourcing contract when the vendor is subject to the cost uncertainty and investment pressure. I compare the results from the real option approach and the net present value approach and investigate the relationships between vendors' decision-making thresholds and three parameters as well as the effects of learning on renewal.

In Chapter five, I outline its contributions for the current outsourcing and supply chain literature, and suggest possible directions for future research.

Chapter 2

An Analytical Study of Market Based Gainsharing Contract

The market based gainsharing contract is emerging in Chinese outsourcing market. However, how to determine the target price and the share ratio of gains between the client firm and the vendor firm is an under-researched topic in the current literature. Thus far, research on gainsharing contracts is predominantly descriptive and the output is too vague to be applied in practice. This part of my dissertation provides several important properties of gainsharing outsourcing contract through a continuous-time analytical approach. Specifically, I consider the determination of a market based gainsharing contract between two risk-averse firms through a Nash bargaining process. The optimal gainsharing contract is derived analytically and an extensive analysis on how the cost and price uncertainties and correlations affect the optimal gainsharing contract are provided. I also discuss the implications of this study on research and practice.

2.1 Introduction

After years of being one of the most attractive destinations of outsourcing in the world, China has recently become less competitive in its famous cost advantages. A long list of concerns about China is feeding this trend: high inflation since 2008, shortages of skilled workers and energy, a strengthening currency and changing government policies (e.g., China is phasing out its practice of tax return or subsidy policy for export-oriented companies). In addition, the Chinese government's introduction of minimum wage legislation in January 2008 raises the prospect that labor costs will soar even faster soon.

While China still holds enough advantages to ensure that there will not be major relocations by foreign clients (Euromonitor International's special report, 2008), Chinese manufacturers have to look for new approaches to protect cost overruns. Ongoing practices show that an obvious change of outsourcing in China is a trend away from fixed-price or cost-plus contracts toward gainsharing contracts. Based on national industry statistics, one in four textile OEM firms operating in China signed gainsharing contracts in the spring session of the 2008 China Import and Export Fair (source: CCCIET).

Under a gainsharing contract, a vendor firm (Chinese supplier) and its client (international outsourcing firm) originally negotiate a gain share ratio and a target price. After a certain time, when the vendor delivers the product to the client, the client will pay the vendor based on the target price and the current real market price of this product. The real market price may be higher than the target price due to inflation, increasing labor or energy cost (which are happening in China). The vendor and the client will share the unpredictable cost overrun. For instance, a gainsharing contract's target price is \$100 and the agreed share ratio between the vendor and the client is 6:4. When the real market price of this product has increased to \$120 on the delivery date, the final gainsharing price for the client will be \$108 (i.e., \$100 + \$(120-100) x 40%). In other words, the client still enjoys somewhat benefits from outsourcing and the vendor firm gets somewhat remedy for its cost overruns. In contrast, if the real market price reduces to \$80 on the delivery date, the final gainsharing price for the client will be \$92 (i.e., \$100 +

$(80-100) x 40%) rather than $80. In other words, the client still pays less than its expected price, while the vendor also enjoys somewhat cost savings.

It seems that gainsharing contracts bring more mutual benefits to vendors and clients than fixed-price or cost-plus contracts. For example, a fixed-price contract has the simplest form and needs the least information (only a fixed price) but suffers from cost uncertainty. A cost–plus contract addresses the cost uncertainty concern but requires efforts to monitor the vendor’s operating cost. A gainsharing contract avoids the trouble to watch the vendor’s operating cost and relies on public information from the open market. In the real world, however, the application of gainsharing contracts in outsourcing is restricted due to two puzzles (Digrius and Koenig, 2006): how to estimate the target price and how to decide the share ratio between the client and the vendor.

This part of my dissertation aims to investigate the emerging gainsharing contract in China and to provide practical guidelines to managers, particularly with respect to the above two puzzles. This research will serve as an earliest attempt to explore the gainsharing contract’s mechanism in outsourcing.

2.2 Literature Review

The quest for a definition of gainsharing has led me to perform an extensive review on the literature. I summarize the finding of how gainsharing and its related terms are defined in the literature in table 1.

Table 2.1 Defining gainsharing

	Field	Authors	Concept	Definition
Gainsharing literature	Human Resources Management	Gross and Duncan(1998) Welbourne and Gomez Mejia(1995)	Gainsharing	Gainsharing is not a single type of incentive program. it is an umbrella for a family of aggregate pay-for-performance approaches that link financial rewards for employees to improvement in the performances of the entire unit
	Vendor Relationship Management	PR Newswire (2007)	Gainsharing	Gainsharing provides financial and qualitative incentives to the vendor for exceeding goals.
	Health Care	Ketcham and Furukawa (2008)	Gainsharing	gainsharing arrangements are contracts where physicians receive cash payments for reducing hospital spending
Related literature in supply chain management		Li and Kouvelis(1999)	Risk-sharing	within a prespecified price window the firm pays the realized price, but outside of it the firm shares, in an agreed way, added costs or benefits
		Cachon and Lariviere (2005) Pasternack (2002) Gerchak and Wang (2004)	Revenue sharing	Under a revenue-sharing contract, a retailer pays a supplier a wholesale price for each unit purchases, plus a percentage of the revenue the retailer generates.
		McAfee and McMillan (1986) Chu and Sappington(2007)	Cost-sharing	payment which reimburses part of the cost actually incurred.

The concept of gainsharing originally emerges in the literature of human resource management and organizational behavior. Gainsharing represents a family of aggregate pay-for-performance approaches that link group-wide financial rewards to employee created improvements in organizational performance, so that both employees and the firm share the risks of relative success or failure (Gross and Duncan, 1998, Welbourne and Gomez-Mejia, 1995). Shifting towards a more communicative and participatory approach, a gainsharing contract is a style of interactive governance between an organization and its members (Goggin, 1986; Schuster, 1987; Belcher, 1991; Gomez-Mejia et al., 2000). Gainsharing's history of successful application in human resource management and organizational behavior has long served as an example for the other industries as strategies of reducing costs and promoting cooperation. For instance, NPI Financial, the leader in technology spending management and fair market value analysis, realized gainsharing as one of the key areas to improve outsourcing relationship. They promote the outsourcing relationship by inventing the cost saving back into the relationship, which can ensure that the vendor and the client can both benefit from top performance from outsourcing (PR Newswire, 2007). Ketcham and Furukawa (2008) demonstrate empirically that the gainsharing contract can significantly reduce the hospital's cost without any compromise in the quality of health care.

The popularity of gainsharing raises the question of how gainsharing can benefit the supply chain and outsourcing literature. In recent years, several studies have begun to investigate gainsharing in supply chains. For example, Lim (2000) investigates the penalty and gainsharing scheme's impacts on third-party-logistics providers. Thomson and Anderson (2000) describe a process for determining the suitability of gainsharing contracts in the hospital supply chain. Ghosh and John (2005) find empirical evidence that the gainsharing formula can encourage cost reduction efforts among industrial alliances. Gulati and Kletter (2005) argue that to create a bond of loyalty between two financially independent companies, gainsharing or other financial rewards are necessary for mutual success. Barthelemy (2003) emphasizes the importance of incentive to encourage the right behavior from vendors and designs a roadmap of how the client-vendor relationship will change over its life cycle: "unit-based pricing may be used at the beginning of the relationship. The pricing could switch to cost-plus as the relationship develops. The contract could eventually call for a change to a gain-sharing arrangement so that the client and the vendor have a joint stake in the outcome." (Barthelemy, 2003, p.90)

Thus far, many share-oriented contracts have been investigated in the supply chain management literature. For example, Li and Kouvelis (1999) consider flexible contracts with risk-sharing feature where risk of purchasing price is shared between the buyer and the supplier. However, they assume that risk-sharing mechanism is *given* (i.e., non-negotiable) and focus on the optimal purchasing timing and quantity for the buyer. How to determine and negotiate such a sharing contract remains an unanswered question in their research.

Revenue sharing is another similar research stream to gainsharing. Revenue sharing refers to the sharing of a client's (retailer's) realized revenue between this client and its vendor (manufacturer or supplier). For example, Cachon and Lariviere (2005) study revenue sharing contracts in a general supply chain model with revenues determined by each retailer's purchase quantity and price, i.e., the retailer chooses supply chain optimal actions (quantity and price) and the supply chain's profit can be arbitrarily divided between the retailer and the manufacturer. Pasternack (2002) also studies revenue sharing contracts in which suppliers can implement revenue sharing either by requiring a percentage of realized revenue or by demanding a fixed payment per unit sold. Gerchak and Wang (2004) further investigate a revenue-plus-surplus-subsidy incentive scheme, where in addition to revenue sharing, the client also provides a subsidy to component suppliers for their unsold components. Even though revenue sharing and gainsharing of this research are similar in the nature of sharing, the fundamental difference is that revenue sharing occurs *after* the client's final sale, but gainsharing in my research occurs *before* the client's final sales. For instance of today's global supply chains, suppliers in developing countries are usually in a passive position and lack of negotiation power to require a share of global buyers' revenue in developed countries. Therefore, few Western purchasers share their revenues with suppliers in emerging economies.

Another close but different research stream to this study's gainsharing is cost sharing, which arises whenever a group of agents jointly shares a production function or undertakes a joint project. McAfee and McMillan (1986) consider the optimal contract design problem and they show that a cost sharing mechanism is usually optimal for government bidding contracts. An appropriate cost sharing rule can fairly allocate the total cost among the users for every conceivable profile of output demands (Moulin and Shenker, 1994; Kaplan and Wettstein, 1999; Devanur et al., 2005). Other considerations of cost sharing include budget balance: that the users are not charged in excess of the incurring cost, while at the same time, recovering as much of the cost as possible. For example, Laffont and Tirole (1986), Rogerson (2003), and Chu and Sappington (2008) show that the principal (buyer) can implement the optimal incentive menu so that it is in the agent's (supplier's) interest to truthfully announce his expected cost. In order to calculate the optimal cost sharing method or menu, however, the buyer should be able to specify the supplier's entire disutility of effort function. Indeed, a critical premise behind the use of cost sharing is that it is prohibitively costly to identify the holders of valuable private information ex ante (Gomez-Mejia et al., 2000). For a market based gainsharing contract in this research, however, the client can easily obtain the information of price from an open market, so that the vendor's private information is not necessary for the client's monitoring process.

In a gainsharing contract, there are three basic elements (Charles, 2006): 1)*Baseline*: the performance level and point in time from which improvements will be measured, 2)*Performance target*: the desired performance level which the parties wish to achieve and 3)*Sharing mechanism*: the formula for splitting potential gains (or losses). While the current research provides empirical or anecdotal evidence of gainsharing contracts' impact on supply chain collaboration, and contributes to my understanding of gain sharing's impacts in supply chain management, the fundamental questions regarding gainsharing contracts are still not answered. For example, how to determine the performance target and optimal sharing mechanism of a gain-sharing contract? How to determine and negotiate the gain sharing contract as it applies to the context of outsourcing. In this research, I study a gainsharing contract in the presence of spot markets and use the market price as the baseline. Specifically, I derive the optimal performance target and the optimal share ratio of such a market based gainsharing contract. I address the determinants that influence the performance target and the share ratio and provide managerial insights on how to negotiate a market based gainsharing contract.

2.3 The Model

I consider a simple model with a single client and a single vendor. The client and the vendor negotiate a gainsharing contract at time *t*, determining the optimal target price and sharing ratio based on their uncertain costs and the uncertain spot market for such a product. The client can save costs by purchasing from the vendor instead of producing in-house, while the vendor firm can profit by providing this service. The client and the vendor choose the target cost and sharing ratio to maximizing the sum of their utilities that are based on their risk-averse nature.

After some fixed lead time *L*, the vendor delivers the product to the client. The client's final payment will be determined by three factors: the negotiated target price, the spot market price, and the negotiated share ratio between the client and the vendor.

Figure 2.1 is a pictorial illustration of the interactions among the vendor, the client and the spot market in a gain-sharing contract.

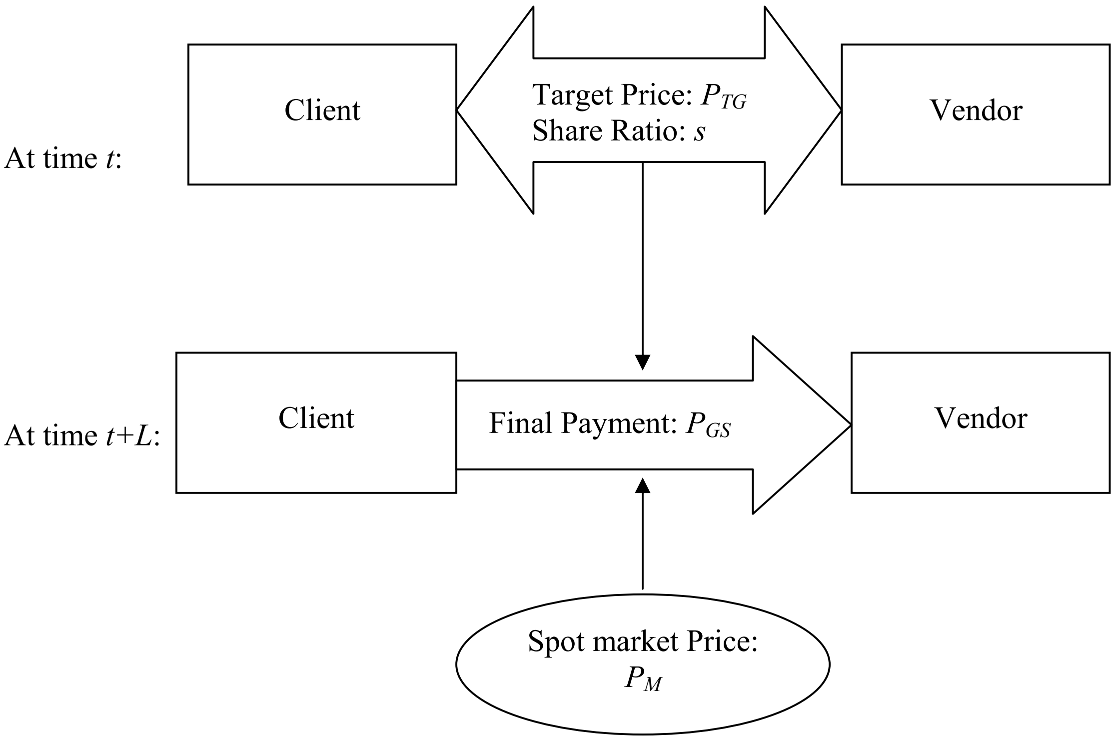

Figure 2.1 The interactions among the vendor, the client and the spot market

The model is outlined in details by the following elements.

1. The client's in-house operation cost, the vendor's operation cost, and the spot market price are W_C , W_V , and P_M , respectively. To introduce the influence of cost and market uncertainties, I assume operating costs and market price evolve over time as Geometric Brownian Motion (GBM):

$$dW_C(t) = \mu_C W_C(t)dt + \sigma_C W_C(t)dB_C(t),$$

$$dW_V(t) = \mu_V W_V(t)dt + \sigma_V W_V(t)dB_V(t),$$

$$dP_M(t) = \mu_M P_M(t)dt + \sigma_M P_M(t)dB_M(t)$$

Where $dB_C(t), dB_V(t), dB_M(t)$ are standard Wienner processes, $E[dB_i(t), dB_j(t)] = \rho_{ij}dt$, $i, j \in \{C, V, M\}, i \neq j$. I assume ρ_{CM} >0 and ρ_{VM} >0, meaning the market price is positively correlated with the client's and vendor's costs, which are not unreasonable for outsourcing markets. μ_C, μ_V, μ_M are the shift rates of expected future changes, $\sigma_C, \sigma_V, \sigma_M$ are the uncertainty rates of such processes. Brownian motions have been widely applied in the finance as well as the production and operation management literatures (e.g., Dixit and Pindyck, 1994; Abel and Eberly, 1994; Li and Kouvelis, 1999; Caldentey and Wein 2002, Chod and Rudi 2006, Xu and Hopp 2006, and the references therein).

2. To carry out a gainsharing contract, the client needs to pay cost K_C (e.g., liquidation cost); the vendor needs to pay cost K_V (e.g., investment in capacity, opportunity cost, etc.).

3. There is a deterministic lead time *L*>0 which is the time difference between the negotiation (initiation) of contract and the first cash flow (delivery).

4. The final price of a gainsharing contract at time τ is not the nominal target price P_{TG} but the gainsharing price $P(\tau) \equiv P_{TG} + [P_M(\tau) - P_{TG}](1-s) = P_{TG}s + P_M(\tau)(1-s)$, given the negotiated target price P_{TG}, the market price P_M , and the vendor's share ratio $s \in [0,1]$ of the gain (consequently, the client's share ratio is 1-*s*). Note that *s*=0 corresponds to the case where the client prefers to trades in the spot market instead of outsourcing. s=1 is the fixed price contract where the vendor will be solely responsible for the cost overrun or reduction. If 0 < s < 1 , then the gainsharing contract dominates

the spot market and the fixed price contract. Thus, this linear contract is a generic form of the outsourcing contract where the extreme cases are the fixed price contract and the spot market case.

5. Client's discounted benefit from a gainsharing contract is: $\Pi_C(t) = \int_{t+L}^{\infty} (W_C(\tau) - P(\tau))e^{-r(\tau-t)}d\tau - K_C$. r is the capital cost and is positively related to the real interest rate and the industry specific risk rate. I assume $\mu_C, \mu_V, \mu_M < r$ for convergence and the infinite duration of the contract for tractability. Such infinite time horizon with exponential discounting is a reasonable assumption in practice and standard in literature.

6. Vendor's discounted benefit from a gainsharing contract is: $\Pi_V(t) = \int_{t+L}^{\infty} (P(\tau) - W_V(\tau))e^{-r(\tau-t)}d\tau - K_V$.

7. Assume the client and the vendor are risk-averse and have the mean-variance preference. When initiating the contract at time *t*, the firm's utility is

$U_i(t) = E_t[\Pi_i(t)] - \eta_i VAR_t[\Pi_i(t)], i \in \{C, V\}$,

where $\eta_C > 0$ and $\eta_V > 0$ are the risk aversion coefficients. Refer to Ding et al. (2007) and Dong and Liu (2007) for details of mean-variance utility functions.

8. Vendor's negotiation power is $\gamma \in [0,1]$ (consequently, the client's power is 1 - γ). The vendor and the client share the utility based on their negotiation powers.

That is, $U_V(t) = \gamma U(t)$

where $U(t) = U_V(t) + U_C(t)$ is the total utility gain.

2.4 Target Price and Share Ratio

In this section, I first calculate the client's and the vendor's utilities from a market based gainsharing contract with given parameters (P_{TG}, s). I then solve the Nash bargaining equilibrium gainsharing contract (P_{TG}^*, s^*).

2.4.1 Client's and Vendor's Utilities

The client's utility is

$$U_C(t) = E_t[\Pi_C(t)] - \eta_C VAR_t[\Pi_C(t)] \tag{2.1}$$

with

$$E[\Pi_C(t)] = \left[\frac{W_C(t)e^{\mu_C L}}{r-\mu_C} - \left(\frac{P_{TG}s}{r} + \frac{P_M(t)e^{\mu_M L}(1-s)}{r-\mu_M}\right)\right]e^{-rL} - K_C \tag{2.2}$$

$$VAR_t[\Pi_C(t)] = \left[VAR_C + (1-s)^2 VAR_M - 2(1-s)COV_{CM}\right]e^{-2rL}$$

where

$$VAR_C = \frac{W_C^2(t)e^{2\mu_C L}(e^{\sigma_C^2 L} - 1)}{(r-\mu_C)^2}, \quad VAR_M = \frac{P_M^2(t)e^{2\mu_M L}(e^{\sigma_M^2 L} - 1)}{(r-\mu_M)^2}, \text{ and}$$

$$COV_{CM} = \frac{W_C(t)P_M(t)e^{(\mu_C+\mu_M)L}(e^{\rho_{CM}\sigma_C\sigma_M L} - 1)}{(r-\mu_C)(r-\mu_M)}$$

The vendor's utility is

$$U_V(t) = E_t[\Pi_V(t)] - \eta_V VAR_t[\Pi_V(t)] \tag{2.3}$$

$$E_t[\Pi_V(t)] = [(\frac{P_{TG}s}{r} + \frac{P_M(t)e^{\mu_M L}(1-s)}{r-\mu_M}) - \frac{W_V(t)e^{\mu_V L}}{r-\mu_V}]e^{-rL} - K_V \tag{2.4}$$

$$VAR_t[\Pi_V(t)] = \left[VAR_V + (1-s)^2 VAR_M - 2(1-s)COV_{VM}\right]e^{-2rL}$$

where

$$VAR_V = \frac{W_V^2(t)e^{2\mu_V L}(e^{\sigma_V^2 L}-1)}{(r-\mu_V)^2}, \quad VAR_M = \frac{P_M^2(t)e^{2\mu_M L}(e^{\sigma_M^2 L}-1)}{(r-\mu_M)^2}, \text{ and}$$

$$COV_{VM} = \frac{W_V(t)P_M(t)e^{(\mu_V+\mu_M)L}(e^{\rho_{VM}\sigma_V\sigma_M L}-1)}{(r-\mu_V)(r-\mu_M)}$$

The client and the vendor share the total utility $U(t) = U_C(t) + U_V(t)$ based on their negotiation powers. That is,

$$U_V(t) = \gamma U(t) \tag{2.5}$$

Therefore, s^* and P_{TG}^* can be solved jointly from the following maximization problem:

$$\begin{aligned} &\underset{s,P_{TG}}{Max}\, U(t) = U_C(t) + U_V(t) \\ &s.t. \quad U_V(t) = \gamma U(t) \end{aligned} \tag{2.6}$$

2.4.2 Nash Bargaining Equilibrium

Let s^* and P_{TG}^* denote the optimal gainsharing ratio and the optimal target price respectively. Solving (2.6), I have the following results.

Proposition 2.1. *A market based gainsharing contract has a unique optimal share ratio s*, which is expressed as*

$$s^* = \arg\max_{0 \le s \le 1} U(t;s) = \begin{cases} 0, & if \quad s^0 \le 0 \\ s^0, & if \ 0 < s^0 < 1 \\ 1, & if \quad s^0 \ge 1 \end{cases} \tag{2.7}$$

where

$$s^0 = 1 - \frac{(\eta_V COV_{VM} + \eta_C COV_{CM})}{(\eta_C + \eta_V) VAR_M}$$

Proof:

$$\underset{s,\, P_{TG}}{Max}\, U(t) = U_C(t) + U_V(t)$$

$$s.t. \qquad U_V(t) = \gamma U(t)$$

$$U_V(t) = [(\frac{P_{TG}s}{r} + \frac{P_M(t)e^{\mu_M L}(1-s)}{r-\mu_M}) - \frac{W_V(t)e^{\mu_V L}}{r-\mu_V}]e^{-rL} - K_V$$
$$-\eta_V \left[VAR_V + (1-s)^2 VAR_M - 2(1-s)COV_{VM}\right]e^{-2rL} \quad ;$$

$$U_C(t) = [\frac{W_C(t)e^{\mu_C L}}{r-\mu_C} - (\frac{P_{TG}s}{r} + \frac{P_M(t)e^{\mu_M L}(1-s)}{r-\mu_M})]e^{-rL} - K_C$$
$$-\eta_C \left[VARC + (1-s)^2 VAR_M - 2(1-s)COV_{CM}\right]e^{-2rL}$$

$$U(t) = U_C(t) + U_V(t)$$
$$= \frac{W_C(t)e^{(\mu_C - r)L}}{r-\mu_C} - \frac{W_V(t)e^{(\mu_V - r)L}}{r-\mu_V} - K_C - K_V - \eta_C VAR_C - \eta_V VAR_V$$
$$+ 2(1-s)(\eta_V COV_{VM} + \eta_C COV_{CM})e^{-2rL} - (1-s)^2(\eta_C + \eta_V)VAR_M e^{-2rL}$$

$\frac{\partial U(t)}{\partial P_{TG}} = 0$ implies that U(t) does not depend on P_{TG}:

U(t) is a concave function of *s*, because

$$\frac{\partial U^2(t)}{\partial s^2} = -2(\eta_C + \eta_V)VAR_M e^{-2rL} = -2(\eta_C + \eta_V)\frac{P_M^2(t)e^{2(\mu_M - r)L}(e^{\sigma_M^2 L} - 1)}{(r - \mu_M)^2} < 0\,.$$

Also, $0 \le s \le 1$. Thus, there exists a unique optimal s^* which can maximizes *U(t)*. Once I found the maximum of U(t), the constraint $U_V(t) = \gamma U(t)$ can be satisfied with appropriate P_{TG}^* since it is the only one involving P_{TG}.

$$\frac{dU(t)}{ds} = -2(\eta_V COV_{VM} + \eta_C COV_{CM}) + 2(1-s)(\eta_C + \eta_V)VAR_M$$

Suppose s^0 solves $\frac{dU(t)}{ds} = 0$, then

$$s^0 = 1 - \frac{(\eta_V COV_{VM} + \eta_C COV_{CM})}{(\eta_C + \eta_V)VAR_M}$$

$$= 1 - \frac{(\eta_V \frac{W_V(t)e^{\mu_V L}(e^{\rho_{VM}\sigma_V\sigma_M L} - 1)}{r - \mu_V} + \eta_C \frac{W_C(t)e^{\mu_C L}(e^{\rho_{CM}\sigma_C\sigma_M L} - 1)}{r - \mu_C})(r - \mu_M)}{P_M(t)e^{\mu_M L}(e^{\sigma_M^2 L} - 1)(\eta_C + \eta_V)}$$

Thus,

$$s^* = \arg\max_{0 \le s \le 1} U(t;s) = \begin{cases} 0, & if \quad s^0 \le 0 \\ s^0, & if\ 0 < s^0 < 1 \\ 1, & if \quad s^0 \ge 1 \end{cases}$$

Q.E.D.

It is interesting to find that the optimal share ratio is independent to the client's and the vendor's negotiation powers. In other words, a market based gainsharing contract's optimal share ratio between the client and the vendor is non-negotiable.

Eq. (2.7) solves the optimal share ratio to maximize the total utility. This can be illustrated by the figure below:

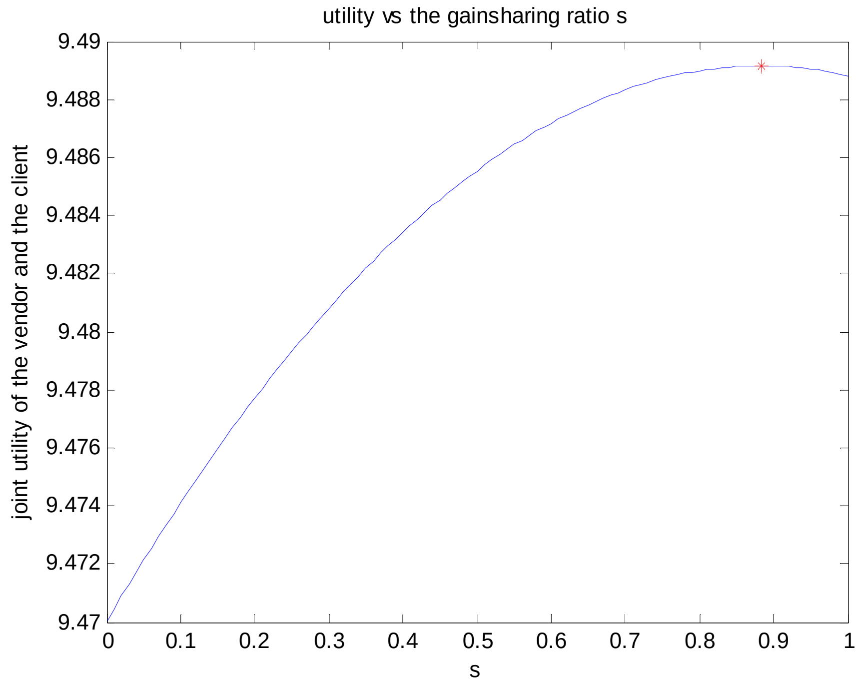

Figure 2.2 The joint utility vs. the share ratio

Accordingly, the optimal share ratio for the client will be $1-s^*$. $s^*=0$ corresponds to the case of spot market, in which the client prefers to purchase the product from an open market instead of outsourcing. If $0<s^*<1$, then the market based gainsharing contract dominates the spot market and the fixed-price contract. $s^*=1$ is the fixed-price contract where the vendor will be solely responsible for the cost overrun or saving.

I summarize my results regarding P_{TG}^* in proposition 2.2:

Proposition 2.2 *When* $0<s^0<1$, *a market based gainsharing contract has a unique optimal target price* P_{TG}^*, *which is expressed as*

$$P_{TG}^{*}=\frac{re^{rL}}{s^{*}}\left\{\begin{array}{l}\gamma[\frac{W_C(t)e^{\mu_C L}}{r-\mu_C}-(\frac{P_M(t)e^{\mu_M L}(1-s^{*})}{r-\mu_M})]e^{-rL}-\gamma K_C\\-(1-\gamma)[(\frac{P_M(t)e^{\mu_M L}(1-s^{*})}{r-\mu_M})-\frac{W_V(t)e^{\mu_V L}}{r-\mu_V}]e^{-rL}+(1-\gamma)K_V\\-\gamma\eta_C e^{-2rL}[VAR_C+(1-s^{*})^2 VAR_M-2(1-s^{*})COV_{CM}]\\+(1-\gamma)\eta_V e^{-2rL}[VAR_V+(1-s^{*})^2 VAR_M-2(1-s^{*})COV_{VM}]\end{array}\right\} \tag{2.8}$$

Proof:

P_{TG} can be solved from $U_V(t)=\gamma U(t)$ or equivalently $(1-\gamma)U_V(t)=\gamma U_C(t)$

$$(1-\gamma)U_V(t)=(1-\gamma)\left\{\begin{array}{l}[(\frac{P_{TG}s^{*}}{r}+\frac{P_M(t)e^{\mu_M L}(1-s^{*})}{r-\mu_M})-\frac{W_V(t)e^{\mu_V L}}{r-\mu_V}]e^{-rL}-K_V\\-\eta_V(VAR_V+(1-s^{*})^2 VAR_M-2(1-s^{*})COV_{VM})e^{-2rL}\end{array}\right\};$$

$$\gamma U_C(t)=\gamma\left\{\begin{array}{l}[\frac{W_C(t)e^{\mu_C L}}{r-\mu_C}-(\frac{P_{TG}s^{*}}{r}+\frac{P_M(t)e^{\mu_M L}(1-s^{*})}{r-\mu_M})]e^{-rL}-K_C\\-\eta_C(VAR_C+(1-s^{*})^2 VAR_M-2(1-s^{*})COV_{CM})e^{-2rL}\end{array}\right\};$$

Thus,

$$P_{TG}^{*}=\frac{re^{rL}}{s^{*}}\left\{\begin{array}{l}\gamma[\frac{W_C(t)e^{\mu_C L}}{r-\mu_C}-(\frac{P_M(t)e^{\mu_M L}(1-s^{*})}{r-\mu_M})]e^{-rL}-\gamma K_C\\-(1-\gamma)[(\frac{P_M(t)e^{\mu_M L}(1-s^{*})}{r-\mu_M})-\frac{W_V(t)e^{\mu_V L}}{r-\mu_V}]e^{-rL}+(1-\gamma)K_V\\-\gamma\eta_C[VAR_C+(1-s^{*})^2 VAR_M-2(1-s^{*})COV_{CM}]e^{-2rL}\\+(1-\gamma)\eta_V[VAR_V+(1-s^{*})^2 VAR_M-2(1-s^{*})COV_{VM}]e^{-2rL}\end{array}\right\}$$

While the optimal share ratio is non-negotiable, the optimal target price is clearly dependent on the client's and the vendor's negotiation powers.

Based on propositions 2.1 and 2.2, I present the Nash bargaining equilibrium of a market based gainsharing contract in the following Theorem.

Theorem 2.1. *When* $0 < s^0 < 1$*, a market based gainsharing contract has a unique equilibrium* (P_{TG}^*, s^*)*. The negotiation is not over the share ratio but over the target price only.*

According to Theorem 2.1, a market based gainsharing contract's optimal share ratio is non-negotiable, because the client and the vendor have to take the naturally existing s^* in order to maximize their total utility gain. However, to maximize their own utilities, the client and the vendor should negotiate the optimal target price based on their negotiation powers.

2.4.3 Discussion on the Target Price and the Share Ratio

In this section, by studying how the cost/price volatilities and correlations affect the optimal share ratio and the target price under a gainsharing contract($0 < s^0 < 1$), I provide some practical guidelines for managers to pursue the optimal gainsharing contract. However, given the compound relations among those parameters, it is difficult to obtain analytical comparative statics for all parameters. Thus, I conduct extensive numerical analyses instead when the analytical results are not available.

I provide a basis for the numerical analysis by assuming that the risk-aversion coefficients for the client and the vendor are same (i.e., $\eta_C = \eta_V = 0.01$). I take $W_V(t) = 0.2$, $W_C(t) = 0.5$ and $P_M(t) = 0.3$. I assume lead time $L = 5$ and the initial costs for the client and the vendor are: $K_C = 0.1$ and $K_V = 0.1$. The capital cost $r = 0.12$ and the shift rates of the expected future changes in cost and price are: $\mu_M = 0.11$,

$\mu_C = 0.10$, and $\mu_V = 0.09$, respectively. The uncertainty rates are $\sigma_M = 0.04$, $\sigma_C = 0.01$, and $\sigma_V = 0.01$. The correlation coefficients are $\rho_{CM} = \rho_{VM} = 0.9$. In the numerical analysis, I vary σ_M, σ_C and σ_V from 0.00 to 0.05, L from 1 to 10, ρ_{CM} and ρ_{VM} from 0.0 to 1.0, respectively. In Figures 6-10, I vary one parameter at a time and hold other parameters constant in order to study the effect of that varying parameter's impact on the target price. I summarize the results as follows:

Properties of the optimal share ratio s^*: *Given other conditions stable, a larger share should be assigned to the client when*

(1) *The cost is more volatile (larger σ_V or larger σ_C);*

(2) *The cost is highly correlated with the spot market (larger ρ_{VM} or larger ρ_{CM});*

Proof:

$$\frac{\partial(1-s^*)}{\partial\sigma_V} = \frac{\eta_V \dfrac{W_V(t)e^{\mu_V L}e^{\rho_{VM}\sigma_V\sigma_M L}}{r-\mu_V}(r-\mu_M)}{P_M(t)e^{\mu_M L}(e^{\sigma_M^2 L}-1)(\eta_C+\eta_V)}\rho_{VM}\sigma_M L$$
$$= \frac{\eta_V W_V(t)e^{\mu_V L}e^{\rho_{VM}\sigma_V\sigma_M L}(r-\mu_M)}{P_M(t)e^{\mu_M L}(e^{\sigma_M^2 L}-1)(\eta_C+\eta_V)(r-\mu_V)}\rho_{VM}\sigma_M L > 0$$

$$\frac{\partial(1-s^*)}{\partial\sigma_C} = \frac{\eta_C \dfrac{W_C(t)e^{\mu_C L}e^{\rho_{CM}\sigma_C\sigma_M L}}{r-\mu_C}(r-\mu_M)}{P_M(t)e^{\mu_M L}(e^{\sigma_M^2 L}-1)(\eta_C+\eta_V)}\rho_{CM}\sigma_M L$$
$$= \frac{\eta_C(r-\mu_M)W_C(t)e^{(\mu_C+\rho_{CM}\sigma_C\sigma_M)L}}{P_M(t)e^{\mu_M L}(e^{\sigma_M^2 L}-1)(\eta_C+\eta_V)(r-\mu_C)}\rho_{CM}\sigma_M L > 0$$

$$\frac{\partial(1-s^*)}{\partial\rho_{CM}}=\frac{\eta_C\dfrac{W_C(t)e^{\mu_C L}e^{\rho_{CM}\sigma_C\sigma_M L}}{r-\mu_C}(r-\mu_M)}{P_M(t)e^{\mu_M L}(e^{\sigma_M^2 L}-1)(\eta_C+\eta_V)}\sigma_C\sigma_M L$$

$$=\frac{\eta_C(r-\mu_M)W_C(t)e^{(\mu_C+\rho_{CM}\sigma_C\sigma_M)L}}{P_M(t)e^{\mu_M L}(e^{\sigma_M^2 L}-1)(\eta_C+\eta_V)(r-\mu_C)}\sigma_C\sigma_M L>0$$

$$\frac{\partial(1-s^*)}{\partial\rho_{VM}}=\frac{\eta_V\dfrac{W_V(t)e^{\mu_V L}e^{\rho_{VM}\sigma_V\sigma_M L}}{r-\mu_V}(r-\mu_M)}{P_M(t)e^{\mu_M L}(e^{\sigma_M^2 L}-1)(\eta_C+\eta_V)}\sigma_V\sigma_M L$$

$$=\frac{\eta_V(r-\mu_M)W_V(t)e^{(\mu_V+\rho_{VM}\sigma_V\sigma_M)L}}{P_M(t)e^{\mu_M L}(e^{\sigma_M^2 L}-1)(\eta_C+\eta_V)(r-\mu_V)}\sigma_V\sigma_M L>0$$

Since $\eta_V>0,\eta_C>0,W_V(t)>0,W_C(t)>0,P_M(t)>0,\sigma_M^2>0,L>0,\rho_{VM}>0,\rho_{CM}>0,$ $r>\mu_V$, $r>\mu_C$ and $r>\mu_M$.

Q.E.D.

Recall $P(\tau)=P_{TG}s+P_M(\tau)(1-s)$, the share of the client under a market based gainsharing contract is actually the weight of the market price in the final gainsharing price. Part (1) reveals that the more volatile the cost is, the more difficult to compute the benefits of the gainsharing contract. Thus, in order to coordinate the joint operation formed by the vendor and the client, the final gainsharing price should rely more on the market price to mitigate the risks in the large potential cost overrun or reduction. Part (2) suggests that if the cost is more correlated with the market price, the market price should take a larger weight in the final gainsharing price.

The relationship between the share ratio (1- s^*) and the market volatility can be derived as follows:

$$\frac{\partial(1-s^*)}{\partial\sigma_M}=\frac{\left(\eta_V\frac{W_V(t)e^{\mu_V L}(e^{\rho_{VM}\sigma_V\sigma_M L}-1)}{r-\mu_V}+\eta_C\frac{W_C(t)e^{\mu_C L}(e^{\rho_{CM}\sigma_C\sigma_M L}-1)}{r-\mu_C}\right)(r-\mu_M)}{P_M(t)e^{\mu_M L}(\eta_C+\eta_V)}\frac{-e^{\sigma_M^2 L}2\sigma_M L}{(e^{\sigma_M^2 L}-1)^2}$$
$$+\frac{\left(\eta_V\frac{W_V(t)e^{\mu_V L}(e^{\rho_{VM}\sigma_V\sigma_M L}\rho_{VM}\sigma_V L)}{r-\mu_V}+\eta_C\frac{W_C(t)e^{\mu_C L}(e^{\rho_{CM}\sigma_C\sigma_M L}\rho_{CM}\sigma_C L)}{r-\mu_C}\right)(r-\mu_M)}{P_M(t)e^{\mu_M L}(e^{\sigma_M^2 L}-1)(\eta_C+\eta_V)}$$
$$=\frac{\left(\eta_V\frac{W_V(t)e^{\mu_V L}(e^{\rho_{VM}\sigma_V\sigma_M L}-1)}{r-\mu_V}+\eta_C\frac{W_C(t)e^{\mu_C L}(e^{\rho_{CM}\sigma_C\sigma_M L}-1)}{r-\mu_C}\right)(r-\mu_M)}{P_M(t)e^{\mu_M L}(\eta_C+\eta_V)}\frac{-e^{\sigma_M^2 L}2\sigma_M L}{(e^{\sigma_M^2 L}-1)^2}$$
$$+\frac{\left(\eta_V\frac{W_V(t)e^{\mu_V L}(e^{\rho_{VM}\sigma_V\sigma_M L}\rho_{VM}\sigma_V L)}{r-\mu_V}+\eta_C\frac{W_C(t)e^{\mu_C L}(e^{\rho_{CM}\sigma_C\sigma_M L}\rho_{CM}\sigma_C L)}{r-\mu_C}\right)(r-\mu_M)(e^{\sigma_M^2 L}-1)}{P_M(t)e^{\mu_M L}(e^{\sigma_M^2 L}-1)^2(\eta_C+\eta_V)}$$

Because it is difficult to obtain the sign of $\frac{\partial(1-s^*)}{\partial\sigma_M}$, I provide numerical experiments and depict the relationship in Figures C.

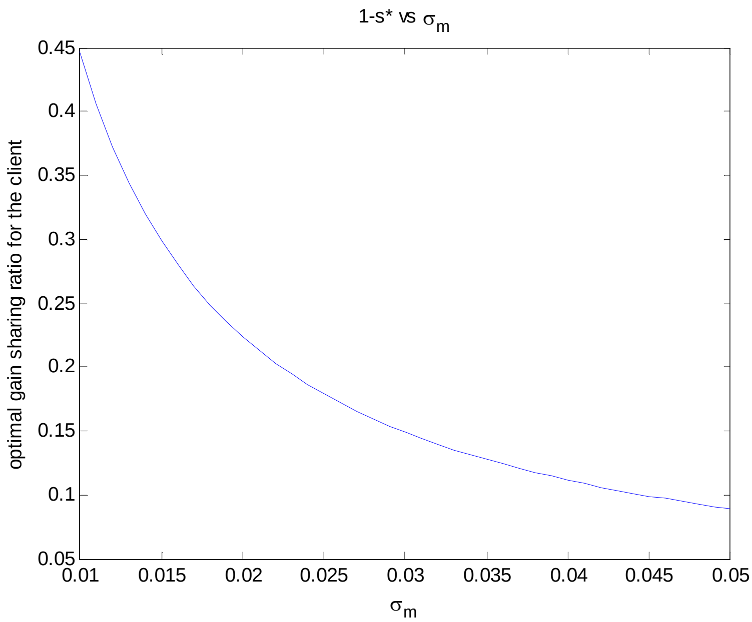

Figure 2.3 1-s^* vs σ_M

This figure indicates that as the uncertainty in the market price increases, the client and the vendor should rely less on the market in order to coordinate the joint operation.

According to the Theorem 2.1, I know the client and the vendor of a market based gainsharing contract only need to negotiate on P_{TG}^*. As a result, it is necessary to provide some negotiation strategies for managers. I conduct extensive numerical analyses and summarize the results as follows:

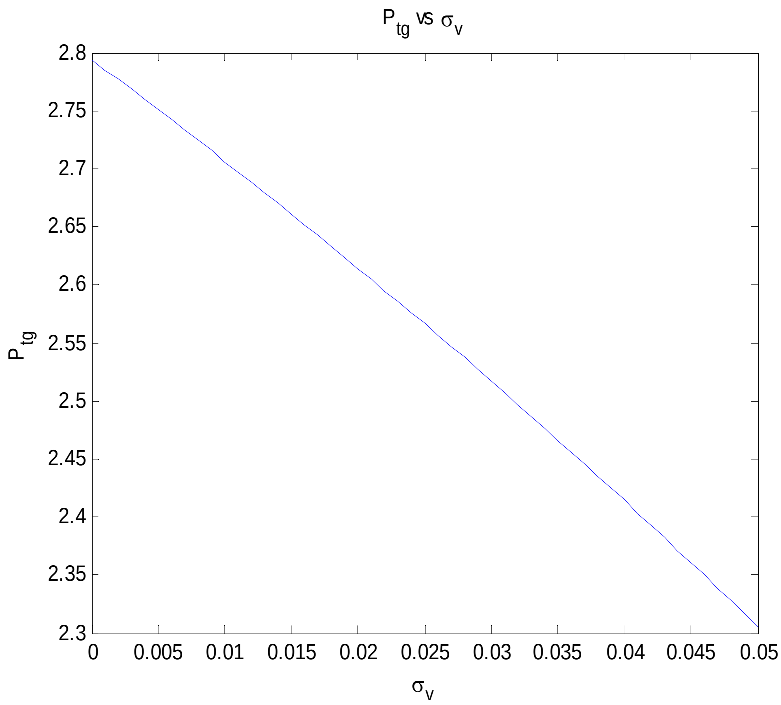

Figure 2.4 P_{TG}^* vs σ_V

This figure illustrates that since the vendor's cost is highly uncertain, it will become difficult for the risk-averse client to calculate his/her responsibility to the cost overrun or saving in the final gainsharing price, $P(\tau) = P_{TG}s + P_M(\tau)(1-s)$. To enter a gain-sharing contract, the client should ask a lower target price, which can lower the client's risk.

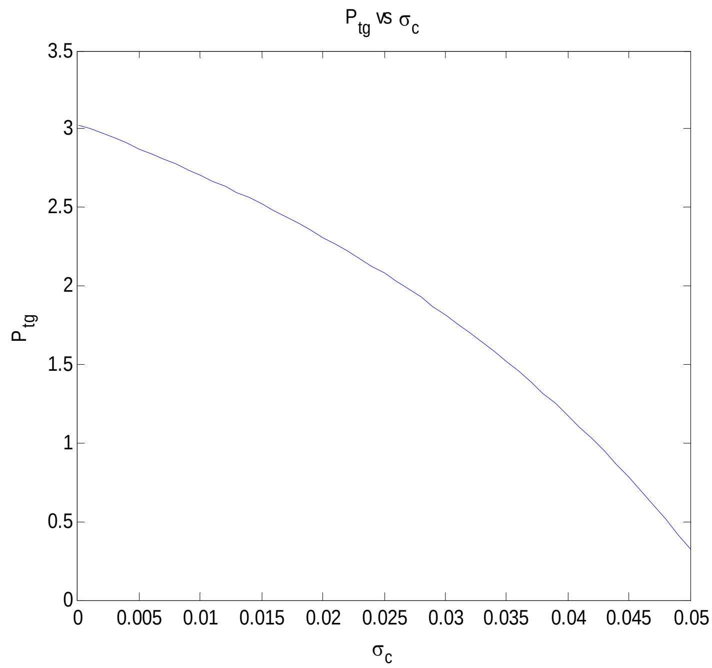

Figure 2.5 P_{TG}^{*} vs σ_C

This figure shows that when the client's cost is highly uncertain, it will become difficult for the risk-averse client to determine the benefits of outsourcing. Therefore, the client should ask a lower target price to hedge the outsourcing risk.

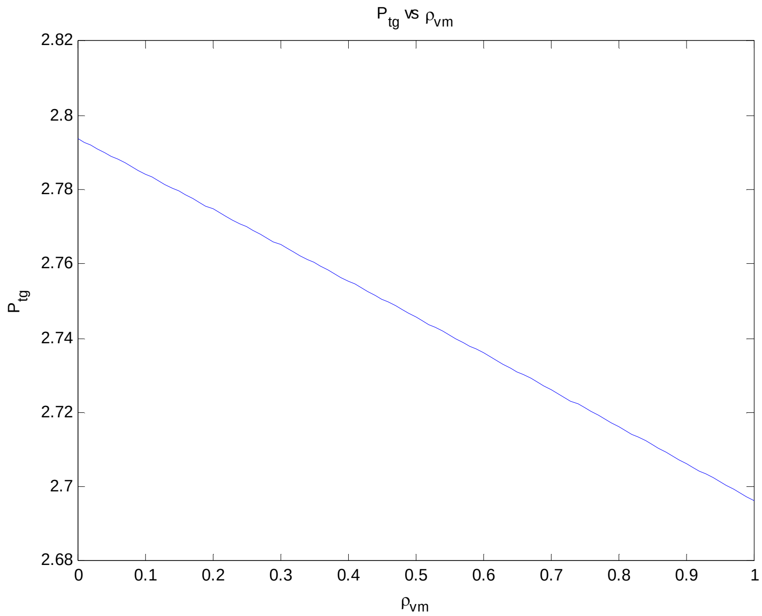

Figure 2.6 P_{TG}^{*} vs ρ_{VM}

This figure shows that the correlation coefficient ρ_{VM} has a negative relationship with the optimal target price (see Figure 5). ρ_{VM} measures how much the vendor's cost is correlated with the market price. When the vendor's cost is highly correlated the market price, the client can more accurately predict its outsourcing expenses due to the market reference. If the target price the vendor is too high (e.g., close to the spot market price), the client may simply purchase from the spot market rather than enter the gain-sharing contract.

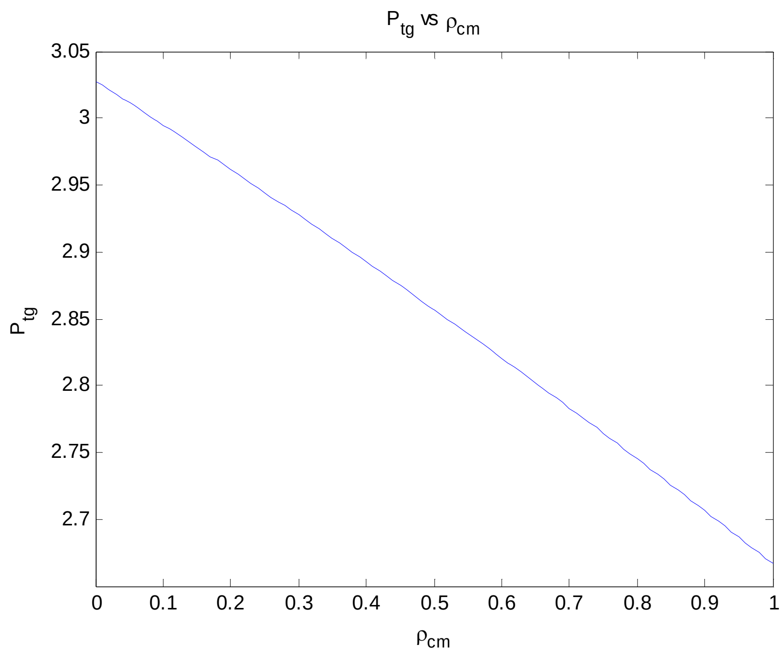

Figure 2.7 P^*_{TG} vs ρ_{CM}

This figure demonstrates that the correlation coefficient ρ_{CM} has a negative effect on the optimal target price. When the client's cost is highly correlated the market price, the risk of the market-based gain-sharing contract will increase. Hence, the client needs a lower target price to engage in the gain-sharing contract and enjoy the risk-hedging benefits.

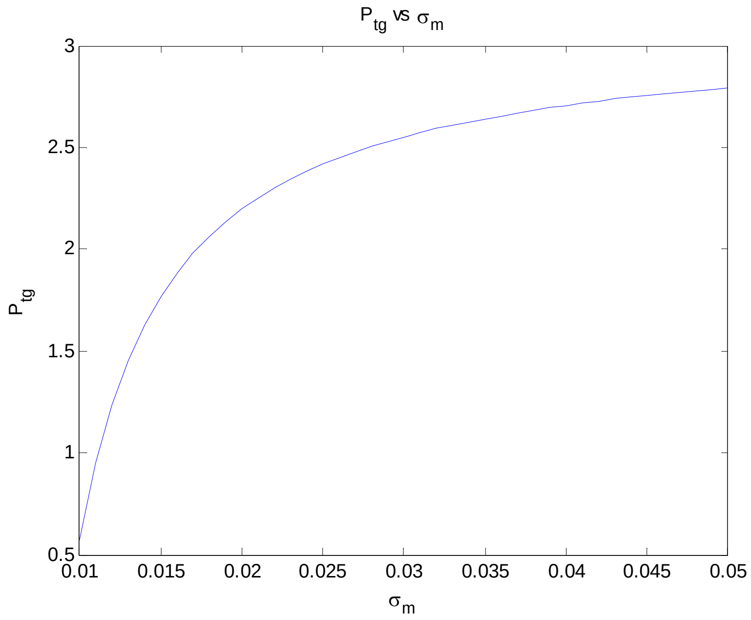

Figure 2.8 P^*_{TG} vs σ_M

This figure depicts that the market uncertainty is positively proportional to the target price. When the market's is more stable, the client will not ask a higher target price to protect the future market risk. As noted in this figure, the positive effect of the market price uncertainty on the target price is diminishing as the market price uncertainty increase. The reason is that when the market price is highly uncertain, the gain-sharing contract will behave similar to the fixed price contract and the optimal target price will be close to the optimal whole sale price.

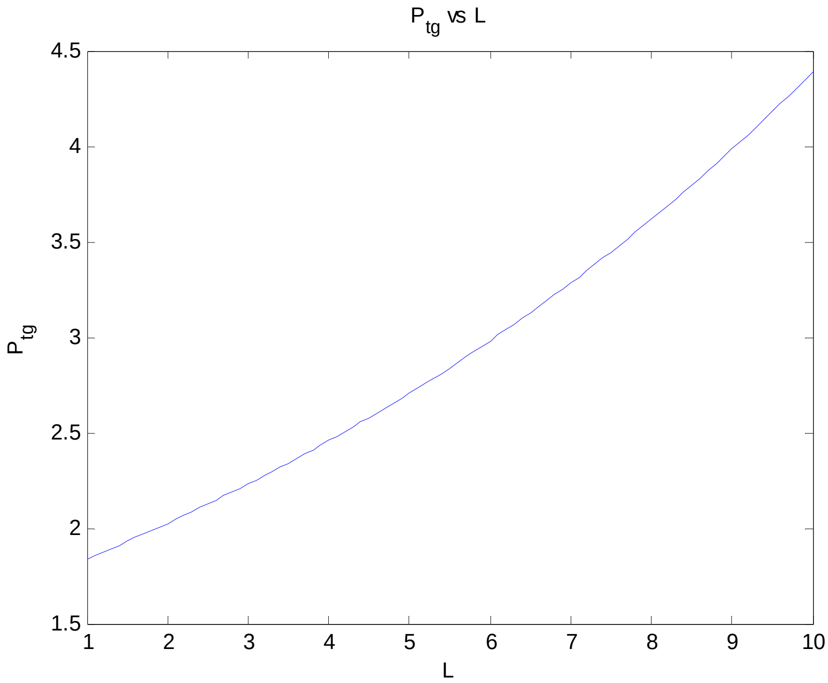

Figure 2.9 P^*_{TG} vs L

This figure shows that the target price is positively proportional to the lead time. As the lead-time decreases, the market price at delivery will be more certain. Thus, the vendor cannot ask a higher target price to hedge risk.

2.5 Further Guidance on Contract Selection

While the market based gainsharing contract can help client and vendor reduce their risks under the uncertainties of costs and market, it is obvious that such a contract is not a universal solution because this contract does not dominate in outsourcing. In this section, I investigate the boundaries of market based gainsharing contract, i.e., when managers should and should not consider it.

If I restrict $P_{TG}^{*} \geq 0$, I have the following theorem:

Theorem 2.2 *There is a threshold 1-* γ^{L} *for the client's negotiation power. A client with negotiation power larger than 1-* γ^{L} *cannot reach a gainsharing agreement with its vendor. Similarly, there is a threshold* γ^{L} *for the vendor's negotiation power. A vendor with negotiation power smaller than* γ^{L} *cannot reach a gainsharing agreement with its client.*

Proof:

$$U^{*}(t) = U_{C}^{*}(t) + U_{V}^{*}(t)$$

$$= \frac{W_{C}(t)e^{(\mu_{C}-r)L}}{r-\mu_{C}} - \frac{W_{V}(t)e^{(\mu_{V}-r)L}}{r-\mu_{V}} - K_{C} - K_{V} - \eta_{V}VAR_{V}e^{-2rL} - \eta_{C}VAR_{C}e^{-2rL}$$
$$+ 2(1-s^{*})(\eta_{V}COV_{VM} + \eta_{C}COV_{CM})e^{-2rL} - (1-s^{*})^{2}(\eta_{C} + \eta_{V})VAR_{M}e^{-2rL}$$

$$U_{V}^{*}(t) = [(\frac{P_{TG}s^{*}}{r} + \frac{P_{M}(t)e^{\mu_{M}L}(1-s^{*})}{r-\mu_{M}}) - \frac{W_{V}(t)e^{\mu_{V}L}}{r-\mu_{V}} -]e^{-rL} - K_{V} - \eta_{V}[VAR_{V} + (1-s^{*})^{2}VAR_{M}$$
$$- 2(1-s^{*})COV_{VM}]e^{-2rL}$$

$$U_{V}^{*}(t) = \gamma U^{*}(t) \Rightarrow \gamma = \frac{U_{V}^{*}(t)}{U^{*}(t)}$$

Clearly γ is an increasing function of P_{TG}. Thus, γ^{L} is obtained by setting $P_{TG} = 0$ in the above equation and constrained to [0, 1]. Define

$$U_{V}^{*,0}(t) = U_{V}^{*}(t)\Big|_{P_{TG}=0} = [(\frac{P_{M}(t)e^{\mu_{M}L}(1-s^{*})}{r-\mu_{M}}) - \frac{W_{V}(t)e^{\mu_{V}L}}{r-\mu_{V}} -]e^{-rL} - K_{V} - \eta_{V}e^{-2rL}[VAR_{V}$$
$$+ (1-s^{*})^{2}VAR_{M} - 2(1-s^{*})COV_{VM}]$$

Thus, $\gamma^{L} = \min(0, \frac{U_V^{*,0}(t)}{U^{*}(t)})$ where $U_V^{*,0}(t)$ and are $U^{*}(t)$ defined above.

Theorem 2.2 reveals that only if the client's and the vendor's negotiation powers are relatively close, the market based gainsharing contract can exist. This theorem exactly reflects the reason why gainsharing contracts did not emerge in China until recently. Traditionally, local suppliers in China were often in a subordinate position in buyer-driven value chains. They did not have necessary marketing channels to reach end customers in developed countries. Thus, they were very dependent on international buyers. In other words, the bargaining power between global buyers and Chinese suppliers was extremely unequal, allowing the powerful buyers to squeeze purchasing prices (Browning, et al., 1995; Frenkel, 2001). After two decades development and the growth of outsourcing, some Chinese suppliers have begun to dominate their industries after beating their local competitors and the global buyers have became more and more dependent on such Chinese suppliers. Thus, these Chinese suppliers have gained more negotiation powers, which enable them to require gainsharing contracts rather than using traditional fixed-price contracts.

As discussed earlier, the value of the optimal gainsharing ratio determines the types of contracts the client and the vendor could agree on. $s^{*} = 0$ ($s^{0} \leq 0$) corresponds to the case of spot market trade where the client prefers to purchase from an open market. $s^{*} = 1$ ($s^{0} \geq 1$) is the scenario of a fixed-price contract where the vendor will be solely responsible for the cost overrun or reduction. Figure 2.10-2.11 illustrates how the optimal share ratio is affected by the uncertainties in vendor's and client's costs. As shown in

Figure 2.10, the region of σ_V and σ_C corresponding to $s^0 > 0$ (Region B in Figure 2.11) is the region where the market based gainsharing contract is optimal. The remaining region (Region A in Figure 2.11) corresponding to $s^0 \leq 0$ is the region where the spot market is optimal. As indicated in Figure 8a, s^0 is always less than 1, indicating that the fixed-price contract is never optimal. However, for some extreme small values of σ_V and σ_C, $s^0 \to 1$ and the optimal gainsharing contract will be close to the fixed-price contract. I summarize this result in the following theorems that can help the decision makers to select the appropriate contract.

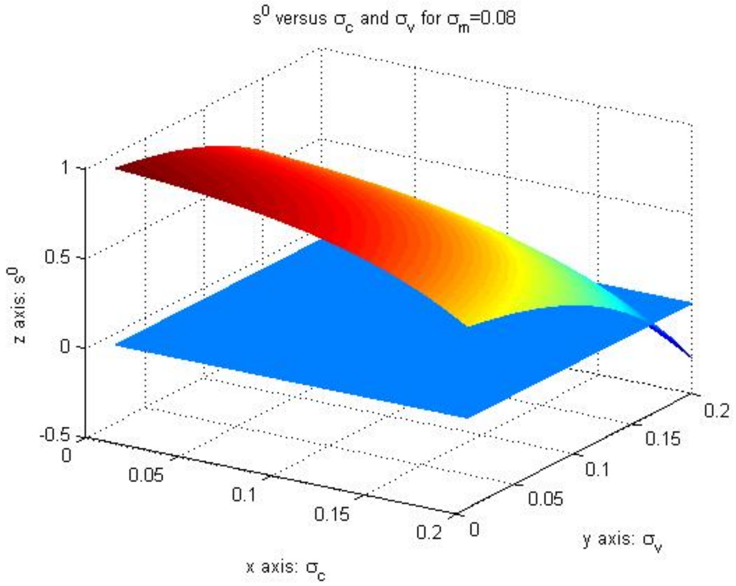

Figure 2.10 s^0 vs σ_V and σ_C

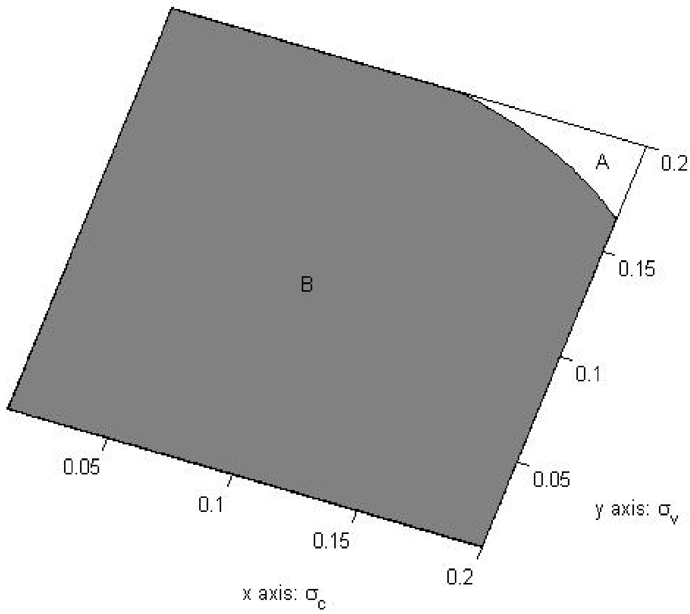

Figure 2.11 Projection of figure 2.10

Theorem 2.3. *Fixed-price contract is never optimal for risk-averse decision makers. However, if* $\frac{(\eta_V COV_{VM} + \eta_C COV_{CM})}{(\eta_C + \eta_V) VAR_M} \to 0$*, then a gainsharing contract would approach to a fixed-price contract.*

Proof:

$$s^0 = 1 - \frac{(\eta_V COV_{VM} + \eta_C COV_{CM})}{(\eta_C + \eta_V) VAR_M}$$

$$= 1 - \frac{(\eta_V \frac{W_V(t) e^{\mu_V L}(e^{\rho_{VM}\sigma_V\sigma_M L} - 1)}{r - \mu_V} + \eta_C \frac{W_C(t) e^{\mu_C L}(e^{\rho_{CM}\sigma_C\sigma_M L} - 1)}{r - \mu_C})(r - \mu_M)}{P_M(t) e^{\mu_M L}(e^{\sigma_M^2 L} - 1)(\eta_C + \eta_V)}$$

The assumptions indicate that $\eta_V > 0, \eta_C > 0, W_V(t) > 0,\ W_C(t) > 0, P_M(t) > 0,$ $\sigma_M^2 > 0, L > 0, \rho_{VM} > 0, \rho_{CM} > 0,\ r > \mu_V,\ r > \mu_C$ and $r > \mu_M$.

Thus, $\dfrac{(\eta_C \dfrac{W_V(t)e^{\mu_V L}(e^{\rho_{VM}\sigma_V\sigma_M L}-1)}{r-\mu_V} + \eta_V \dfrac{W_C(t)e^{\mu_C L}(e^{\rho_{CM}\sigma_C\sigma_M L}-1)}{r-\mu_C})(r-\mu_M)}{P_M(t)e^{\mu_M L}(e^{\sigma_M^2 L}-1)(\eta_C+\eta_V)}$ >0,

which implies that s^0<1. Therefore, the fixed-price contract is never optimal.

However, if $\dfrac{(\eta_C \dfrac{W_V(t)e^{\mu_V L}(e^{\rho_{VM}\sigma_V\sigma_M L}-1)}{r-\mu_V} + \eta_V \dfrac{W_C(t)e^{\mu_C L}(e^{\rho_{CM}\sigma_C\sigma_M L}-1)}{r-\mu_C})(r-\mu_M)}{P_M(t)e^{\mu_M L}(e^{\sigma_M^2 L}-1)(\eta_C+\eta_V)}$ $\to 0$, it is better for the decision maker to choose the fixed price contract as it is easy to implement and monitor.

Theorem 2.3 reveals that the fixed-price contract will be dominated by the market based gainsharing contract if the operating costs and the market price are volatile. However, if the operating costs are deterministic and the market price is volatile, i.e., $\sigma_C = \sigma_V = 0$, $\sigma_M > 0$. I summarize one interesting scenarios in the following lemma.

Lemma: In the extreme case where $\sigma_M > 0$ and $\sigma_V = \sigma_C = 0$, $s^0 = 1$ and the fixed price contract is optimal.

Proof:

If $\sigma_M > 0$ and $\sigma_V = \sigma_C = 0$, then

$$\frac{(\eta_C \dfrac{W_V(t)e^{\mu_V L}(e^{\rho_{VM}\sigma_V\sigma_M L}-1)}{r-\mu_V} + \eta_V \dfrac{W_C(t)e^{\mu_C L}(e^{\rho_{CM}\sigma_C\sigma_M L}-1)}{r-\mu_C})(r-\mu_M)}{P_M(t)e^{\mu_M L}(e^{\sigma_M^2 L}-1)(\eta_C+\eta_V)} = 0.$$

Thus s^*=1 which indicates that the fixed price contract is optimal.

Furthermore, if the market price is much more volatile than operations costs, the market based gain-sharing contract would approach to a fixed-price contract. This model sheds some lights on the evolution of the outsourcing contract in China. As I noted in the introduction, the gainsharing contract started to emerge in China in 2008 due to the increase of cost uncertainty. Before that, the fixed-price dominates which can be explained by this Lemma. However, as the cost uncertainty increases, the gainsharing contract will outperform the fixed-price contract which is exactly why some of the Chinese manufacturers started to sign gainsharing contract with the international buyers. However, based on Theorem 2.3, I also note that for certain Chinese manufacturers, the benefits of gainsharing contract may not be that significant they will just stay with the fixed price contract which also reflected the practice since not all the Chinese suppliers signed gainsharing contract with the international buyers.

I now look at the case when the spot market is optimal.

Theorem 2.4. *The spot market case is optimal when* $\eta_V COV_{VM} + \eta_C COV_{CM} > (\eta_C + \eta_V) VAR_M$.

Proof:

From Eq. (2.7), the spot market case is optimal when $s^* = 0$ which implies:

$$1 - \frac{(\eta_V COV_{VM} + \eta_C COV_{CM})}{(\eta_C + \eta_V) VAR_M} \leq 0$$

$(\eta_C + \eta_V) VAR_M = (\eta_C + \eta_V) \dfrac{P_M^2(t) e^{2\mu_M L}(e^{\sigma_M^2 L} - 1)}{(r - \mu_M)^2}$ >0. Thus the spot market case is optimal when $\eta_V COV_{VM} + \eta_C COV_{CM} \geq (\eta_C + \eta_V) VAR_M$.

Theorem 2.4 shows that when the operations costs are more volatile than the market, the client should use the spot market trade instead of outsourcing.

This model sheds lights on the evolution of outsourcing contracts in China. Previously, fixed-price contracts dominated the outsourcing market in China. Recently, however, the cost uncertainties significantly increase in China (i.e., $\sigma_V \uparrow$) and clients and suppliers become more conservative (i.e., $\eta_C > 0; \eta_V > 0$) under uncertainties, the market based gain-sharing contract begins to outperform the fixed-price contract.

Table 2.2 shows the qualitative description of strategies based on different scenarios:

Table 2.2 Qualitative description of strategies based on different scenarios

Scenario	Contract Selection
$\dfrac{(\eta_C \dfrac{W_V(t)e^{\mu_V L}(e^{\rho_{VM}\sigma_V\sigma_M L}-1)}{r-\mu_V} + \eta_V \dfrac{W_C(t)e^{\mu_C L}(e^{\rho_{CM}\sigma_C\sigma_M L}-1)}{r-\mu_C})(r-\mu_M)}{P_M(t)e^{\mu_M L}(e^{\sigma_M^2 L}-1)(\eta_C+\eta_V)} \to 0$	*Fixed-price contract*
$\dfrac{(\eta_C \dfrac{W_V(t)e^{\mu_V L}(e^{\rho_{VM}\sigma_V\sigma_M L}-1)}{r-\mu_V} + \eta_V \dfrac{W_C(t)e^{\mu_C L}(e^{\rho_{CM}\sigma_C\sigma_M L}-1)}{r-\mu_C})(r-\mu_M)}{P_M(t)e^{\mu_M L}(e^{\sigma_M^2 L}-1)(\eta_C+\eta_V)} > 1$	*spot market case*
$0 < \dfrac{(\eta_C \dfrac{W_V(t)e^{\mu_V L}(e^{\rho_{VM}\sigma_V\sigma_M L}-1)}{r-\mu_V} + \eta_V \dfrac{W_C(t)e^{\mu_C L}(e^{\rho_{CM}\sigma_C\sigma_M L}-1)}{r-\mu_C})(r-\mu_M)}{P_M(t)e^{\mu_M L}(e^{\sigma_M^2 L}-1)(\eta_C+\eta_V)} < 1$	*Gain-sharing contract*

2.6 Concluding Remarks and Managerial Guidelines

This study provides a continuous-time analysis on the emerging market based gainsharing contract in outsourcing. The first purpose of this study is to identify the performance target P_{TG}^{*} and the optimal share ratio s^{*} of a gainsharing contract, and the second purpose is to address the determinants that influence P_{TG}^{*} and s^{*}.

Theorem 2.1 implies that the share ratio is selected to maximize the total utility, and the target price is then chosen according to the market power. There are two key insights from Theorem 2.1.

First, if the vendor and clients are risk-averse and $0 < s^{*} < 1$, the gain sharing contract does have benefits over the spot market and the fixed-price contract. In the tight air of the recent economic recession, more and more Chinese suppliers and Western buyers have become more risk-averse. This may explain why the market based gainsharing contract is emerging recently.

Second, although a market based gainsharing contract is defined by both the share ratio and the target price, the negotiation is only over the target price and not over the share ratio. As indicated by Theorem 2.1, no matter what their negotiation power is, both parties agree on the same optimal share ratio, while the bargaining power only affects the optimal target price. This has important implication in practice in that the managers should focus on the performance target (target price) instead of the sharing mechanism when they negotiate a market based gainsharing outsourcing contract.

Theorem 2.2 states the necessary condition of a market based gainsharing contract: only if the client's and the vendor's negotiation powers are relatively close, the gainsharing can exist.

Finally, Theorem 2.3 and 2.4 provide the guideline for outsourcing contract selection. For the risk-averse vendor and client, the fixed-price contract is always not optimal. This has important implications in practice and can simplify the decision map for the managers when they deal with outsourcing options.

This study can be extended in several ways. First, one can consider the learning effect that takes into account the fact the vendor can reduce the cost faster than the client expects, because the vendor can produce similar product for multiple clients thereby accumulating relevant learning curves. Second, I did not consider the optimal timing to start the outsourcing operation in this study. One could set up an optimal stopping problem where the optimal outsourcing can be derived. Finally, I only consider one client and one vendor for simplicity. Future studies are encouraged to explore the situations involving multiple clients and vendors.

Chapter 3

Incentive Outsourcing Contracts For Technology Adoption: A Principal Agent Perspective

In this chapter, I analyze how the client can stimulate the vendor to adopt a new technology based on the incentive outsourcing contract. Such incentive outsourcing contract is based on investment timing where agency issues occur in an outsourcing setting. The incentive contract provides incentives for vendors to both make costly efforts and truthfully share private information. I show how to derive the optimal parameters for such an incentive outsourcing contract and the effects of agency issues.

3.1 Introduction

The continuous environmental deterioration has drastically increased the consumer's awareness of environmental problems (Boeck and Ward, 1997). Carter and Narasimhan (2000) predict that there will be a rapid increase in the consumer awareness of environmental issues in this decade. According to the 2009 Cone Consumer Environmental Survey, American consumers' interests in the environment have not been decreased given the current state of the economy. Instead, many consumers are inclined to hold companies accountable for their environmental commitments today and in the future. Here are some of the stats from the survey:

"35 percent of Americans have higher interest in the environment today than they did one year ago;

35 percent of Americans have higher expectations for companies to make and sell environmentally responsible products and services during the economic downturn; and,

70 percent of Americans indicate that they are paying attention to what companies are doing with regard to the environment today, even if they cannot buy until the future."

Many companies are aware of their environmental accountabilities. One of the ambitious goals of Wal-Mart is to sell products that sustain Wal-Mart's resources and the environment and to implement a "green" supply chain. In order to meet this goal, their new sustainability strategy would need to be deeply embedded in Wal-Mart's operations and supply chain management (Plambeck (2007)). In this global environment where many firms are sourcing their manufacturing operations overseas to take advantage of the low cost of material and labor in emerging market, the whole supply chain needs to be integrated and coordinated in order to make and sell the green products. One of the implementations of the green supply chain is to deploy the green technology in the supply chain, particular in the suppliers. Green technology refers to a group of methods and materials, from techniques for generating energy to non-toxic cleaning products to achieve sustainability (http://www.green-technology.org/what.htm). To implement a green technology in a supply chain, all the parties in the supply chain need to be coordinated. In particular, the buyers need to promote such environmental practice through the whole supply chain by maintaining a good relationship with the suppliers. Simpson and Power (2005) argue that the environmental management practice of a supplier is positively affected by a relational buyer-supplier relationship. Their preliminary results also indicate that the buyer will mostly affect the supplier's environmental management practice during sourcing period. Other empirical research also suggest that the practice of green supply chain is affected by the strategic purchasing and supply management approach (Florida (1996), Min and Galle (2001) ,Bowen et al. (2001) and Crandall (2006)). Hence, one of the strategic problems faced by the outsourcing firms today is how to promote the vendor or supplier to implement the green technology to make the green products to undertake their environmental responsibility and meet the needs of the consumers. The fast green technology innovation and development provide the firms not only with new innovational opportunities but also new challenges for firms as they strive to survive in the globally competitive business environment. The ability of a firm to develop and adopt new technologies has been a crucial factor for the firm's success in many industries.

In the outsourcing context, a client and a vendor is usually cooperating under an outsourcing contract which specifies that the vendor manufactures certain goods for the client while the client sells the products directly to the end consumers. Within such agreements, it is crucial for both parties to adopt a new production technology when it is available for both parties to remain competitive in the global business environment. However, such adoption poses different questions than the traditional technology adoption by single firms. Specifically, how should the client promote the vendor to adopt such new technology at the right timing? Furthermore, the adoption cost is usually uncertain and the vendor can exert effort to reduce the expected adoption cost. How should the client modify the existing contract with vendor where information asymmetries are present because the vendor has better understanding of the adoption cost than the client. How could the client provide a contract to the vendor so that the vendor can not only exert effort to reduce the adoption cost but also truthfully reveal his adoption cost to the client?

In this study, motivated by Grenadier and Wang (2005), I propose an incentive outsourcing contract which is based on investment timing where agency conflicts and information asymmetries are present. This continuous-time contract provides incentives to induce vendors to both incur effort and truthfully disclose private cost information. I show analytically that the how to derive the optimal parameters for such incentive outsourcing contract and investment timing differs between the outsourcing solution.

The remainder of the chapter is organized as follows: the next section provides the literature review. Section 3.3 introduces the definition and the models for first-best solution and under principal-agent settings. Section 3.4 summarizes the model and presents the solutions of the model. Section 3.5 identifies the model implication and discusses the managerial insights. Section 3.6 concludes with concluding remarks and future research suggestions.

3.2 Literature Review

My study draws three streams of literature: principal agent models, outsourcing contracts and technology adoption. Grenadier and Wang (2005) consider how a firm can promote the manager to take hidden actions and truthfully reveal hidden information when the manager is delegating the firm to invest on a risky project. They found out that the investment timing could be delayed that because the manager can benefits from waiting. A handful of studies in the field of operations management have devoted to the principal-agent setting. For instance, Plambeck and Zenios (2003) use the principal agent model in a make-to-stock production system where the principal can not monitor the agent's production rate. They show that the principal, by designing a payment scheme based on inventory level, can induce the agent to adjust production in a way that can minimize the principal's expected discount cost. Gilbert and Weng (1998) compare the incentive strategies used by a coordinating agency in a service network to motivate two independent operating facilities to minimize its cost. Shumsky and Pinker (2003) study a principal-agent problem in a service context. In their study, the firm needs to design an incentive payment scheme to overcome the information asymmetry between the firm (principal) and its gatekeepers (agent), who initially diagnose the customer's problem and then may refer the customer to a specialist. They show that optimal contracts based on customer volume can be derived for both homogeneous and heterogeneous gatekeepers to achieve the first best system performance. Lovejoy (2006) uses a Bayes-Nash equilibrium concept to develop an optimal procurement mechanism for a principal to agents with finite unknown types. Schwarz and Zenios (2005) consider the case where the principal (buyer) has to develop incentive schemes when the agents' (supplier's) resource allocation and capability are all hidden to the principal. The principal's problem is to determine contracts to minimize her total expected cost. They study how the substitutability of the buyer's resource and supplier's capacity affect the level of the buyer-internal resource in the supplier's production. All these studies have added value to the existing literature on principal-agent models, but to date, no attention has been paid to the situation where the principal (client) and the agent (vendor) are already committed to a contract but the principal wants to add some additional requirements to the agent afterwards. For instance, in an outsourcing contract, through which the client has already outsourced its previous internal operations to a vendor, the client wants the vendor to adopt a newly available green technology to the vendor's existing production. In such an outsourcing context, the client has to modify the existing contract with the vendor to reduce the effect information asymmetry and minimize the adaption cost.

The second literature stream is related to supply chain/outsourcing contracts. Cachon (2005), Lariviere (1999) and Tsay and colleagues (1999) provide comprehensive reviews of the field of supply chain contracting, such as quantity flexibility contracts (Tsay, 1999), backup arrangements (Eppen & Iyer, 1997), buy back or return contracts (Emmons & Gilbert, 1998), quantity discount arrangements (Weng, 1995), wholesale price contracts (Lariviere & Porteus, 2001) and the revenue-sharing contract (Cachon & Lariviere, 2005). In addition, several scholars also have investigated supply chain contracts under competition. For instance, Cachon and Lariviere (1999) examine supplier's capacity allocation mechanisms among multiple retailers, where a supplier servies multiple retailers with a constant wholesale price. The supplier has a chosen finite capacity and has an allocation mechanism which will be used when the total orders reach the chosen capacity. In this research, I also assume that the client and the vendor are committed to a wholesale price/fixed price contract because such contract is widely used and easy to implement and negotiate. I only consider one client and one vendor in this current study and am interested in how the client can stimulate a new wholesale price contract which will motivate the vendor to exert effort and adopt a new green technology.

The last stream of literature is related to green technology adoption or in general, technology adoption. Gaimon (2008) highlights several research themes on how to manage technology from the perspective of production and operations management. In particular, the timing of technology adoption, i.e., when to invest in the adoption, has been an important consideration. For instance, Bethuyne (2002) studies the adoption timing of a technology which could reduce costs of a cost-minimizing firm. Isik (2004) studies how the uncertainty about a cost-share subsidy policy could affect the farmers' decision on the adoption of improved nutrient management technology, and reveals that the uncertainty in the policy could lead to a delay in adoption decision. In a two-stage game-theoretic model with two firms, Zhu and Weyant (2003) study how the asymmetric information about the future performance affects firms' decisions on technology adoption. The asymmetric information is defined as one firm has full information on both firms' cost function while the other has only incomplete information on its competitor's. They find that the information asymmetry results in different incentives and equilibrium strategy. In addition, they demonstrate that having better information could lead to a lower equilibrium profit under certain conditions. In addition, several scholars have addressed issues related to the impacts of outsourcing on investment timing and cost competition. For example, Ulku et al. (2005) studies how the timing of new process investment in outsourcing affects the profit under demand uncertainty. In this study, I also focus on the timing of new technology adoption so that the profit of the principle firm (client) can be maximized. However, going beyond current literature, I use the adoption timing as a contract parameter to stimulate the agent firm (vendor) to adopt a newly available green technology.

In summary, in this chapter I study how should the client modify the current outsourcing contract with the vendor so that the vendor can induce effort to adopt a new green technology in a way that the client's profit will be maximized.

3.3 The Model

A risk-neutral client and a risk-neutral vendor have been cooperating under an outsourcing contract at time 0. The vendor will deliver a product to the client at an expense of X(t). The client, in turn, can sell the product to the end consumer at the price of P(t). In this chapter, I use *she* to refer to the client and use *he* to refer to the vendor. The market size for this product for the client is normalized to 1 (i.e., M = 1). I assume that the outsourcing contract is a fixed price contract with the fixed price of F_0. When there is a newly available green technology at time 0, the client wants the vendor to adopt it. The benefits of adopting the green technology have three folds: 1. change the market size for this green product for the client to Q (i.e. M=Q); 2.increase the price of this product from P(t) to P_G(t); and 3. switch the production cost of the vendor from X(t) to Y(t). For simplicity, I assume that P(t) = P and $P_G(t)=P_G$. I further assume that $P_G>P$ which indicates that the green products will be evaluated higher by the customer than the Non-Environmentally-Friendly products. Since this technology is new, the cost of adoption, K, is uncertain. To simplify the analysis, I assume that the adaption cost may take on two possible values: K_H or K_L, with $K_H > K_L$. The probability of having a low adoption cost K_L will be q_1. Accordingly, the probability of having a high adoption cost K_H will be 1-q_1. The vendor could exert an effort at a cost of ξ at time zero to affect the probability distribution of the adoption cost and discover the true value of the adoption cost. If the vendor exerts the effort at time zero, the probability of getting a low adoption cost K_L will increase from q_1 to q_2 ($q_2 > q_1$). Accordingly, the probability of getting a high adoption cost K_H will be 1-q_2. In addition, after exerting the efforts at time zero, the vendor could observe the true value of the adoption cost. Since this technology is adopted at the vendor's end, the client can neither observe the adoption cost of this technology (hidden information) nor verify the effort of the vendor (hidden action). Hence, the client should provide incentives for the vendor so that the vendor would make the costly effort and truthfully reveal the adoption cost.

Since the old technology is already mature, the production cost X(t) will be more stable. To simplify the analysis, I assume it is X_0. After adopting the new technology, the vendor's new production cost is Y(t), which is not mature and evolves as a geometric Brownian motion:

$$dY(t) = \mu Y(t)dt + \sigma Y(t)dB(t)$$

where μ is the instantaneous conditional expected percentage change in Y(t) per unit time, σ is the instantaneous conditional standard deviation per unit time; $dB(t)$ is the increment of a standard Wiener process. For convergence purpose, I assume that $\mu < \rho$. Let Y_0 equal the observable cost of the project at time zero, i.e. Y_0 = Y(0). Such

GBM settings are good approximations for general uncertainty (Bollen,1999; Li and Kouvelis, 1999). I assume that both the vendor and the client can observe the production cost Y(t).

Thus, to adopt the new technology, both the client and the vendor have to consider two kinds of costs. One is observable and contractible to both parties, while the other is privately observed only by the vendor. The observable component is the new production cost Y(t) and the privately observed component is the adoption cost K and the effort ξ.

Although the client cannot contract on the private component, she can contract on the observable component to promote the vendor to adopt the green technology. Contingent on the level of Y(t), the client will pay the vendor based on the investment timing, i.e. the client will specify the investment timing Y(t) and the corresponding new fixed price F(Y(t)) . Given that K has only two possible values, there are at most two fixed price/adoption timing pairs: (F_L, Y_L) and (F_H, Y_H). The client wants the vendor to select pair (F_L, Y_L) the vendor observes a low adoption cost K_L and (F_H, Y_H) when the vendor observes a high adoption cost $K_{H.}$ Therefore, the new contract should promise a fixed price of F_L if the green technology is adopted at Y_L and a fixed price of F_H if technology is adopted at Y_H. This contract should guarantee the vendor truthfully reveal the adoption cost information. In other words, such a contract should assure that when the vendor privately observes K_L, he will definitely adopt the technology at the Y_L trigger instead of the Y_H trigger; when he privately observes K_H, he will adopt the technology at the F_H trigger instead of the Y_L trigger. Furthermore, the client should provide incentive for the vendor so that the vendor will exert the effort to increase the likelihood of having a low production cost.

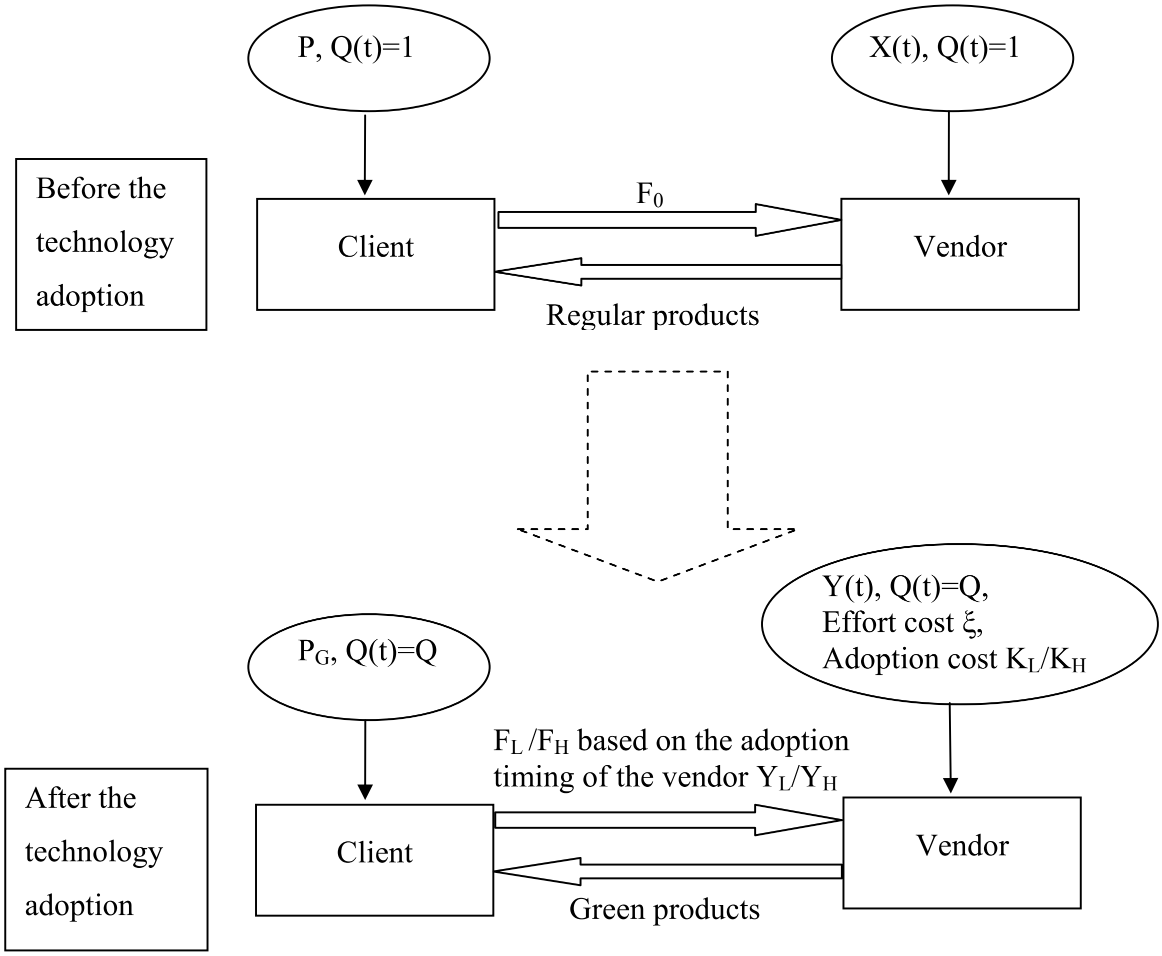

Figure 3.1 The green technology adoption problem for the client and the vendor

Figure 3.1 summarizes the setting of this research. The client and the vendor are working under a fixed price contract. At time 0, a new green technology is available and the client wants the vendor to adopt this technology. The adoption cost for this technology is uncertain and the vendor can induce efforts to increase the likelihood of incurring a low adoption cost. Thus, from the client's perspective, she faces a problem with both hidden information (the client cannot observe the true realization of K) and hidden action (the client cannot verify the vendor's effort level). The client needs to provide an incentive contract not only to prompt the vendor to adopt the technology at the right timing but also to induce the vendor's efforts of adoption and to have the vendor reveal his cost of adoption voluntarily and truthfully.

The rest of this subsection is organized as follows. In subsection 3.3.1, I derive a first-best benchmark which assumes the client can fully observe the vendor's effort and the adoption cost. In subsection 3.3.2, a principal-agent model is proposed to model the incentive contract under information asymmetry.

3.3.1 First-best Benchmark

As a benchmark, I consider the case in which there is no delegation of the technology adoption decision. The client and the vendor will cooperate as a joint venture and they observe the true value of K and adopt the technology based on the value of Y(t). Let V(Y; K) denote the benefit of the technology adoption option, in a world where K is known and Y is the level of Y(t) at time t. Before the technology adoption, the benefit of outsourcing is:

$$Z = \mathrm{E}\left[\int_0^\infty (P(\tau) - X(\tau))e^{-\rho\tau} d\tau\right]$$

After the adoption of such technology at time t, the benefit of outsourcing becomes:

$$Z^T = \max_t \mathrm{E}\left[\int_0^t (P(\tau) - X(\tau))e^{-\rho\tau} d\tau + \int_t^\infty Q(P_G(\tau) - Y(\tau))e^{-\rho\tau} d\tau - Ke^{-\rho t} - \xi\right]$$

Thus, after simplifying, the benefit of the technology adoption is:

$$V(Y;K) = Z^T - Z = \max_t \mathrm{E}\left[(\frac{X_0 + P_G Q - P}{\rho} - K - \frac{Q}{\rho - \mu} Y(t))e^{-\rho t}\right] - \xi$$

This is because $P(\tau) = \mathrm{P}$, $P_G(\tau) = P_G$, and X(τ)=X$_0$, $\forall \tau \geq 0$

I need to solve the following stopping problem.

$$V(Y;K) = \max_t \mathrm{E}\left[(\frac{X_0 + P_G Q - P}{\rho} - K - \frac{Q}{\rho - \mu} Y(t))e^{-\rho t}\right] \tag{3.1}$$

In what follows, I assume that $\frac{X_0 + P_G Q - P}{\rho} - K > 0$ for K=K$_L$ and K=K$_H$. This assumption makes sure that the technology adoption is preferable to the joint venture even when the adoption cost is high. The value of $V(Y;K)$ can be derived as follows: At each time τ , $0 \leq \tau < t$, while the product is still manufactured using the old technology, the only return for holding this option is the capital appreciation $\rho V dt$. Hence, in the continuation region (values of Y(t) for which is not to adopt the new technology) , the bellman equation is:

$$\rho V dt = E(dV)$$

Expand dV using Ito's Lemma, then

$$E(dV) = E[\mu Y V_Y dt + \frac{1}{2}\sigma^2 Y^2 V_{YY} dt + \sigma Y V_Y dB(t)]$$

$$= E[\mu Y V_Y dt + \frac{1}{2}\sigma^2 Y^2 V_{YY} dt];$$

Where V_Y is the first derivative of V with respect to Y and V_{YY} is the second derivative of V with respect to Y.

Thus, the Bellman equation is:

$$\frac{1}{2}\sigma^2 Y^2 V_{YY} + \mu\, YV_Y - \rho V = 0 \tag{3.2}$$

Eq. (3.2) must be solved subject to appropriate boundary conditions. These boundary conditions are as follows, which ensure that an optimal technology adoption strategy can be chosen.

$$V(Y^*(K), K) = \frac{X_0 + P_G Q - P}{\rho} - K - \frac{Q}{\rho - \mu} Y^*(K) \tag{3.3}$$

$$V_Y(Y^*(K), K) = -\frac{Q}{\rho - \mu} \tag{3.4}$$

$$V(0, K) = \frac{X_0 + P_G Q - P}{\rho} - K \tag{3.5}$$

Here, Y*(K) is the value of Y(t) that triggers the adoption decision. The first boundary condition is the value-matching condition. It simply states that at the moment when the technology is adopted, the payoff is $\frac{X_0 + P_G Q - P}{\rho} - K - \frac{Q}{\rho - \mu} Y^*(K)$. The second boundary condition is the smooth-pasting condition. This condition ensures that the adoption trigger is chosen so as to maximize the value of the technology adoption option. The last condition arises from the observation that if Y goes to zero, it will stay at 0. Therefore, the value of technology adoption option will be $\frac{X_0 + P_G Q - P}{\rho} - K$.

The joint venture's technology adoption option value at time zero, V(Y_0; K), is

$$V(Y_0;K)=\begin{cases}\dfrac{X_0+P_GQ-P}{\rho}-K-\dfrac{Q}{\rho-\mu}Y_0 & \text{for } Y_0<Y^*(K)\\ \left(\dfrac{Y_0}{Y^*(K)}\right)^{\beta}\left(\dfrac{X_0+P_GQ-P}{\rho}-K-\dfrac{Q}{\rho-\mu}Y^*(K)\right) & \text{for } Y_0\geq Y^*(K)\end{cases} \tag{3.6}$$

where

$$Y^*(K)=\frac{\beta}{\beta-1}\left(\frac{\rho-\mu}{Q}\right)\left(\frac{X_0+P_GQ-P}{\rho}-K\right) \tag{3.7}$$

$$\beta=\frac{1}{\sigma^2}\left[-\left(\mu-\frac{\sigma^2}{2}\right)-\sqrt{\left(\mu-\frac{\sigma^2}{2}\right)^2+2\rho\sigma^2}\right]<0 \tag{3.8}$$

Because the realized value of K can be either K_L or K_H, I denote $Y^*(K_L) = Y_L^*$ and $Y^*(K_H) = Y_H^*$. I assume that the initial production cost of the product is larger than the higher technology adoption trigger, $Y_0 > Y^*(K_L)$, to ensure some positive technology adoption option value of waiting/delaying.

$$Y_L^*=Y^*(K_L)=\frac{\beta}{\beta-1}\left(\frac{\rho-\mu}{Q}\right)\left(\frac{X_0+P_GQ-P}{\rho}-K_L\right) \tag{3.9}$$

and

$$Y_H^*=Y^*(K_H)=\frac{\beta}{\beta-1}\left(\frac{\rho-\mu}{Q}\right)\left(\frac{X_0+P_GQ-P}{\rho}-K_H\right) \tag{3.10}$$

Therefore, the condition on the value of the adoption cost K, the joint venture's option value at time zero ($Y=Y_0$) is:

$$V(Y_0)=q_2\left(\frac{Y_0}{Y_L^*}\right)^{\beta}\left(\frac{X_0+P_GQ-P}{\rho}-K_L-\frac{Q}{\rho-\mu}Y_L^*\right)$$
$$+(1-q_2)\left(\frac{Y_0}{Y_H^*}\right)^{\beta}\left(\frac{X_0+P_GQ-P}{\rho}-K_H-\frac{Q}{\rho-\mu}Y_H^*\right)-\xi$$

3.3.2 A Principal-agent Setting

Under this setting, the client offers the vendor a contract at time zero that commits her to pay the vendor a new fixed price at the time of technology adoption. The payment can be made based on the adoption timing Y(t). In this optimal contracting setting, the client sets the contract parameters that encourage the vendor to adopt the green technology in a way that maximizes the value of the client's option and ensure that the vendor makes the costly effort and truthfully share the adoption cost.

Similar to Grenadier and Wang (2005), since I express the contract in terms of the adoption timing Y(t) (which might not be same as those from the first-best benchmark), it is useful to define the discount function $D(Y_0;\hat{Y})$ when the technology is specified to be adopted at $\hat{Y}$. This discount function is simply the solution to Eq. (2) subject to the boundary conditions that $D(\hat{Y};\hat{Y})$ =1 and $D(\infty;\hat{Y})$=0. The solution can be written as

$$D(Y_0;\hat{Y}) = \left(\frac{Y_0}{\hat{Y}}\right)^{\beta}, \quad Y_0 \geq \hat{Y} \tag{3.11}$$

Now I release the previous assumption that K is known in the first-best solution case since the client cannot observe the true value of K. In theory, the client could specify a fixed price F(Y) for any adoption timing Y or infinite fixed price and adoption timing pairs. However, given that K has only two possible values, there are at most two fixed prices and trigger pairs for the vendor: one exists when he observes K_L; and one exists when he observes K_H. Therefore, the client offers a contract that pays a fixed price of F_L if the technology is adopted at Y_L when the adoption cost is $K_{L,}$ and a fixed price of F_H if the technology is adopted at Y_H when the adoption cost is K_H. However, because the client cannot observe the value of the adoption cost K, she needs to make sure that the vendor reveals his true adoption cost information, i.e. the vendor who privately observes K_L will adopt the technology at the Y_L and the vendor privately observes K_H will adopt the technology at the Y_H.

For the client, before the technology adoption, the benefit of outsourcing is:

$$Z_C = \mathrm{E}\left[\int_0^{\infty}(P(\tau)-F_0)e^{-\rho\tau}d\tau\right]$$

After the adoption of such technology at time t when the production cost is Y (In this section, I used the term adoption timing to refer to both the time when the technology is adopted and the value of Y(t) at which the technology is adopted), the benefit of outsourcing becomes:

$$Z_C^T = \max_t \mathrm{E}\left[\int_0^{t}(P(\tau)-F_0)e^{-\rho\tau}d\tau + \int_t^{\infty} Q(P_G(\tau)-F)e^{-\rho\tau}d\tau\right]$$

Thus, after simplifying, the benefit of the technology adoption is:

$$W^C(Y;K) = Z_c^T - Z_c = [\frac{P_G Q - P + F_0 - QF}{\rho}]e^{-\rho t}$$

At the adoption time t, the value of Y(t) is Y, then based on the discounting function developed early, the benefit of technology adoption at time 0 is:

$$W^C(Y;K) = \left(\frac{Y_0}{Y}\right)^{\beta}[\frac{P_G Q - P + F_0 - QF}{\rho}]$$

Thus, conditional on the vendor exerting effort, the value of the client's option at time 0, $\pi^C(F_L, F_H, Y_L, Y_H)$, can be written as

$$\pi^C(F_L,F_H,Y_L,Y_H)=q_2\left(\frac{Y_0}{Y_L}\right)^\beta\left[\frac{P_GQ-P+F_0-QF_L}{\rho}\right]+(1-q_2)\left(\frac{Y_0}{Y_H}\right)^\beta\left[\frac{P_GQ-P+F_0-QF_H}{\rho}\right] \quad (3.12)$$

For the vendor, before the technology adoption, the benefit of outsourcing is:

$$Z_V = \mathrm{E}\left[\int_0^\infty (F_0 - X_0)e^{-\rho\tau}d\tau\right]$$

After the adoption of such technology at time t, the benefit of outsourcing becomes:

$$Z_V^T = \max_t \mathrm{E}\left[\int_0^t (F_0 - X_0)e^{-\rho\tau}d\tau + \int_t^\infty Q(F - Y(\tau))e^{-\rho\tau}d\tau - Ke^{-\rho t}\right] - \xi$$

Thus, the benefit of the technology adoption is:

$$W^V(Y;K) = Z_V^T - Z_V = \left(\frac{Y_0}{Y}\right)^\beta\left[\frac{QF - F_0 + X_0}{\rho} - \frac{QY}{\rho-\mu} - K\right] - \xi$$

Thus, conditional on the vendor exerting effort, the value of the vendor's option, $\pi^V(F_L,F_H,Y_L,Y_H)$, can be written as

$$\pi^V(F_L,F_H,Y_L,Y_H)=q_2\left(\frac{Y_0}{Y_L}\right)^\beta\left(\frac{QF_L-F_0+X_0}{\rho}-\frac{QY_L}{\rho-\mu}-K_L\right)+(1-q_2)\left(\frac{Y_0}{Y_H}\right)^\beta\left(\frac{QF_H-F_0+X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H\right)-\xi \quad (3.13)$$

If the vendor does not exert effort, the value of the vendor's option, $\pi_0^V(F_L,F_H,Y_L,Y_H)$, can be written as

$$\pi_0^V(F_L,F_H,Y_L,Y_H)=q_1\left(\frac{Y_0}{Y_L}\right)^\beta\left(\frac{QF_L-F_0+X_0}{\rho}-\frac{QY_L}{\rho-\mu}-K_L\right)+(1-q_1)\left(\frac{Y_0}{Y_H}\right)^\beta\left(\frac{QF_H-F_0+X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H\right)$$

The client's objective is to maximize her option thereby solving the following optimization problem

$$\max_{F_L,F_H,Y_L,Y_H} q_2\left(\frac{Y_0}{Y_L}\right)^{\beta}[\frac{P_GQ-P+F_0-QF_L}{\rho}]+(1-q_2)\left(\frac{Y_0}{Y_H}\right)^{\beta}[\frac{P_GQ-P+F_0-QF_H}{\rho}] \quad (3.14)$$

Where the decision variables for the clients are the contract parameters F_L, F_H, Y_L and Y_H.

This optimization must be solved under two sets of constraints: the incentive constraints and the participation constraints. The incentive constraints will provide incentives for the vendor to ensure that the vendor makes the costly effort and truthfully shares the adoption cost. The participation constraints will ensure that the contract will be acceptable to the vendor if the vendor makes the costly effort and truthfully shares the adoption cost.

The first constraint is the effort-inducing incentive constraint that ensures the vendor will exert the costly effort. This incentive constraint is

$$\begin{aligned} &q_2\left(\frac{Y_0}{Y_L}\right)^{\beta}(\frac{QF_L-F_0+X_0}{\rho}-\frac{QY_L}{\rho-\mu}-K_L)+(1-q_2)\left(\frac{Y_0}{Y_H}\right)^{\beta}(\frac{QF_H-F_0+X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H)-\zeta \\ &\geq q_1\left(\frac{Y_0}{Y_L}\right)^{\beta}(\frac{QF_L-F_0+X_0}{\rho}-\frac{QY_L}{\rho-\mu}-K_L)+(1-q_1)\left(\frac{Y_0}{Y_H}\right)^{\beta}(\frac{QF_H-F_0+X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H) \end{aligned} \quad (3.15)$$

This constraint guarantees that the vendor will have a higher option value if he exerts the effort. When the vendor exerts the effort at time zero, he will have an option value of $\pi^V(F_L,F_H,Y_L,Y_H)$, which is the left side of the inequality (3.15). If the vendor does not exert the effort, he will have an option value of $\pi_0^V(F_L,F_H,Y_L,Y_H)$, which is the right side of the inequality (3.15). Thus, this constraint ensures that the vendor will exert the effort.

In order to stimulate the vendor to reveal the true adoption cost and adopt the technology in accordance with the client's expectations, I also need the following cost-revealing incentive constraints. Specifically, the client needs to make sure that the vendor adopts the technology at the Y_L trigger when observing an adoption cost of K_L and adopts the technology at the Y_H trigger when observing an adoption cost of K_H. To provide such a timing expectation, the vendor must not have any incentive to lie. The cost-revealing incentive constraints are

$$\left(\frac{Y_0}{Y_L}\right)^{\beta}\left(\frac{QF_L - F_0 + X_0}{\rho} - \frac{QY_L}{\rho-\mu} - K_L\right) \geq \left(\frac{Y_0}{Y_H}\right)^{\beta}\left(\frac{QF_H - F_0 + X_0}{\rho} - \frac{QY_H}{\rho-\mu} - K_L\right) \quad (3.16)$$

$$\left(\frac{Y_0}{Y_H}\right)^{\beta}\left(\frac{QF_H - F_0 + X_0}{\rho} - \frac{QY_H}{\rho-\mu} - K_H\right) \geq \left(\frac{Y_0}{Y_L}\right)^{\beta}\left(\frac{QF_L - F_0 + X_0}{\rho} - \frac{QY_L}{\rho-\mu} - K_H\right) \quad (3.17)$$

Constraint (3.16) guarantees that when observing an adoption cost of K_L, then vendor will adopts the technology at the Y_L trigger. When the vendor observed K_L and adopt the technology at Y_L, he will get a new fixed price contract of F_L and his present value of payoff is $\left(\frac{Y_0}{Y_L}\right)^{\beta}\left(\frac{QF_L - F_0 + X_0}{\rho} - \frac{QY_L}{\rho-\mu} - K_L\right)$. When the vendor observed K_L and adopt the technology at Y_H, he will get a new fixed price contract of F_H and his present value of payoff is $\left(\frac{Y_0}{Y_H}\right)^{\beta}\left(\frac{QF_H - F_0 + X_0}{\rho} - \frac{QY_H}{\rho-\mu} - K_L\right)$. In order to make the vendor truthfully reveal his privately observed adoption cost, the client should make the vendor's benefits of truly revealing the adoption cost not worse than that of deviating the adoption cost and exerting at a different trigger. Similarly, constraint (3.17) ensures that when observing an adoption cost of K_H, the vendor will adopts the technology at the Y_H

trigger instead at the Y_L trigger. Hence, constraints (3.16) and (3.17) jointly ensure that the vendor will truthfully reveal his privately observed adoption cost and does not misrepresent the adoption cost.

The next constraint is the effort-inducing participation constraint that ensures the contract is accepted by the vendor if he exerts the effort.

$$q_2\left(\frac{Y_0}{Y_L}\right)^{\beta}\left(\frac{QF_L-F_0+X_0}{\rho}-\frac{QY_L}{\rho-\mu}-K_L\right)+(1-q_2)\left(\frac{Y_0}{Y_H}\right)^{\beta}\left(\frac{QF_H-F_0+X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H\right)-\zeta\geq 0 \quad (3.18)$$

This constraint ensures that if the vendor accepts the contract, the value of the vendor's benefit if effort is exerted minus the cost of effort is non-negative.

The last two are cost-revealing participation constraints

$$\frac{QF_L-F_0+X_0}{\rho}-\frac{QY_L}{\rho-\mu}-K_L\geq 0 \quad (3.19)$$

and

$$\frac{QF_H-F_0+X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H\geq 0 \quad (3.20)$$

These constraints ensure that the benefits of adopting the technology received by the vendor will be non-negative no matter what the adoption cost is.

Therefore, under the principal-agent setting, the client's problem can be summarized as maximizing the objective function in Eq. (3.14) by choose the contract parameters F_L, F_H, Y_L and Y_H, subject to one effort-inducing incentive constraint (Eq. 3.15), two cost-revealing incentive constraints (Eq. 3.16 and 3.17), one effort-inducing participation constraint (Eq. 3.18) and two cost-revealing participation constraints (Eq. 3.19-3.20) for the vendor. These constraints not only guarantee that the vendor will accept the contract and adopt the technology but also ensure the vendor will exert the costly effort and truthfully reveal the adoption cost. I will provide the analysis of this optimization problem in the next section.

3.4 Analysis and Results

In this section, I show how to analyze the client's optimization problem under the principal-agent setting and characterize the solutions.

Theorem 3.1: The six inequality constraints in the client's optimization problem can be reformulated as follows with three constraints.

$$\max_{F_L,F_H,Y_L,Y_H} q_2\left(\frac{Y_0}{Y_L}\right)^{\beta}[\frac{P_G Q-P+F_0-QF_L}{\rho}]+(1-q_2)\left(\frac{Y_0}{Y_H}\right)^{\beta}[\frac{P_G Q-P}{\rho}+\frac{X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H]$$

Subject to:

$$\left(\frac{Y_0}{Y_L}\right)^{\beta}(\frac{QF_L-F_0+X_0}{\rho}-\frac{QY_L}{\rho-\mu}-K_L)\geq\frac{\zeta}{(q_2-q_1)}$$

$$\left(\frac{Y_0}{Y_L}\right)^{\beta}(\frac{QF_L-F_0+X_0}{\rho}-\frac{QY_L}{\rho-\mu}-K_L)\geq\left(\frac{Y_0}{Y_H}\right)^{\beta}(K_H-K_L)$$

$$-(\frac{QF_L-F_0+X_0}{\rho}-\frac{QY_L}{\rho-\mu}-K_H)\geq 0$$

F_H can be computed from the following equation after solving the above optimization problem.

$$\frac{QF_H-F_0+X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H=0$$

Proof:

The proof is based on the following three propositions.

Proposition 3.1: The cost-revealing participation constraint (3.19) is not binding.

From constraint (3.16), it can be seen that

$$(\frac{QF_L - F_0 + X_0}{\rho} - \frac{QY_L}{\rho - \mu} - K_L) \geq \left(\frac{Y_L}{Y_H}\right)^{\beta} (\frac{QF_H - F_0 + X_0}{\rho} - \frac{QY_H}{\rho - \mu} - K_L)$$

$$> \left(\frac{Y_L}{Y_H}\right)^{\beta} (\frac{QF_H - F_0 + X_0}{\rho} - \frac{QY_H}{\rho - \mu} - K_H)$$

In addition, constraint (3.20) implies that $\frac{QF_H - F_0 + X_0}{\rho} - \frac{QY_H}{\rho - \mu} - K_H \geq 0$

Thus, $(\frac{QF_L - F_0 + X_0}{\rho} - \frac{QY_L}{\rho - \mu} - K_L) > 0$

Proposition 3.2: The effort-inducing participation constraint is (3.18) is not binding.

Constraint (3.15) implies that:

$$\left(\frac{Y_0}{Y_L}\right)^{\beta} (\frac{QF_L - F_0 + X_0}{\rho} - \frac{QY_L}{\rho - \mu} - K_L) - \left(\frac{Y_0}{Y_H}\right)^{\beta} (\frac{QF_H - F_0 + X_0}{\rho} - \frac{QY_H}{\rho - \mu} - K_H) \geq \frac{\zeta}{(q_2 - q_1)}$$

Thus, for constraint (3.18)

$$\left(\frac{Y_0}{Y_L}\right)^{\beta} (\frac{QF_L - F_0 + X_0}{\rho} - \frac{QY_L}{\rho - \mu} - K_L) + \frac{(1-q_2)}{q_2}\left(\frac{Y_0}{Y_H}\right)^{\beta} (\frac{QF_H - F_0 + X_0}{\rho} - \frac{QY_H}{\rho - \mu} - K_H) - \frac{\zeta}{q_2}$$

$$\geq \frac{\zeta}{(q_2 - q_1)} - \frac{\zeta}{q_2} = \frac{q_1 \zeta}{q_2 (q_2 - q_1)} > 0$$

Proposition 3.3 The cost-revealing participation constraint (3.20) is binding.

Since constraint (3.18) and (3.19) are not binding, the optimization for the client becomes:

$$\max_{F_L,F_H,Y_L,Y_H} q_2\left(\frac{Y_0}{Y_L}\right)^{\beta}[\frac{P_G Q-P+F_0-QF_L}{\rho}]+(1-q_2)\left(\frac{Y_0}{Y_H}\right)^{\beta}[\frac{P_G Q-P+F_0-QF_H}{\rho}] \qquad (3.14)$$

Subject to:

$$\left(\frac{Y_0}{Y_L}\right)^{\beta}(\frac{QF_L-F_0+X_0}{\rho}-\frac{QY_L}{\rho-\mu}-K_L)-\left(\frac{Y_0}{Y_H}\right)^{\beta}(\frac{QF_H-F_0+X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H)\geq\frac{\zeta}{(q_2-q_1)} \qquad (3.15)$$

$$\left(\frac{Y_0}{Y_L}\right)^{\beta}(\frac{QF_L-F_0+X_0}{\rho}-\frac{QY_L}{\rho-\mu}-K_L)\geq\left(\frac{Y_0}{Y_H}\right)^{\beta}(\frac{QF_H-F_0+X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_L) \qquad (3.16)$$

$$\left(\frac{Y_0}{Y_H}\right)^{\beta}(\frac{QF_H-F_0+X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H)\geq\left(\frac{Y_0}{Y_L}\right)^{\beta}(\frac{QF_L-F_0+X_0}{\rho}-\frac{QY_L}{\rho-\mu}-K_H) \qquad (3.17)$$

$$\frac{QF_H-F_0+X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H\geq 0 \qquad (3.20)$$

Let λ_1, λ_2, λ_3 are λ_4 be the corresponding dual variables for constraints (3.15), (3.16), (3.17) and (3.20).

KKT conditions with respects to F_L imply that

$$q_2\left(\frac{Y_0}{Y_L}\right)^{\beta}[\frac{-Q}{\rho}]+\lambda_1(q_2-q_1)\left(\frac{Y_0}{Y_L}\right)^{\beta}(\frac{Q}{\rho})+\lambda_2\left(\frac{Y_0}{Y_L}\right)^{\beta}(\frac{Q}{\rho})-\lambda_3\left(\frac{Y_0}{Y_L}\right)^{\beta}(\frac{Q}{\rho})=0$$

Or $-q_2+\lambda_1(q_2-q_1)+\lambda_2-\lambda_3=0$.

KKT conditions with respects to F_H imply that

$$(1-q_2)\left(\frac{Y_0}{Y_H}\right)^{\beta}[\frac{-Q}{\rho}]-\lambda_1(q_2-q_1)\left(\frac{Y_0}{Y_H}\right)^{\beta}(\frac{Q}{\rho})-\lambda_2\left(\frac{Y_0}{Y_H}\right)^{\beta}(\frac{Q}{\rho})+\lambda_3\left(\frac{Y_0}{Y_H}\right)^{\beta}(\frac{Q}{\rho})+\lambda_4\frac{Q}{\rho}=0$$

Or $-(1-q_2)-\lambda_1(q_2-q_1)-\lambda_2+\lambda_3+\lambda_4\left(\frac{Y_0}{Y_H}\right)^{-\beta}=0$

Therefore:

$$\lambda_4=-\left(\frac{Y_0}{Y_H}\right)^{\beta}[-(1-q_2)-\lambda_1(q_2-q_1)-\lambda_2+\lambda_3]=-\left(\frac{Y_0}{Y_H}\right)^{\beta}[-(1-q_2)-q_2]=\left(\frac{Y_0}{Y_H}\right)^{\beta}>0$$

Thus, constraint (3.20) is binding:

$$\frac{QF_H-F_0+X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H=0\ .$$

Based on proposition 1 to 3, the optimization could be reformulated as follows:

$$\max_{F_L,F_H,Y_L,Y_H} q_2\left(\frac{Y_0}{Y_L}\right)^{\beta}[\frac{P_GQ-P+F_0-QF_L}{\rho}]+(1-q_2)\left(\frac{Y_0}{Y_H}\right)^{\beta}[\frac{P_GQ-P}{\rho}+\frac{X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H] \quad (3.14)$$

Subject to:

$$\left(\frac{Y_0}{Y_L}\right)^{\beta}(\frac{QF_L-F_0+X_0}{\rho}-\frac{QY_L}{\rho-\mu}-K_L)\geq\frac{\zeta}{(q_2-q_1)} \quad (3.15)$$

$$\left(\frac{Y_0}{Y_L}\right)^{\beta}(\frac{QF_L-F_0+X_0}{\rho}-\frac{QY_L}{\rho-\mu}-K_L)\geq\left(\frac{Y_0}{Y_H}\right)^{\beta}(K_H-K_L) \quad (3.16)$$

$$-(\frac{QF_L-F_0+X_0}{\rho}-\frac{QY_L}{\rho-\mu}-K_H)\geq 0 \quad (3.17)$$

Theorem 3.2 reveals that the cost-revealing participation constraint (3.19) and the effort-inducing participation constraint (3.18) are not binding while the cost-revealing participation constraint (3.20) is binding. Therefore, I could derive the fixed price F_H from cost-revealing participation constraint (3.20) once I know the value of Y_H.

Theorem 3.2: If the optimization problem in theorem 3.1 has feasible solutions, then the optimal trigger when the adoption cost is low is the same as the one in the first-best solution. i.e. $Y_L = Y_L^*$.

Proof:

From theorem 3.1, it can be seen that constraint (3.15) and (3.16) provides lower bounds on the value of F_L and constraint (3.17) provides an upper bound of F_L. In order for this optimization problem to have feasible solutions, this upper bound of F_L has to be greater than the lower bounds of the F_L. In addition, the objective function increases as F_L decreases. Hence, when this optimization has feasible solutions and is at optimality, constraint (3.17) can be dropped from the optimization problem. Furthermore, at least one of constraint (3.15) and (3.16) is binding. Hence, the optimization problem becomes:

$$\max_{F_L,F_H,Y_L,Y_H} q_2\left(\frac{Y_0}{Y_L}\right)^{\beta}\left[\frac{P_G Q-P+F_0-QF_L}{\rho}\right]+(1-q_2)\left(\frac{Y_0}{Y_H}\right)^{\beta}\left[\frac{P_G Q-P}{\rho}+\frac{X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H\right] \quad (3.14)$$

Subject to:

$$\left(\frac{Y_0}{Y_L}\right)^{\beta}\left(\frac{QF_L-F_0+X_0}{\rho}-\frac{QY_L}{\rho-\mu}-K_L\right)\geq\frac{\zeta}{(q_2-q_1)} \quad (3.15)$$

$$\left(\frac{Y_0}{Y_L}\right)^{\beta}\left(\frac{QF_L-F_0+X_0}{\rho}-\frac{QY_L}{\rho-\mu}-K_L\right)\geq\left(\frac{Y_0}{Y_H}\right)^{\beta}(K_H-K_L) \quad (3.16)$$

Simplify constraint (3.15) and (3.16) to one constraint, which is:

$$F_L \geq \max(\frac{\rho}{Q}[\left(\frac{Y_L}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2-q_1)}+\frac{QY_L}{\rho-\mu}+K_L]+\frac{F_0-X_0}{Q},\frac{\rho}{Q}[\left(\frac{Y_L}{Y_H}\right)^{\beta}(K_H-K_L)+\frac{QY_L}{\rho-\mu}+K_L]+\frac{F_0-X_0}{Q})$$

Or

$$F_L \geq \frac{F_0-X_0}{Q}+\frac{\rho}{Q}\left[\frac{QY_L}{\rho-\mu}+K_L\right]+\frac{\rho}{Q}\max(\left[\left(\frac{Y_L}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2-q_1)}\right],\left[\left(\frac{Y_L}{Y_H}\right)^{\beta}(K_H-K_L)\right])$$

Substituting this into the objective function, it can be seen that:

$$\max_{F_L,F_H,Y_L,Y_H} q_2\left(\frac{Y_0}{Y_L}\right)^{\beta}[\frac{P_GQ-P+F_0-QF_L}{\rho}]+(1-q_2)\left(\frac{Y_0}{Y_H}\right)^{\beta}[\frac{P_GQ-P+X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H]$$

$$=\max_{F_L,F_H,Y_L,Y_H} q_2\left(\frac{Y_0}{Y_L}\right)^{\beta}[\frac{P_GQ-P+X_0-\rho\left[\frac{QY_L}{\rho-\mu}+K_L\right]-\rho\max(\left[\left(\frac{Y_L}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2-q_1)}\right],\left[\left(\frac{Y_L}{Y_H}\right)^{\beta}(K_H-K_L)\right])}{\rho}]$$

$$+(1-q_2)\left(\frac{Y_0}{Y_H}\right)^{\beta}[\frac{P_GQ-P+X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H]$$

$$=\max_{F_L,F_H,Y_L,Y_H} q_2\left(\frac{Y_0}{Y_L}\right)^{\beta}[\frac{P_GQ-P+X_0}{\rho}-\left[\frac{QY_L}{\rho-\mu}+K_L\right]]$$

$$-q_2\left(\frac{Y_0}{Y_L}\right)^{\beta}\max(\left[\left(\frac{Y_L}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2-q_1)}\right],\left[\left(\frac{Y_L}{Y_H}\right)^{\beta}(K_H-K_L)\right)]$$

$$+(1-q_2)\left(\frac{Y_0}{Y_H}\right)^{\beta}[\frac{P_GQ-P+X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H]$$

$$=\max_{F_L,F_H,Y_L,Y_H} q_2\left(\frac{Y_0}{Y_L}\right)^{\beta}[\frac{P_GQ-P+X_0}{\rho}-\left[\frac{QY_L}{\rho-\mu}+K_L\right]]-q_2\max(\left[\frac{\zeta}{(q_2-q_1)}\right],\left[\left(\frac{Y_0}{Y_H}\right)^{\beta}(K_H-K_L)\right]]$$

$$+(1-q_2)\left(\frac{Y_0}{Y_H}\right)^{\beta}[\frac{P_GQ-P+X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H]$$

Thus, the only part in the objective function which involves Y_L is

$q_2\left(\frac{Y_0}{Y_L}\right)^{\beta}[\frac{P_G Q-P+X_0}{\rho}-\left[\frac{QY_L}{\rho-\mu}+K_L\right]]$ and the optimal adoption timing Y_L is the maximizer of this part:

Take the derivative with respect to Y_L and set it to 0, it can been seen

$$0=q_2 Y_0^{\beta}\left\{-\beta Y_L^{-\beta-1}[\frac{P_G Q-P+X_0}{\rho}-\left[\frac{QY_L}{\rho-\mu}+K_L\right]+Y_L^{-\beta}\left[-\frac{Q}{\rho-\mu}\right]\right\}$$

Noticing $Y_0>Y_L>0$ and q_2 >0, hence $Y_L=\frac{\beta}{\beta-1}\frac{(\rho-\mu)}{Q}\left[\frac{P_G Q-P+X_0}{\rho}-K_L\right]=Y_L^*$.

Theorem 3.2 shows that the solution under the principal-agent perspective is the same as that of the first best solution for Y_L. Hence, if the uncertain adoption cost K is K_L, then the client should promote the vendor to adopt the technology at the same time when the client and vendor are working as a joint venture (first best solution). Therefore, under the principal-agent setting, the client has no incentive to deviate the adoption timing when the adoption cost is low. As I can see in theorem 3.1, the effort-inducing incentive constraint (3.15) remains in the client's optimization problem and ensures the vendor makes effort to increase the likelihood of having a lower adoption cost. The cost-revealing incentive constraints (3.16) and (3.17) remain in the client's optimization problem, jointly ensuring that the vendor does not imitate the adopting time for the low (high) adoption cost when the true adoption cost is high (low). In addition, as pointed out earlier, I could derive the fixed price F_H from cost-revealing participation constraint (3.20) once I know the value of Y_H. Hence, I need to find values for of F_L and Y_H in a way that provides incentives for the client to make costly effort and at the same time prevent the vendor from deviating the adoption timing. However, as can been seen from optimization problem in theorem 3.1, the effort-inducing incentive constraint (3.15) requires a high F_L while the cost-revealing incentive constraints (3.17) requires a low F_L which ensures that when observing an adoption cost of K_H, the vendor will adopts the technology at the Y_H trigger instead the Y_L trigger. This trade-off plays a pivotal role in determining when the client's optimization problem will have feasible solutions and is reflected in theorem 3.3.

To facilitate discussion, I define $\alpha = \dfrac{\zeta}{(q_2 - q_1)(K_H - K_L)}$. The denominator can be written as $[q_1 K_L + (1-q_1)K_H] - [q_2 K_L + (1-q_2)K_H]$ which is the expected saving of the technology adoption cost at time 0 if the vendor exerts the effort. The numerator is the direct cost of exerting effort for the vendor at time 0. I call α the cost-saving ratio which shows the cost of obtaining per expected unit of adoption cost saving. A high value of α means that a large effort is needed in order to reduce the expected adoption cost for the technology even a little. While a low value of α means that a small effort will reduce the expected adoption cost for the technology significantly.

Theorem 3.3: The optimization problem in theorem 3.1 is not feasible when $\alpha > \left(\dfrac{Y_0}{Y_L^*}\right)^{\beta}$.

Proof:

From theorem 3.1, it can be seen that constraint (3.15) and (3.16) provides lower bounds on the value of F_L and constraint (3.17) provides an upper bound of F_L. Hence, in order for the client's optimization problem to be feasible, the upper bound of F_L cannot be smaller than the lower bounds of F_L:

Furthermore, constraint (3.15) and (3.16) can be written as:

$$F_L \geq \frac{F_0 - X_0}{Q} + \frac{\rho}{Q}\left[\frac{QY_L}{\rho - \mu} + K_L\right] + \frac{\rho}{Q}\max(\left[\left(\frac{Y_L}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2 - q_1)}\right], \left[\left(\frac{Y_L}{Y_H}\right)^{\beta}(K_H - K_L)\right])$$

Thus, in order for the client problem to have feasible solutions, the following must be true:

$$\frac{\rho}{Q}(\frac{F_0 - X_0}{\rho} + \frac{QY_L}{\rho - \mu} + K_H) \geq F_L \geq \frac{F_0 - X_0}{Q} + \frac{\rho}{Q}\left[\frac{QY_L}{\rho - \mu} + K_L\right] + \frac{\rho}{Q}\max(\left[\left(\frac{Y_L}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2 - q_1)}\right], \left[\left(\frac{Y_L}{Y_H}\right)^{\beta}(K_H - K_L)\right]$$

Substituting $Y_L = Y_L^*$ into the above equation, the following can be obtained:

$$\frac{\rho}{Q}(\frac{F_0 - X_0}{\rho} + \frac{QY_L^*}{\rho - \mu} + K_H) \geq F_L \geq \frac{F_0 - X_0}{Q} + \frac{\rho}{Q}\left[\frac{QY_L^*}{\rho - \mu} + K_L\right] + \frac{\rho}{Q}\max(\left[\left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2 - q_1)}\right], \left[\left(\frac{Y_L^*}{Y_H}\right)^{\beta}(K_H - K_L)\right]$$

In order for this problem to be feasible, the following must be true:

$$\frac{\rho}{Q}(\frac{F_0 - X_0}{\rho} + \frac{QY_L^*}{\rho - \mu} + K_H) \geq \frac{F_0 - X_0}{Q} + \frac{\rho}{Q}\left[\frac{QY_L^*}{\rho - \mu} + K_L\right] + \frac{\rho}{Q}\max(\left[\left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2 - q_1)}\right], \left[\left(\frac{Y_L^*}{Y_H}\right)^{\beta}(K_H - K_L)\right])$$

Simplifying this will yield the follows:

$$K_H \geq \max(\left[\left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2 - q_1)} + K_L\right], \left[\left(\frac{Y_L^*}{Y_H}\right)^{\beta}(K_H - K_L) + K_L\right]$$

Since $\left(\frac{Y_L^*}{Y_H}\right)^\beta < 1$ ($Y_L^* > Y_H$ and $\beta < 0$), $\left(\frac{Y_L^*}{Y_H}\right)^\beta (K_H - K_L) + K_L < (K_H - K_L) + K_L = K_H$.

Hence, $K_H \geq \left[\left(\frac{Y_L^*}{Y_0}\right)^\beta \frac{\zeta}{(q_2 - q_1)} + K_L\right]$ must be true in order to have the preceding inequality valid. Or equivalently,

$$K_H - K_L \geq \left(\frac{Y_L^*}{Y_0}\right)^\beta \frac{\zeta}{(q_2 - q_1)}$$

When the value of cost-saving ratio, α , is high. The client needs to keep the fixed price F_L and F_H further apart so that the client will exert effort and pursue the high return F_L from the low adoption cost. However, the fixed price F_L and F_H is so further apart that the vendor has the incentive to cheat and adopt the technology at Y_L even a high adoption cost is realized just to get the high fixed price F_L. This theorem reveal that when the cost-saving ratio is very high such that it is impossible to find a new contract, through which can simultaneously induce the vendor to exert costly effort and ensure the vendor does not deviate the technology adoption cost when it is high(make the technology investment at time Y_L when the adoption cost is K_H). In practice, when the cost-saving ratio is high, the client should decide between inducing the vendor to exert effort and making the vendor not deviate the technology adoption cost when the adoption cost is high. For example, when the vendor is not very familiar with the technology thereby having a high effort cost, the client should make the vendor induce the effort while hireling a third party to make sure that the vendor does not deviate the technology adoption cost.

Theorem 3.4: The solution of the optimization problem in theorem 3.1 can be characterized by table 3.1:

Table 3.1 The solutions of the client's optimization problem for technology adoption

Regions	Parameter Ranges	Y_L	Y_H
Hidden information only	$\alpha < \left(\frac{Y_0}{\widetilde{Y}_H}\right)^\beta$	Y_L^*	$\widetilde{Y}_H = Y_H^* - \frac{\beta}{\beta-1}\frac{(\rho-\mu)}{Q}\left[\frac{q_2}{1-q_2}\left(\frac{Y_0}{Y_L^*}\right)^\beta (K_H - K_L)\right]$
Hidden information and hidden action	$\left(\frac{Y_0}{\widetilde{Y}_H}\right)^\beta \le \alpha \le \left(\frac{Y_0}{Y_H^*}\right)^\beta$	Y_L^*	$\widetilde{Y}_H \le Y_H = Y_0 \alpha^{-\frac{1}{\beta}} \le Y_H^*$
Hidden action only	$\left(\frac{Y_0}{Y_H^*}\right)^\beta < \alpha \le \left(\frac{Y_0}{Y_L^*}\right)^\beta$	Y_L^*	$Y_H = Y_H^* = \frac{\beta}{\beta-1}\frac{(\rho-\mu)}{Q}\left[\frac{P_G Q - P + X_0}{\rho} - K_H\right]$
Infeasible	$\alpha > \left(\frac{Y_0}{Y_L^*}\right)^\beta$	N/A	N/A

Table 3.1 (cont)

Parameter Ranges	F_L	F_H
$\alpha < \left(\frac{Y_0}{\widetilde{Y}_H}\right)^\beta$	$\frac{\rho}{Q}\left[\left(\frac{Y_L^*}{\widetilde{Y}_H}\right)^\beta (K_H - K_L) + \frac{QY_L^*}{\rho-\mu} + K_L\right] + \frac{F_0 - X_0}{Q}$	$F_H = \frac{\rho}{Q}\left[\frac{QY_H}{\rho-\mu} + K_H\right] + \frac{F_0 - X_0}{Q}$
$\left(\frac{Y_0}{\widetilde{Y}_H}\right)^\beta \le \alpha \le \left(\frac{Y_0}{Y_H^*}\right)^\beta$	$\frac{\rho}{Q}\left[\left(\frac{Y_L^*}{Y_0}\right)^\beta \frac{\zeta}{(q_2 - q_1)} + \frac{QY_L^*}{\rho-\mu} + K_L\right] + \frac{F_0 - X_0}{Q}$	$F_H = \frac{\rho}{Q}\left[\frac{QY_H}{\rho-\mu} + K_H\right] + \frac{F_0 - X_0}{Q}$
$\left(\frac{Y_0}{Y_H^*}\right)^\beta < \alpha \le \left(\frac{Y_0}{Y_L^*}\right)^\beta$	$\frac{\rho}{Q}\left[\left(\frac{Y_L^*}{Y_0}\right)^\beta \frac{\zeta}{(q_2 - q_1)} + \frac{QY_L^*}{\rho-\mu} + K_L\right] + \frac{F_0 - X_0}{Q}$	$F_H = \frac{\rho}{Q}\left[\frac{QY_H}{\rho-\mu} + K_H\right] + \frac{F_0 - X_0}{Q}$
$\alpha > \left(\frac{Y_0}{Y_L^*}\right)^\beta$	N/A	N/A

Proof:

At this stage, the expressions for F_H (which depends on Y_H) and $Y_L(=Y_L^*)$ have been obtained, the parameters remained to be derived are F_L and Y_H. The difference between Y_H and the first best solution will account for the effect of hidden action and hidden information in the principal-agent model. Assuming that the client's optimization problem is feasible, which means $K_H - K_L \geq \left(\frac{Y_L^*}{Y_0}\right)^\beta \frac{\zeta}{(q_2-q_1)}$, and substituting $Y_L = Y_L^*$ in to the objective and the constraints:

Case 1: $(\frac{\rho}{Q}[\left(\frac{Y_L^*}{Y_0}\right)^\beta \frac{\zeta}{(q_2-q_1)} + \frac{QY_L}{\rho-\mu} + K_L] + \frac{F_0 - X_0}{Q} > \frac{\rho}{Q}[\left(\frac{Y_L^*}{Y_H}\right)^\beta (K_H - K_L) + \frac{QY_L}{\rho-\mu} + K_L]$ $+ \frac{F_0 - X_0}{Q}$ or $\left(\frac{Y_L^*}{Y_0}\right)^\beta \frac{\zeta}{(q_2-q_1)} > \left(\frac{Y_L^*}{Y_H}\right)^\beta (K_H - K_L)$

For this case, at optimality, the effort-inducing incentive constraint is binding while the cost-revealing constraint (3.16) is not. Hence,

$$F_L = \frac{\rho}{Q}[\left(\frac{Y_L^*}{Y_0}\right)^\beta \frac{\zeta}{(q_2-q_1)} + \frac{QY_L}{\rho-\mu} + K_L] + \frac{F_0 - X_0}{Q}$$

Substituting this into the objective,

$$\max_{F_L,F_H,Y_L,Y_H} q_2\left(\frac{Y_0}{Y_L^*}\right)^\beta [\frac{P_G Q - P + F_0 - QF_L}{\rho}] + (1-q_2)\left(\frac{Y_0}{Y_H}\right)^\beta [\frac{P_G Q - P + X_0}{\rho} - \frac{QY_H}{\rho-\mu} - K_H]$$

$$= \max_{F_L,F_H,Y_L,Y_H} q_2\left(\frac{Y_0}{Y_L^*}\right)^\beta [\frac{P_G Q - P + X_0}{\rho} - \left(\frac{Y_L^*}{Y_0}\right)^\beta \frac{\zeta}{(q_2-q_1)} - \frac{QY_L}{\rho-\mu} - K_L]$$
$$+ (1-q_2)\left(\frac{Y_0}{Y_H}\right)^\beta [\frac{P_G Q - P + X_0}{\rho} - \frac{QY_H}{\rho-\mu} - K_H]$$

It is proven in theorem 3.2 that $Y_L = Y_L^*$. Therefore, the only decision variable in the above function is Y_H and it is easy to show that if there is no constraint for Y_H, $Y_H = Y_H^* = \frac{\beta}{\beta-1}\frac{(\rho-\mu)}{Q}\left[\frac{P_G Q - P + X_0}{\rho} - K_H\right]$.

However, $\left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2-q_1)} > \left(\frac{Y_L^*}{Y_H}\right)^{\beta}(K_H - K_L)$.

Thus, if $\left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2-q_1)} > \left(\frac{Y_L^*}{Y_H^*}\right)^{\beta}(K_H - K_L)$, then $Y_H = Y_H^* = \frac{\beta}{\beta-1}\frac{(\rho-\mu)}{Q}\left[\frac{(Q-1)P + X_0}{\rho} - K_H\right]$.

In order to have feasible solution, the following condition (theorem 3) needs to be satisfied: $(K_H - K_L) \geq \left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2-q_1)}$;

If $\left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2-q_1)} \leq \left(\frac{Y_L^*}{Y_H^*}\right)^{\beta}(K_H - K_L)$, then $(K_H - K_L) > \left(\frac{Y_L^*}{Y_H^*}\right)^{\beta}(K_H - K_L) \geq \left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2-q_1)}$, which means theorem 3.3 is satisfied.

If $\left(\frac{Y_L^*}{Y_H}\right)^{\beta}(K_H - K_L) \leq \left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2-q_1)} \leq \left(\frac{Y_L^*}{Y_H^*}\right)^{\beta}(K_H - K_L)$ or $Y_H \leq Y_0\left[\frac{\zeta}{(q_2-q_1)(K_H-K_L)}\right]^{-\frac{1}{\beta}} \leq Y_H^*$,

it can be seen that $\left(\frac{Y_0}{Y_H}\right)^{\beta}[\frac{P_G Q - P + X_0}{\rho} - \frac{QY_H}{\rho-\mu} - K_H]$ is a decreasing function as Y_H increases when $Y_0 \geq Y_H^* \geq Y_H > 0$ (the objective function increases from 0 to Y_H^* and decreases from Y_H^* to Y_0. At Y_H^*, it reaches its maximum. Suppose it is not monotonically decreasing, then there is another Y_H which will make the first derivative of this function 0. This contradicts to the fact that only one Y_H^* makes the derivative 0). Hence,

$\left(\frac{Y_0}{Y_H}\right)^{\beta}[\frac{P_G Q - P + X_0}{\rho} - \frac{QY_H}{\rho-\mu} - K_H]$ is maximized at $\left(\frac{Y_L^*}{Y_H}\right)^{\beta}(K_H - K_L) = \left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2 - q_1)}$

or $\left(\frac{Y_L^*}{Y_H}\right)^{\beta}(K_H - K_L) = \left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2 - q_1)}$ when $\left(\frac{Y_L^*}{Y_H}\right)^{\beta}(K_H - K_L) \le \left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2 - q_1)} \le \left(\frac{Y_L^*}{Y_H^*}\right)^{\beta}(K_H - K_L)$.

In summary:

if $(K_H - K_L) \ge \left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2 - q_1)} > \left(\frac{Y_L^*}{Y_H^*}\right)^{\beta}(K_H - K_L)$, then $Y_H = Y_H^* = \frac{\beta}{\beta-1}\frac{(\rho-\mu)}{Q}\left[\frac{P_G Q - P + X_0}{\rho} - K_H\right]$.

If $\left(\frac{Y_L^*}{Y_H}\right)^{\beta}(K_H - K_L) \le \left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2 - q_1)} \le \left(\frac{Y_L^*}{Y_H^*}\right)^{\beta}(K_H - K_L)$, then $Y_H = Y_0\left[\frac{\zeta}{(q_2 - q_1)(K_H - K_L)}\right]^{-\frac{1}{\beta}}$.

Case 2:

$$(\frac{\rho}{Q}[\left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2 - q_1)} + \frac{QY_L^*}{\rho-\mu} + K_L] + \frac{F_0 - X_0}{Q} < \frac{\rho}{Q}[\left(\frac{Y_L^*}{Y_H}\right)^{\beta}(K_H - K_L) + \frac{QY_L^*}{\rho-\mu} + K_L] + \frac{F_0 - X_0}{Q}$$

or $\left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2 - q_1)} < \left(\frac{Y_L^*}{Y_H}\right)^{\beta}(K_H - K_L)$

For this case, theorem 3.3 is satisfied which means the optimization problem is feasible. At optimality, the effort-inducing incentive constraint is not binding while the cost-revealing incentive constraint (3.16) is.

Thus: $F_L = \frac{\rho}{Q}[\left(\frac{Y_L^*}{Y_H}\right)^{\beta}(K_H - K_L) + \frac{QY_L^*}{\rho-\mu} + K_L] + \frac{F_0 - X_0}{Q}$

Substituting this into the objective:

$$\max_{F_L,F_H,Y_L,Y_H} q_2\left(\frac{Y_0}{Y_L^*}\right)^{\beta}[\frac{P_GQ-P+F_0-QF_L}{\rho}]+(1-q_2)\left(\frac{Y_0}{Y_H}\right)^{\beta}[\frac{P_GQ-P+X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H]$$

$$=\max_{F_L,F_H,Y_L,Y_H} q_2\left(\frac{Y_0}{Y_L^*}\right)^{\beta}[\frac{P_GQ-P+X_0}{\rho}-\left(\frac{Y_L^*}{Y_H}\right)^{\beta}(K_H-K_L)-\frac{QY_L^*}{\rho-\mu_Y}-K_L]$$

$$+(1-q_2)\left(\frac{Y_0}{Y_H}\right)^{\beta}[\frac{P_GQ-P+X_0}{\rho}-\frac{QY_H}{\rho-\mu}-K_H]$$

$$=\max_{F_L,F_H,Y_L,Y_H} q_2\left(\frac{Y_0}{Y_L^*}\right)^{\beta}\left[\frac{P_GQ-P+X_0}{\rho}-\frac{QY_L^*}{\rho-\mu}-K_L\right]$$

$$+(1-q_2)\left(\frac{Y_0}{Y_H}\right)^{\beta}[\frac{P_GQ-P+X_0}{\rho}-K_H-\frac{q_2}{1-q_2}\left(\frac{Y_0}{Y_L^*}\right)^{\beta}(K_H-K_L)-\frac{QY_H}{\rho-\mu}]$$

The only decision variable in the above function is Y_H and it is easy to show that if there is no constraint for Y_H, then $Y_H=\widetilde{Y}_H=\frac{\beta}{\beta-1}\frac{(\rho-\mu)}{Q}\left[\frac{P_GQ-P+X_0}{\rho}-K_H-\frac{q_2}{1-q_2}\left(\frac{Y_0}{Y_L^*}\right)^{\beta}(K_H-K_L)\right]$.

However, $\left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2-q_1)}<\left(\frac{Y_L^*}{Y_H}\right)^{\beta}(K_H-K_L)$

Thus, if $\left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2-q_1)}<\left(\frac{Y_L^*}{\widetilde{Y}_H}\right)^{\beta}(K_H-K_L)$, then $Y_H=\widetilde{Y}_H$

If $\left(\frac{Y_L^*}{Y_H}\right)^{\beta}(K_H-K_L)\geq\left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2-q_1)}\geq\left(\frac{Y_L^*}{\widetilde{Y}_H}\right)^{\beta}(K_H-K_L)$, it is easy to show $(1-q_2)\left(\frac{Y_0}{Y_H}\right)^{\beta}[\frac{X_0}{\rho}-\frac{Y_H}{\rho-\mu}-K_H-\frac{q_2}{1-q_2}\left(\frac{Y_0}{Y_L^*}\right)^{\beta}(K_H-K_L)]$ is a decreasing function as Y_H increases when $Y_0\geq Y_H\geq\widetilde{Y}_H>0$ (at $\widetilde{Y}_H$, it reaches its maximum, so it should decrease from $Y_H=\widetilde{Y}_H$ to Y_0. Suppose it is not monotonically decreasing. Then there is another Y_H which will make the first derivative of this function 0. This contradicts to the fact that only one $\widetilde{Y}_H$ makes the derivative 0).

Hence, $(1-q_2)\left(\frac{Y_0}{Y_H}\right)^{\beta}[\frac{P_G Q - P + X_0}{\rho} - K_H - \frac{q_2}{1-q_2}\left(\frac{Y_0}{Y_L^*}\right)^{\beta}(K_H - K_L) - \frac{QY_H}{\rho - \mu_Y}]$ is maximized at $\left(\frac{Y_L^*}{Y_H}\right)^{\beta}(K_H - K_L) = \left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2 - q_1)}$ when $\left(\frac{Y_L^*}{Y_H}\right)^{\beta}(K_H - K_L) \geq \left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2 - q_1)} \geq \left(\frac{Y_L^*}{\widetilde{Y}_H}\right)^{\beta}(K_H - K_L)$.

In summary:

if $\left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2 - q_1)} < \left(\frac{Y_L^*}{\widetilde{Y}_H}\right)^{\beta}(K_H - K_L)$, then $Y_H = \frac{\beta}{\beta - 1}\frac{(\rho - \mu)}{Q}\left[\frac{P_G Q - P + X_0}{\rho} - K_H - \frac{q_2}{1-q_2}\left(\frac{Y_0}{Y_L^*}\right)^{\beta}(K_H - K_L)\right]$ $= \widetilde{Y}_H$.

If $\left(\frac{Y_L^*}{Y_H}\right)^{\beta}(K_H - K_L) \geq \left(\frac{Y_L^*}{Y_0}\right)^{\beta}\frac{\zeta}{(q_2 - q_1)} \geq \left(\frac{Y_L^*}{\widetilde{Y}_H}\right)^{\beta}(K_H - K_L)$, then $Y_H = Y_0\left[\frac{\zeta}{(q_2 - q_1)(K_H - K_L)}\right]^{-\frac{1}{\beta}}$.

Summarizing case 1 and 2, the solutions to the client's optimization problem can be derived as table 3.1.

Theorem 3.4 presents the solution map for the client's optimization problem. When $\alpha > \left(\frac{Y_0}{Y_L^*}\right)^{\beta}$, the client's optimization problem is not feasible and I already cover that in theorem 3.3. If the client's optimization problem is feasible, the solution regions can be further classified into three regions based on which constraint(s) of the client's optimization problem is binding. If the effort-inducing incentive constraint is binding while the cost-revealing incentive constraint is not, the solutions are characterized as the hidden action only region since the effort is the hidden action to the client. Accordingly, if only the cost-revealing incentive constraint is binding, then the solutions are described as the hidden information only region since adoption cost is the hidden information to the client. If both incentive constraints are binding, then the solutions are in the hidden information and hidden action region as both constraints jointly affect the solutions. I will analyze these three regions in details in the next section.

3.5 Discussion

When the client's optimization is feasible, I could further characterize the solutions into the following three regions: the hidden information only region, hidden action only region and the hidden information and hidden action region. Figure 3.2 and 3.3 depicts these three regions and the corresponding optimal contract parameters F_L, F_H, Y_L and Y_H. In this section, I discuss how the contract parameters change in each of the three regions.

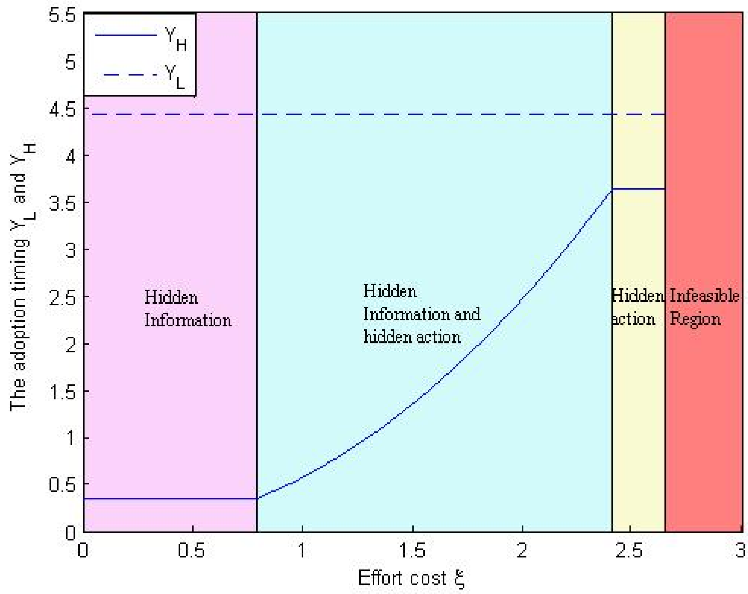

Figure 3.2 Optimal technology adoption timings change with the effort cost

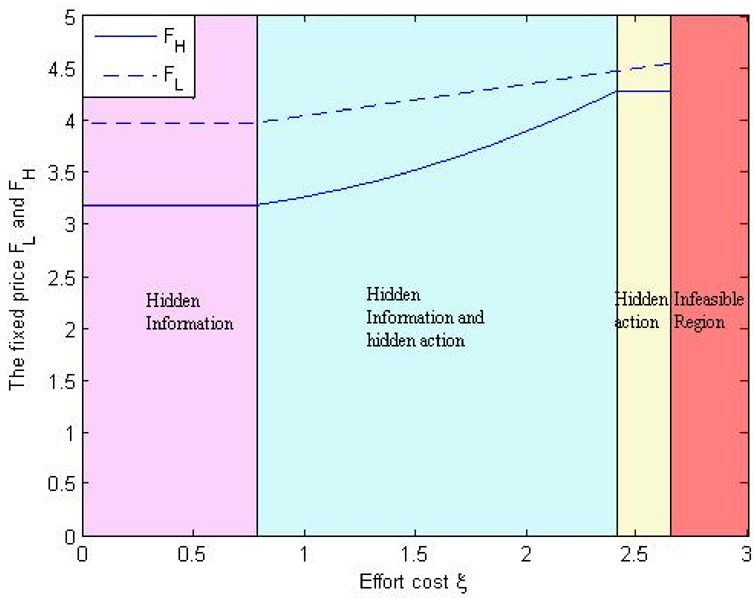

Figure 3.3 Optimal fixed prices change with the effort cost

3.5.1 Region 1: Hidden Information Only

This region corresponds to the ranges of parameters satisfying $\alpha < \left(\frac{Y_0}{\tilde{Y}_H}\right)^{\beta}$. In this region, the effort-inducing incentive constraint does not bind while the cost-revealing incentive constraint binds. For this range, the cost-saving ratio is so low that the effort-inducing incentive constraint is dominated by the cost-revealing incentive constraint. This indicates that if the client provides incentives to the vendor to truthfully disclose the adoption cost and not to misrepresent the adoption timing, then the vendor will make the costly effort voluntarily. The low cost-saving ratio indicates that a very small effort can increase the expected technology adoption cost saving significantly. Therefore, it is always optimal for the vendor to exert effort and increase the likelihood of having a low adoption cost. Hence, the client does not need to provide incentives for the vendor to exert effort. However, the client needs to deviate the optimal Y_H from Y_H* so as to provide cost-revealing incentives. In other words, the client needs to decrease the optimal Y_H to $\tilde{Y}_H$ so that she can make the vendor not deviate the investment timing when observing a low adoption cost. Furthermore, the fixed price F_L when the adoption cost is low is higher than that of F_H when the adoption cost is high due to the cost-revealing incentives when the adoption cost is low. The difference between F_L and F_H does not change with the effort cost due to the nonbinding of the effort-inducing constraint.

The managerial implication of this region is as follows: As indicated in figure 3.2 and 3.3, in this region, the optimal investment timing Y_L and Y_H do not depend on the effort cost. However, the client should delay the optimal investment Y_H to make sure that the vendor will reveal the true adoption cost. The modified fixed price F_L and F_H corresponding to the investment timing Y_L and Y_H do not depend on the effort cost either.

3.5.2 Region 2: Hidden Information and Hidden Action

This region corresponds to the ranges of parameters satisfying $\left(\frac{Y_0}{\widetilde{Y}_H}\right)^{\beta} \leq \alpha \leq \left(\frac{Y_0}{Y_H^*}\right)^{\beta}$. When the cost-saving ration is in this range, both effort-inducing incentive constraint and the cost-revealing incentive constraint bind. The binding of the effort-inducing incentive constraint indicates that the client needs to provide incentives for the vendor to exert effort. This reflects the hidden action component of the contract. The binding of the cost-revealing incentive constraint suggests that the client must provide protection mechanisms to prevent the vendor from deviating the investment timing when observing a low adoption cost. In this region, the investment timing when having a high adoption cost should be delayed. This timing is delayed to provide incentives for the vendor not only to reveal the adoption cost when it is low but also to induce the costly effort. The necessity of inducing effort is precisely the reason why the optimal investment timing Y_H for this region is earlier than $\widetilde{Y}_H$ from hidden information only region where only the incentive for revealing adoption cost is needed. In addition, similar to the hidden information only region, the fixed price F_L which is the fixed price for low adoption cost is higher than F_H which is the fixed price for high adoption cost due to the cost-revealing incentives. The difference between F_L and F_H will increase with effort because of the binding of the effort-inducing constraint.

The managerial implication of this region is as follows: As indicated in figure 3.2 and 3.3, in this region, the optimal investment timing Y_L does not depend on the effort cost, but the optimal investment timing Y_H will be delayed with the increase of the vendor's effort cost. In addition, a high effort cost will lead to a high fixed price F_H which guarantees that the vendor does not deviate the investment timing when observing a high adoption cost K_H. A high fixed price F_L should be assigned to the vendor as well when the effort cost increase because the client needs to provide incentive for the vendor to exert costly effort to increase the probability of obtaining a low adoption cost.

I further extend my analysis in the following subsection on the hidden information and hidden action region because the principal-agent problem is most meaningful in this region. I will discuss the social loss and delays in the adoption timing in the following subsections.

3.5.2.1 Social Loss

Even the client provides the incentives to the vendor, there are still social loss resulted from the agency problem. I define the social loss as the difference in the values of the technology adoption option under the first-best benchmark where the no agency problem occurs and the principal-agent one. In the hidden information and hidden action region, the social loss is $V(Y_0)$ -($\pi^C(F_L, F_H, Y_L, Y_H) + \pi^V(F_L, F_H, Y_L, Y_H)$) where the values of the contract parameters are the optimal ones for the hidden information and hidden action region from table 3.1. It is easily shown that the social loss (SL) is:

$$SL = (1-q_2)\left(\frac{Y_0}{Y_H^*}\right)^{\beta}(\frac{X_0+P_GQ-P}{\rho}-K_H-\frac{Q}{\rho-\mu}Y_H^*\ )$$

$$-\ (1-q_2)\left(\frac{Y_0}{Y_0\alpha^{-\frac{1}{\beta}}}\right)^{\beta}(\frac{X_0+P_GQ-P}{\rho}-K_H-\frac{Q}{\rho-\mu}Y_0\alpha^{-\frac{1}{\beta}})$$

The value of this social loss represents the loss caused by the hidden information and the hidden action from the vendor. The significance of this social loss has an implication on the benefit of outsourcing. For the technology that resulted in a large social loss, the client might need to continue with the previous outsourcing contract without adopting such technology. Later on, after this contract ends, the vendor could switch to another vendor with whom the social loss will be small. When the social loss is small, the client should go ahead and adopt this technology with the vendor. It can be seen that $\left(\frac{Y_0}{Y_H}\right)^{\beta}(\frac{X_0+P_GQ-P}{\rho}-K_H-\frac{Q}{\rho-\mu}Y_H\ )$ represents the benefits of adopting this technology the joint venture will receive when the adoption cost is high. This function is maximized at Y_H^* from the first-best benchmark. Hence, the social loss is the difference in the benefits received by the joint venture when the technology is adopted at Y_H^* or $Y_0\alpha^{-\frac{1}{\beta}}$. The difference between adoption trigger Y_H^* and $Y_0\alpha^{-\frac{1}{\beta}}$ affects the magnitude of the social loss.

The cost-benefit ratio measures the cost of obtaining per expected unit of adoption cost saving for the vendor which shows the vendor's capability of reducing the adoption cost for this technology. This cost-benefit ratio has an important implication on the benefit of outsourcing. Intuitively when α large, the technology adoption trigger $Y_0\alpha^{-\frac{1}{\beta}}$ will be close to Y_H^* which will yield a small social loss. I show analytically that this intuition is valid.

$$\frac{\partial SL}{\partial \alpha} = (1-q_2)\left[-(\frac{X_0 + P_G Q - P}{\rho} - K_H - (1-\frac{1}{\beta})\frac{Q}{\rho-\mu}Y_0\alpha^{-\frac{1}{\beta}})\right]$$

$$< (1-q_2)\left[-(\frac{X_0 + P_G Q - P}{\rho} - K_H - (1-\frac{1}{\beta})\frac{Q}{\rho-\mu}Y_H^*)\right]$$

$$= (1-q_2)\left[-(\frac{X_0 + P_G Q - P}{\rho} - K_H - (1-\frac{1}{\beta})\frac{Q}{\rho-\mu}Y_H^*)\right]$$

Substituting $Y_H^* = \frac{\beta}{\beta-1}(\frac{\rho-\mu_Y}{Q})(\frac{X_0 + P_G Q - P}{\rho} - K_H)$ from equation (3.7) into the above equation, I can see that $\frac{\partial SL}{\partial \alpha} < 0$. This indicates that the social loss will decrease as the value of α increases. A high cost-saving ratio shows the inefficiency of the vendor at reducing the adoption cost. Hence, the client should expect a small social loss when the vendor is incapable of reducing the adoption cost.

3.5.2.2 Adoption Time Lag

I still focus my analysis on the contract that prevails in the joint hidden information/hidden action region. In the first-best benchmark, the technology is adopted at triggers, Y_L^* and Y_H^* for the low and high adoption cost case, respectively. However, in the joint hidden information and hidden action region, while the adoption trigger for low adoption cost remains at Y_L^*; the adoption trigger for the technology for high adoption cost changes to $Y_0\alpha^{-\frac{1}{\beta}}$. The difference in the adoption triggers reflects the difference in times at which the technology is adopted. As pointed before, the agency problem will resulted in a delay in the adoption timing when the adoption cost is high. I will now look at the expected adoption time lag that will occur.

Let T* and T be the times at which the technology is adopted, in the first-best setting and the hidden information and hidden action region under the principal-agent setting respectively. I denote $L = E(T^* - T)$ as the expected time lag, which can be shown as follows:

$$L = q_2 \frac{1}{\mu - \sigma^2/2} \ln(\frac{Y_L^*}{Y_L^*}) + (1-q_2)\frac{1}{\mu - \sigma^2/2} \ln(\frac{Y_0\alpha^{-\frac{1}{\beta}}}{Y_H^*})$$

Substituting $Y_H^* = \frac{\beta}{\beta-1}(\frac{\rho-\mu_Y}{Q})(\frac{X_0 + P(Q-1)}{\rho} - K_H)$ into the above equation, I get

$$L = \frac{1-q_2}{\mu-\sigma^2/2}\left[-\ln\left((\frac{\rho-\mu_Y}{Q})(\frac{X_0+P(Q-1)}{\rho} - K_H)\right) - \frac{1}{\beta}\ln\alpha - \ln(-\beta) + \ln(1-\beta) + \ln Y_0\right]$$

An increase in the cost-saving ratio of inducing effort will lead to less delay in investment timing. This is because

$$\frac{\partial L}{\partial \alpha} = \frac{1-q_2}{\mu-\sigma^2/2}\frac{-1}{\beta\alpha} < 0 \text{ when } \mu - \sigma^2/2 < 0$$

The managerial implication is as follows. When the cost-saving ratio increases, i.e., the cost of obtaining per expected unit of adoption cost saving increases, the client and vendor under the outsourcing contract will expect short delays in the technology adoption as compared to the case when the client and vendor act as a joint venture. From the client's point of view, under the principal-agent setting, she should expect short delay in the technology adoption if the vendor is incapable of reducing the adoption cost. The more incapable of the vendor is at reducing the adoption cost, the less delay the client should expect when the adoption cost is high.

3.5.3 Region 3: Hidden Action Only

This region corresponds to the ranges of parameters satisfying $\left(\frac{Y_0}{Y_H^*}\right)^{\beta} < \alpha \leq \left(\frac{Y_0}{Y_L^*}\right)^{\beta}$.

For this range, the cost-saving ratio is so high that the effort-inducing incentive constraint will dominate the cost-revealing incentive constraint. This case yields the same adoption solutions as the first-best benchmark: $Y_L = Y_L^*$ and $Y_H = Y_H^*$. The high cost-saving ratio indicates that only a large effort can lower the expected savings of the technology adoption cost. Therefore, the client needs to provide enough incentive for the vendor to exert such costly effort. Cleary, this cost-saving ratio could be high enough which makes it not efficient to exert such effort. That is exactly why the cost-saving ratio has an upper bound. Furthermore, as indicated in figure 3.2 and 3.3, when the effort cost increases, the contract parameter F_L will increase while the other contract parameters stay the same. This is because in this range, the technology is always adopted at the right timing as the one from the first-best benchmark no matter what the effort cost is. The fixed price F_H does not change with the effort cost either as it only needs to make sure that the contract will be acceptable to the vendor when the adoption cost is high. The binding of the effort-inducing incentive constraint will lead to an increase in F_L as the effort cost increases.

The managerial implication of this region is as follows: As indicated in figure 3.2 and 3.3, the optimal investment timing Y_L and Y_H does not depend on the effort cost. Furthermore, both the optimal investment timing Y_L and Y_H are the same as if the client and vendor cooperate as a joint venture. In addition, a high price F_L should be assigned to the vendor when the effort cost is high because the client needs to provide incentive for the vendor to exert costly effort to increase the probability of obtaining a low adoption cost.

3.6 Conclusions

In this chapter, I formulate and derive the optimal incentive outsourcing contract for technology adoption to maximize the vendor's expected profit when the client and vendor are already engaged in a current outsourcing contract. This outsourcing contract provides incentives for the vendor to simultaneously make costly effort and truthfully share the private information. I show that the cost-saving ratio plays a pivot role in demining the parameters of the optimal parameters of contract.

When the cost-saving ratio is in certain range, there will be agency problems. The client must both provide protection mechanisms to prevent the vendor from deviating the investment timing when observing a low adoption cost and provide incentives for the vendor to exert costly effort. The hidden information and hidden action could lead to lower investment threshold or delayed investment timing when compared to the first-best benchmark.

When hidden action and information both occur, the client does delay the optimal investment timing for high adoption cost but not that for low adoption cost. In addition, more delay will occur with the increase in the vendor's effort cost. A high fixed price should be also assigned to the vendor for the low adoption cost case when the effort cost is high because the client needs to provide incentives for the vendor to exert costly effort to increase the probability of obtaining a low adoption cost. Furthermore, the client should expect more delay and more social loss when the vendor is not capable of reducing the adoption cost.

This research could be extended in many ways. First, this study assumes that the client and vendor are engaging in a fixed-price contract which is commonly encountered in practice. However, such principal-agent problem should be investigated under other contracts such as the gainsharing and cost-plus outsourcing contracts to confirm the robustness of the results. Second, the market-size for the green products is assumed known or could be predicted when designing the incentive contract. However, this market-size could be hard to predicted and uncertain to both the client and the vendor. Thus, future studies should investigate how the uncertainty in the market-size affects the adopting timing and the performance of this incentive contract. Third, this study provides the incentive outsourcing contracts to promote the vendor to reveal hidden information truthfully. The same performance could be achieved by auditing the vendor. It would be of interest to develop an outsourcing contract with auditing such that it is always optimal for the vendor not to lie about the adoption cost. In addition, with the growth of outsourcing worldwide, the vendors are becoming more and more powerful with regards to their size and market power. Hence, as a future research direction, one could look at how the vendor designs such incentive contract under uncertainty considering the client's hidden information and actions. Furthermore, other stochastic processes could be assumed in this research. For example, the Geometric Brownian motion with mean reversion is adequate in modeling the stochastic process with a long-run equilibrium level. Last, the client and the vendor are assumed to be risk-neutral in this study. Future research could relax this assumption and consider other risk tolerance for the vendor and the client.

Chapter 4

Valuating Outsourcing Contracts from Vendors' Perspective

The outsourcing literature to date has investigated the valuation of the outsourcing contract from the client's point of view to minimize cost and enhance outsourcing performance which often results the notorious "winner's curse" to the vendors. Little research provides practical guidance to vendors for outsourcing contract valuation, helping them avoid the risk of the winner's curse. In this research, I study outsourcing from the vendors' perspective by proposing a new valuation tools for the vendors to avoid the "winner's curse", which incorporates the vendor's managerial flexibility and cost uncertainty. This study uses the real option approach to evaluate the outsourcing contract from the vendor's perspective and finds out that the vendors bid more regressively under the standard NPV approach than under the real option approach.

4.1 Introduction

Traditional outsourcing literature often focuses on performance of the outsourcing from the client's point of view by minimizing the cost of outsourcing. One of the ways to minimize the outsourcing cost for the client is to use the sealed-bid auctions. In such sealed-bid auctions, the client will invite a small pool of vendors to bid and require the vendors to submit their bid within a short period of time. Selection of a "winner" is based on a number of criteria and, not surprisingly, price is a critical component (Li & Kouvelis, 1999). Such mechanism will bring the pressures to potential vendors under intense competition. Specifically, the vendor might new know its competitors' bids and needs to provide its bid low enough to beat is competitors. This often results the vendor to leave a thin profit margin and bids aggressively which leads to the notorious "winner's curse". In addition, when exercising the outsourcing contract, the vendor needs to face different under financial and/or operational risks, which mainly come from three aspects: competitive bidding process, uncertainty of costs, and pressure of shorter contract-duration. This will all contribute to the "winner's curse" and make the vendor suffer. These all make the standard NPV approach insufficient to evaluate the risky outsourcing contracts for the vendor. The vendors are in great needs of a new decision tools to help them evaluate such risky outsourcing contract. This study uses the real option theory (ROT) to evaluate the outsourcing contract from the vendor's point of view. In particular, it shows how the vendor bids aggressively under the standard NPV approach than its counterpart of the real option approach, which would result in the winner's curse. This study also examines the difference in the decision thresholds under the NPV approach and the real option approach and investigates how they are affected by the influential factors. Furthermore, this research analyzes vendors' learning effects within the context of outsourcing contract renewal. The result also reflects the value of vendors' option: the vendors' benefits from treating renewal as an option are higher than an otherwise identical outsourcing contract that treats renewal as an obligation. A vendor should not simply pursue long-term outsourcing opportunities, but pay attention to establish its dynamic learning curve under uncertainties.

The remainder of this chapter is structured as follows. In the next section, athe related literature is briefly reviewed. In section 4.3, the bid and investment thresholds are computed for both the net present value approach and the real option approach. Then in section 4.4, I investigate the relationships between vendors' decision-making thresholds and three parameters and the effects of learning on renewal. Finally, section 4.5 conclude this research and provide practical implications.

4.2 Literature Review

Traditionally Net-present-value(NPV) approach has been widely used by the vendor to evaluate the outsourcing contracts. Jeffery and Leliveld (2004) point out that most vendors are using the standard net-present-value (NPV) to evaluate their outsourcing contracts where the project should be avoid if the NPV for this project is negative. However, the standard NPV approach may be inefficient in certain outsourcing cases where cost uncertainty and investment flexibility exist. It is not uncommon that vendors make unrealistic bidding promises to ensure they win outsourcing contracts, but subsequently discover that they are unable to recover their tendering and operational costs in the near future. Kern et al. (2002) name this situation the “winner's curse,” as the winner of an outsourcing bid systematically bids above the actual value of the contract and thereby systematically incurs losses. Lacity and Willcocks (1998) find 21 out of 85 outsourcing deals were in the winner's curse mode through empirical research.

Real option theory (ROT) has been widely used in finance literature to evaluate a dynamic project and determine the optimal timing to invest. Dixit and Pindyck (1994) apply the ROT to discuss optimal investment timing in the framework of irreversibility and uncertainty, and point out the parallels between an investment opportunity and a "call option." A call option gives an investor the right to acquire an asset of uncertain future value. If conditions favorable to investing arise, the investor can exercise the option by taking the "strike price." Berk et al. (2004) proposes a dynamic model of a multi-stage R&D project under market and technical uncertainty, an important feature of their model is that they incorporate the learning by doing feature where the firm can resolve the technical uncertainty about the R&D project through investment in each stage. Their model captures the important effects of the intermediate investment decisions such as continue, delay or abandon the projects on the value of the project. They illustrate how the different types of risk affect the determination of the value and risk premium of the venture. They also show that the risk premium of the venture is likely to be higher in the beginning and lower at the end of the completion. But these study are mostly in a single project setting. Other literature also looked the project evaluation problem under strategic competition and interaction between multiple firms. Weeds (2002) solves an investment problem under both market and technical uncertainty in which the project requires a fixed one-time cost to complete. This article shows that competition between a small number of rims does not necessarily undermine the option to delay. Instead the fear or starting a R&D war may weaken the effect of competition, therefore raising the value of delay and increasing the time before any investment takes places.

Due to the success of ROT in finance literature to evaluate project under market uncertainty and operational flexibility. A few studies have started to apply the ROT in the supply chain literature to investigate the outsourcing contract. For example, Johnstone (2002) treats outsourcing as a call option for the public sector and use the cost of purchasing as the strike price. If the in-house operating cost is higher than the purchasing cost in the open market, this public sector should outsource its former in-house activities. Alvarez and Stenbacka (2006) use the level of market uncertainty as the strike price, by which to decide an organization's production mode—partial or complete outsourcing (option). However, these studies looked at the outsourcing problem from the client's perspective where the client determines whether to outsource, when to outsource, and how much/many to outsource. They model the outsourcing as an option of clients. However, thus far the current literature does not provide practical guidance to vendors for outsourcing contract valuation. The vendors also play pivotal roles in the outsourcing contracts and they have an important option which was neglected in the literature. That is when to exercise the contract or the option to wait. In fact, the exercise timing of an outsourcing contract usually is out of the vendor's control. It is rare that a client would hold an outsourcing opportunity to meet a vendor's optimal exercising moment. If a vendor signs an outsourcing contract, it must exercise this contract at the given time. If the timing of exercising the outsourcing contract is predetermined by the client, then the vendor will lose this option to wait and could lower the value of the outsourcing contract for the vendors. If the vendor ignores the value of this option, then the vendor could suffer from the winner's curse.

In summary, in this research, the ROT approach is used to study the outsourcing contract from the vendor's perspective. By considering the cost uncertainty faced by the vendor including the vendor's option to wait option in the vendor's decision making principal, a new decision making tool for the vendor is proposed and analyzed. Furthermore practical guidelines to vendors for outsourcing contract valuation under uncertainty are also proposed.

4.3 The Model

A risk-neutral vendor is submitting a bid to win an outsourcing contract of duration D. The outsourcing contract considered in this study is a fixed price contract and the bid the vendor submitting is a fix price under which the vendor agrees to deliver particular products or service to the client at the end of the contract. The auction itself is not the focus of this study. I assume that under this auction held by the client, the vendor must submit his bid truthfully. To win this outsourcing contract, a vendor's bidding price P must be competitive. If the vendor wins, it will invest I to implement the outsourcing contract and incur an operating cost $C(t)$. Here, $C(t)$ evolves over time as a general Brownian motion (GBM), which is the continuous-time formulation of the random walk. This is the standard setting in ROT (Dixit, 1989) and also a good first approximation for uncertainties (Kamien & Li, 1990; Ingersoll & Ross, 1992; Abel & Eberly, 1994; Dixit & Pindyck, 1994; Murto, 1997). Specifically,

$$dC = \mu C dt + \sigma C dB_t \qquad (4.1)$$

where dB_t denotes a standard GBM process; μ implies the shift rate of expected future change; σ describes the uncertainty rate of such a process. I assume μ<0, that is, after taking over an outsourcing contract, the vendor's expected cost keeps decreasing. The source of cost reduction is the outsourcing firm's access to economies of scale, more information, and the unique know-how or learning curve that the vendor has been establishing in the practice (Anderson & Weitz, 1986; Roodhooft & Warlop, 1999).

4.3.1 The NPV Approach

I represent the time when the vendor exercises the contract as t_0. As a consequence, such an outsourcing contract's net present value *NPV* over the contract duration *D* is

$$NPV_{t_0} = E\left[\int_{t_0}^{t_0+D} (P - C(t))e^{-\rho(t-t_0)}dt\right] - I$$

$$= P\frac{1-e^{-\rho D}}{\rho} - C(t_0)\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu} - I \qquad (4.2)$$

Here, ρ is the discount rate of the vendor. Because I assume that the vendor is risk-neutral, this discount rate does not include a term proportional to the uncertainty of the outsourcing contract. Instead, it can be interpreted as the cost of capital the vendor or the vendor's industry faces (i.e., it depends positively on the real interest rate and the industry-specific risk rate).

For each possible bidding price P, there is a particular highest operational cost C_{NPV} for the vendor by letting equation (4.2) = 0:

$$C_{NPV} = \left(P \frac{1-e^{-\rho D}}{\rho} - I \right) \frac{\rho - \mu}{1-e^{-(\rho-\mu)D}} \tag{4.3}$$

If $C(t_0) \leq C_{NPV}$, the vendor can sign this outsourcing contract with this particular price P; if $C(t_0) > C_{NPV}$, the vendor should not accept this contract with this P. Similarly, given the operational cost $C(t_0)$ at t_0, the vendor's lowest bidding price P_{NPV} can be obtained by this standard *NPV* approach, $P_{NPV} = \{P : C_{NPV}(P) = C(t_0)\}$. Hence,

$$P_{NPV} = \left(C(t_0) \frac{1-e^{-(\rho-\mu)D}}{\rho - \mu} + I \right) \frac{\rho}{1-e^{-\rho D}} \tag{4.4}$$

4.3.2 The Real Option Approach

According to ROT, it is helpful to consider that before undertaking an outsourcing contract, a vendor has the option to wait—and thus not to wait. As a result, the dynamic *NPV which is the* standard *NPV plus the* value of option to wait more accurately reflects the value of an investment opportunity than the standard *NPV* does (Benaroch, 2002; Daily & Kotlikoff, 2006). The dynamic *NPV* at t_0, the time before the vendor exercises the contract, can be described by the standard real options expression:

$$F(C) = \max_{T \geq t_0} E_{t_0} \left(P \frac{1-e^{-\rho D}}{\rho} - C(T) \frac{1-e^{-(\rho-\mu)D}}{\rho - \mu} - I \right)^{+} e^{-\rho (T - t_0)} \tag{4.5}$$

where $X^+ = \max(X, 0)$. This reflects the essence of an option: the value of option to wait can never make things worse but can possibly make them better. Because, by definition, there is no obligation to exercise an option, the value of option to wait is always nonnegative. For example, if the standard NPV is negative at t0, the vendor will select to wait rather than to exercise, that is, the value of option to wait is larger than zero. The vendor can maximize its dynamic NPV at t_0 by selecting the optimal investment time T in the future.

The value of $F(C)$ can be derived as follows: At each time τ, $t_0 \leq \tau < T$, while the investment option is still not exercised(the investment opportunity, $F(C)$, produces no cash flow), the only return for holding this option is the capital appreciation ρ Fdt. Hence, in the continuation region (values of C(τ) for which is not optimal to invest) , the bellman equation is:

$$\rho F dt = E(dF)$$

The above equation tells that the expected rate of capital appreciation, $E(dF)$ equals the expected return for the investment opportunity, $\rho F\, dt$.

Expand dF using Ito's Lemma, then

$$E(dF) = E[\mu C F_C dt + \frac{1}{2}\sigma^2 C^2 F_{CC} dt + \sigma C F_C dB] = \mu C F_C dt + \frac{1}{2}\sigma^2 C^2 F_{CC} dt\,;$$

Thus, the bellman equation is:

$$\frac{1}{2}\sigma^2 C^2 F_{CC} + \mu C F_C - \rho F = 0$$

The bellman must be solved subject to appropriate boundary conditions. These boundary conditions are as follows, which ensures that an optimal exercise strategy can be chosen.

$$F(C^*) = P\frac{1-e^{-\rho D}}{\rho} - C^*\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu} - I$$

$$F_C(C^*) = \frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}$$

$$F(\infty) = 0$$

Here, C^* is the value of C(t) that triggers entry. The first boundary condition is the value-matching condition. It simply states that at the moment the option is exercised, the payoff is $F(C^*) = P\frac{1-e^{-\rho D}}{\rho} - C^*\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu} - I$. The second boundary condition is the smooth-pasting condition. This condition ensures that the exercise trigger is chosen so as to maximize the value of the option. The last condition arises from the observation that the option to invest will be of zero value when $C = \infty$.To find $F(C)$, I need to solve the bellman equation subject to the three boundary conditions.

Solving the bellman equation yields the client's option value at time t_0 is

$$F(C) = \begin{cases} P\frac{1-e^{-\rho D}}{\rho} - C\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu} - I & \text{for } C < C_{ROT} \\ (-\frac{1}{\beta})(C)^{1-\beta}(\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}) & \text{for } C \geq C_{ROT} \end{cases} \tag{4.6}$$

where

$$C_{ROT} = \frac{\beta}{\beta-1}\left(P\frac{1-e^{-\rho D}}{\rho} - I\right)\frac{\rho-\mu}{1-e^{-(\rho-\mu)D}} \tag{4.7}$$

$$\beta = \frac{1}{\sigma^2}\left[-\left(\mu-\frac{\sigma^2}{2}\right) - \sqrt{\left(\mu-\frac{\sigma^2}{2}\right)^2 + 2\rho\sigma^2}\right] < 0 \tag{4.8}$$

When $C(t_0) \le C_{ROT}$, the value of the option is $P\frac{1-e^{-\rho D}}{\rho} - C\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu} - I$ which is the same as NPV_{t0}, the outsourcing contract's net present value NPV over the contract duration D. . It means that if the vendor's cost is lower than C_{ROT}, the value of option to wait becomes zero and the option to undertake the contract is immediately valuable; when $C(t_0) > C_{ROT}$, the option to undertake the contract is of no use and value of the option is just the value of option to wait W, which is $(-\frac{1}{\beta})\left(C\right)^{1-\beta}(\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu})$. Thus, C_{ROT} is the threshold of the vendor's decision-making criterion which is termed as the "strike price" in the real option theory, when the uncertain cost value is less than the strike price, it is optimal for the vendor to invest. Otherwise, it is optimal for the vendor to wait and delay the investment.

From equations (4.7), I can obtain the vendor's lowest bidding price through the ROT approach. This lowest bidding price denotes the lowest bid at which it is optimal for the vendor to invest at time t_0. Denote this bid as $P_{ROT} = \{P : C_{ROT}(P) = C(t_0)\}$. Hence,

$$P_{ROT} = \left(\frac{\beta-1}{\beta}C(t_0)\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu} + I\right)\frac{\rho}{1-e^{-\rho D}} \tag{4.9}$$

Facing an outsourcing contract that must be exercised at t_0, if the vendor does not consider the value of option to wait, its investment thresholds are C_{NPV} and P_{NPV}; if the vendor compensates for the loss of option to wait, its investment thresholds become C_{ROT} and P_{ROT}.

4.3.3 Cost Threshold

To understand the risk of an investment, the vendor should investigate the difference in the investment trigger under the ROT and NPV approach. I derive the following proposition to compare these two triggers.

Proposition 1: $C_{ROT} < C_{NPV}$

Proof:

$$\frac{C_{ROT}}{C_{NPV}} = \frac{\beta}{\beta - 1} < 1$$

This is because $\beta = \frac{1}{\sigma^2}\left[-\left(\mu - \frac{\sigma^2}{2}\right) - \sqrt{\left(\mu - \frac{\sigma^2}{2}\right)^2 + 2\rho\sigma^2}\right] < 0$.

These results reveal that the standard *NPV* approach provides a higher investment threshold than that of the real option approach. Given the same bids, the vendor will invest earlier based on the NPV approach than based on the real option approach. The standard NPV approach valuates the outsourcing contract opportunity more aggressively than the ROT approach does.

4.3.4 Bid Threshold

Furthermore, I look at the thresholds for the bid submitted by the vendor under the ROT and NPV approaches to explore the risk of bidding. I obtain the following proposition. For simplicity, use C_{t_0} to denote $C(t_0)$.

Proposition 2: $P_{ROT} > P_{NPV}$

Proof:

$$\frac{P_{ROT}}{P_{NPV}}=1+\frac{\frac{-1}{\beta}C_{t_0}\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}}{C_{t_0}\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}+I}=1+\left(-\frac{1}{\beta}\right)\frac{1}{1+\frac{I}{C_{t_0}}\frac{\rho-\mu}{1-e^{-(\rho-\mu)D}}}>1$$

This is because $\beta=\frac{1}{\sigma^2}\left[-\left(\mu-\frac{\sigma^2}{2}\right)-\sqrt{\left(\mu-\frac{\sigma^2}{2}\right)^2+2\rho\sigma^2}\right]<0$, $\rho>0$, μ <0, *D, I and* C_{t_0} >0.

This result suggest that the bid submitted by the vendor for the outsourcing contract starting at time t_0 under the real option approach is higher than that under the NPV approach. This could help explain the phenomenon of the vendor's "winner's curse." Based on the standard NPV approach, the vendor submits a lower bid P_{NPV} when in fact a high bid of P_{ROT} can guarantee a positive investment return under the cost uncertainty. The lower bid P_{NPV} can help the vendor win the auction but would lead to a nonprofit situation. The standard NPV approach again valuates the outsourcing contract opportunity more aggressively than the ROT approach does because it leads to the aggressive biding.

4.3.5 The Contract Duration

To understand the risk of an investment, the vendor should also understand the investment's payback period—the contract duration. Because contract duration is most likely to be an endogenous variable in outsourcing which is usually specified by the outsourcing client, , a vendor must figure out whether its investment costs and operating costs could be covered over this given duration.

According to the standard *NPV* approach, D_{NPV}, the shortest contract duration the vendor needs to cover its costs under a bidding price *P*, is defined as $D_{NPV} = \{D^+ : C_{NPV}(D) = C_{t_0}\}$. According to the *ROT* approach, the vendor's shortest contract duration D_{ROT} under a bidding price *P* is defined as $D_{ROT} = \{D^+ : CROT\ (D) = C_{t_0}\} = \{D^+ : C_{NPV}(D) = C_{t_0}\frac{\beta - 1}{\beta}\}$. I want to look at whether there is a difference between the shortest contract duration under the standard NPV approach and the real option approach.

Proposition 3: $D_{ROT} > D_{NPV}$

I first show that $C_{NPV}(D)$ is an increasing function of D.

$$C_{NPV} = \left(P\frac{1 - e^{-\rho D}}{\rho} - I \right)\frac{\rho - \mu}{1 - e^{-(\rho - \mu)D}}$$

$$\frac{\partial\left(P\frac{1 - e^{-\rho D}}{\rho} - I \right)}{\partial D} = P\frac{-e^{-\rho D}}{\rho}(-\rho D) = PDe^{-\rho D} > 0$$

In addition,

$$\frac{\partial\left(1 - e^{-(\rho - \mu)D}\right)}{\partial D} = \frac{-e^{-(\rho - \mu)D}}{\rho}(-(\rho - \mu)D) = \frac{(\rho - \mu)De^{-(\rho - \mu)D}}{\rho} > 0$$

Furthermore, $\left(P\frac{1 - e^{-\rho D}}{\rho} - I \right) \geq 0$ and $\frac{\rho - \mu}{1 - e^{-(\rho - \mu)D}} > 0$

Hence:

$$\frac{\partial C_{NPV}}{\partial D} = \frac{\partial\left(P\dfrac{1-e^{-\rho D}}{\rho}-I\right)}{\partial D}\frac{\rho-\mu}{1-e^{-(\rho-\mu)D}} + \left(P\frac{1-e^{-\rho D}}{\rho}-I\right)\frac{\partial \dfrac{\rho-\mu}{1-e^{-(\rho-\mu)D}}}{\partial D} > 0$$

Thus:

$$D_{ROT} = \{D^{+} :\ C_{NPV}(D) = C_{t_0}\frac{\beta-1}{\beta}\} > D_{NPV} = \{D^{+} : C_{NPV}(D) = C_{t_0}\}.$$

4.4 Analysis

4.4.1 The Thresholds of Decision Making

Analyzing vendors' decision-making thresholds, C_{ROT} and P_{ROT}, can provide a useful lens to explore the insights into the vendors' value of waiting (W). If a vendor's operating cost C (or bidding price P) is lower (or higher) than the threshold C_{ROT} (or P_{ROT}), the vendor's value of waiting W becomes zero (i.e., the vendor should act rather than wait); otherwise $W > 0$, the vendor should do more waiting and less investing.

Equations (4.8) and (4.9) show that three exogenous parameters of an outsourcing contract, ρ, μ, and σ, exercise influence upon the vendors' decision-making thresholds C_{ROT} and P_{ROT}. The partial derivatives $\partial C_{ROT}/\partial\rho$, $\partial C_{ROT}/\partial\mu$, and $\partial C_{ROT}/\partial\sigma$ are

$$\frac{\partial C_{ROT}}{\partial \rho}=\frac{2}{(\beta-1)^2\sigma^2\sqrt{(\mu/\sigma^2-1/2)^2+2\rho/\sigma^2}}\frac{\rho-\mu}{1-e^{-(\rho-\mu)D}}\left(P\frac{1-e^{-\rho D}}{\rho}-I\right)$$
$$+\frac{\beta}{\beta-1}\left[\frac{\left(1-e^{-(\rho-\mu)D}\right)-(\rho-\mu)De^{-(\rho-\mu)D}}{(1-e^{-(\rho-\mu)D})^2}\times\right.$$
$$\left.\left(P\frac{1-e^{-\rho D}}{\rho}-I+\frac{\rho-\mu}{1-e^{-(\rho-\mu)D}}\left(P\frac{\rho De^{-\rho D}-(1-e^{-\rho D})}{\rho^2}\right)\right)\right]$$

$$\frac{\partial C_{ROT}}{\partial \mu}=\frac{\sqrt{(\mu/\sigma^2-1/2)^2+2\rho/\sigma^2}+(\mu/\sigma^2-1/2)}{(\beta-1)^2\sigma^2\sqrt{(\mu/\sigma^2-1/2)^2+2\rho/\sigma^2}}\frac{\rho-\mu}{1-e^{-(\rho-\mu)D}}\left(P\frac{1-e^{-\rho D}}{\rho}-I\right)$$
$$+\frac{\beta}{\beta-1}\left[\frac{-\left(1-e^{-(\rho-\mu)D}\right)-(\rho-\mu)De^{-(\rho-\mu)D}}{(1-e^{-(\rho-\mu)D})^2}\left(P\frac{1-e^{-\rho D}}{\rho}-I\right)\right.$$

$$\frac{\partial C_{ROT}}{\partial \sigma}=\frac{\rho-\mu}{1-e^{-(\rho-\mu)D}}\left(P\frac{1-e^{-\rho D}}{\rho}-I\right)\frac{-1}{(\beta-1)^2}\frac{\partial\beta}{\partial\sigma}<0$$

Among the three partial derivatives, only $\partial C_{ROT}/\partial\sigma$ has an obvious analytical result: $\partial C_{ROT}/\partial\sigma < 0$. The signs of the other partial derivatives are hard to determine due to compound effects of the influential factors to the strike price. Therefore, numerical simulation is used to determine how the values ρ, μ, and σ affect the vendor's exercise-or-wait thresholds C_{ROT} and P_{ROT}.

In the numerical simulation, ρ varies from 0.04 to 0.2, σ varies from 0.1 to 0.6, and μ varies from 0 to 0.2, respectively. In Figures 4.1–4.3, each time one parameter is hold constant in order to study the relation between the strike price (C_{ROT} or P_{ROT}) and other two parameters.

These figures clearly reveal that C_{ROT} is positively affected by ρ and μ but negatively affected by σ and P_{ROT} is negatively affected by ρ and μ but positively affected by σ. By definition, ρ is the capital depreciation that the vendor has to take. These figures suggests that a higher capital depreciation will result in a higher C_{ROT} and a smaller P_{ROT}, which in turn will lead to a more aggressive investment decision and submit a more aggressive bid for the vendor. Similarly, $\mu < 0$ measures the decreasing rate of the vendor's operational cost. A smaller μ implies a more significant cost reducing process. Because of the positive relation between C_{ROT} and μ and the negative relation between P_{ROT} and μ, a smaller μ will lead a larger C_{ROT} and a smaller P_{ROT}. Hence, these figures suggest that when the vendor cost is expected to decrease faster, the vendor could hasten his investment and could have a biding advantage.

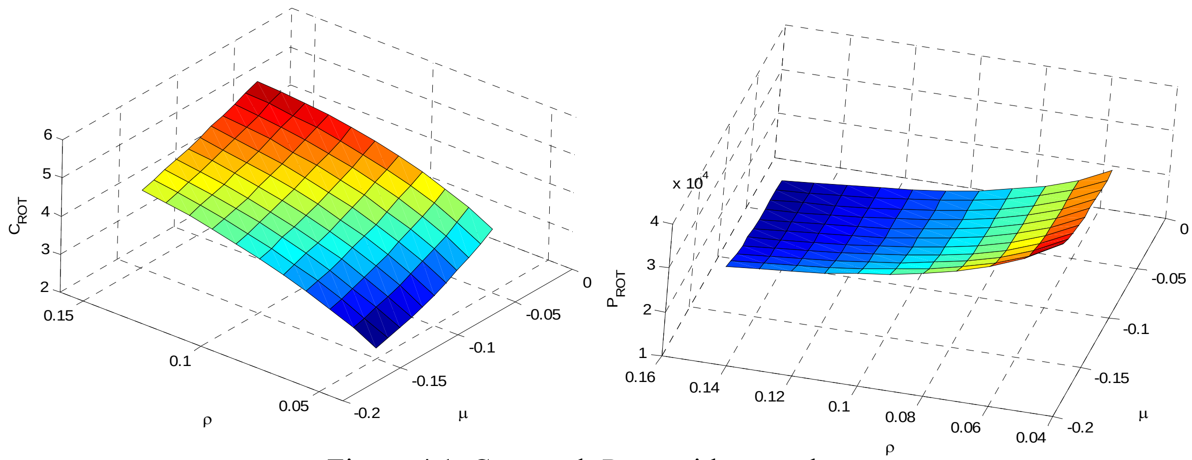

Figure 4.1 C_{ROT} and P_{ROT} with ρ and μ

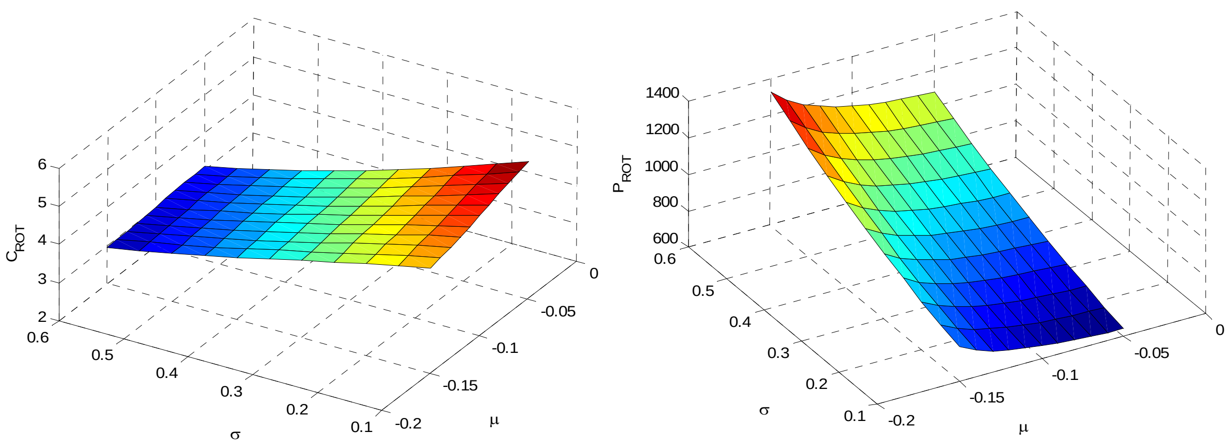

Figure 4.2 C_{ROT} and P_{ROT} with μ and σ

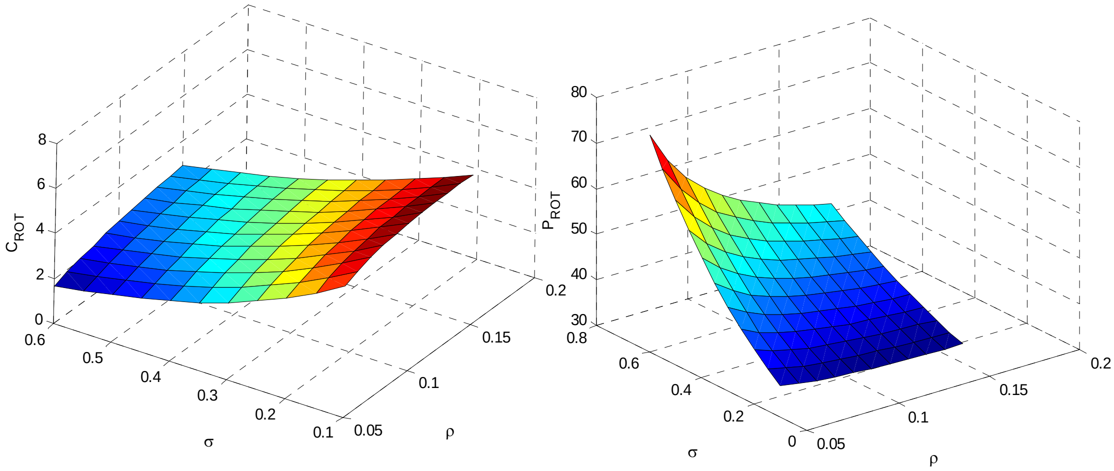

Figure 4.3 C_{ROT} and P_{ROT} with ρ and σ

Furthermore σ measures the uncertainty of the vendor's operational cost during the implementation of an outsourcing contract; a larger σ means that the effect of cost reduction is highly uncertain. These figures suggest that an increase in the cost uncertainty will lead to a decrease in C_{ROT} and an increase P_{ROT}. This result demonstrates that when the vendor's cost is very uncertain; the vendor should make the investment carefully and increase his bid for the outsourcing contract.

4.4.2 The Ratio of D_{ROT}/D_{NPV}

Based on the discussion regarding the shortest contract durations in the last section, it is clear that D_{ROT} is more conservative than D_{NPV}, because the ROT approach considers the vendor's lost option to wait. At each cost state C, the relative D_{NPV} and D_{ROT} can be solved numerically. The figure below shows that at the same operating cost level, the standard NPV approach tends to require shorter contract duration to cover vendors' investment I and operating cost C(t) than the ROT approach does.

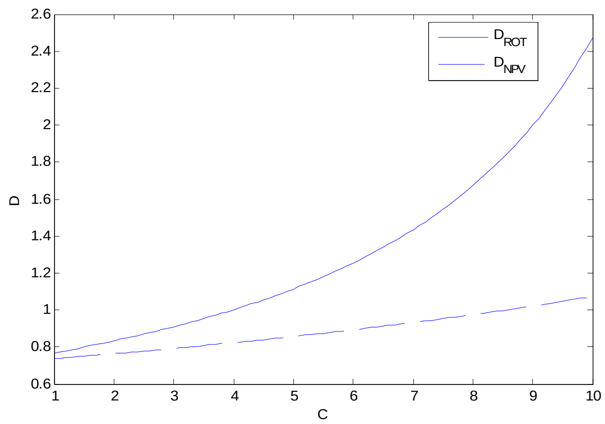

Figure 4.4 The shortest contract durations under the NPV and ROT approaches.

To gain further insight, I need to investigate the relationships between the ratio of D_{ROT}/D_{NPV} and ρ, μ, and σ.

Again, it is difficult to analytically obtain the signs of the derivatives of $\partial(D_{ROT}/D_{NPV})/\partial\rho$, $\partial(D_{ROT}/D_{NPV})/\partial\mu$, and $\partial(D_{ROT}/D_{NPV})/\partial\sigma$. So the numerical simulation approach is used to obtain the relations between this ratio and ρ, μ, and σ (see Figure 5-7). From Figure 4.5, for the given μ, when σ is low, D_{ROT}/D_{NPV} is close to 1 and robust to the perturbation of σ and ρ; when σ is high, D_{ROT}/D_{NPV} becomes sensitive to the change of σ and ρ. Hence, when the cost uncertainty is small, D_{ROT} and D_{NPV} are relatively equal and respond to the capital cost change at the same pace; when the level of uncertainty is high or the capital cost is low, the difference between D_{ROT} and D_{NPV} becomes more profound. Similarly, figure 4.6 suggests that for a given level of ρ, D_{ROT}/D_{NPV} is positively related to σ and negatively related to μ. A higher level of uncertainty or a significant cost reduction increases the value of waiting, the difference between D_{ROT} and D_{NPV} becomes significant. From Figure 4.7, for the given σ, D_{ROT}/D_{NPV} is negatively affected by both ρ and μ. This suggests that a lower capital cost or a small cost reduction implies a smaller difference in different in D_{ROT} and D_{NPV}. *A* higher capital cost or a significant cost reduction increases the value of waiting, thus the difference between D_{ROT} and D_{NPV} becomes significant.

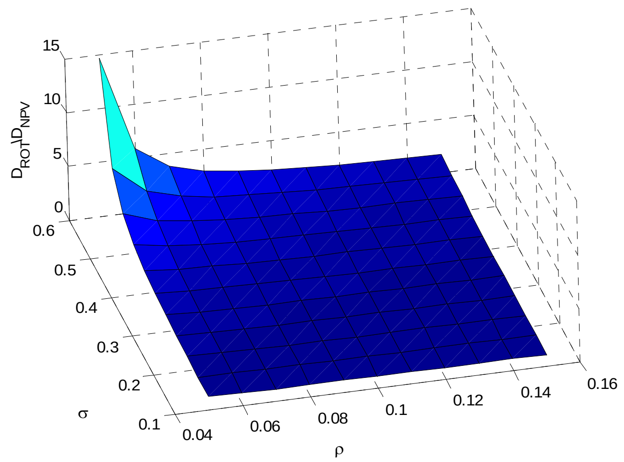

Figure 4.5 D_{ROT}/D_{NPV} with ρ and σ

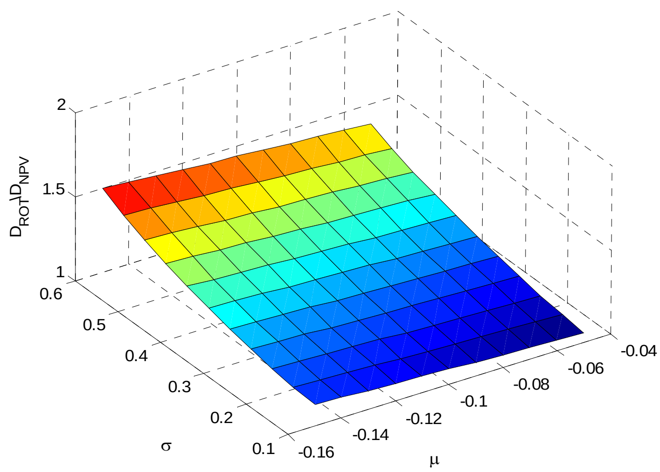

Figure 4.6 D_{ROT}/D_{NPV} with μ and σ

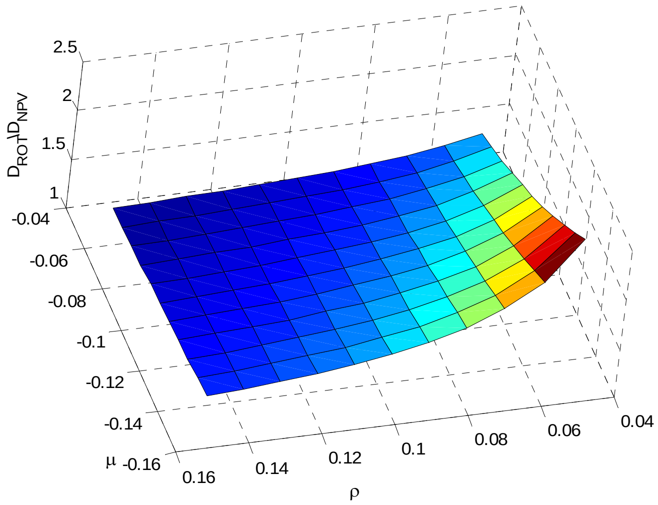

Figure 4.7 D_{ROT}/D_{NPV} with ρ and μ

4.4.3 Influence of Learning on Renewal

Any outsourcing contract will expire after its duration *D*. If a vendor considers the renewal of an outsourcing contract during the bidding stage, such a long-term strategy will directly impact the vendor's bidding. For example, with a strategic intent to hold the contract permanently (always get the renewal), the vendor may offer a low bidding price, believing that it can recoup the investment and broaden margins later. Consequently, facing an outsourcing contract opportunity, a key decision the vendor has to make is whether to valuate this opportunity over a short-term period (for only one-period *D*) or a long-term period (for multiple-period *D*s). To analyze the two different bidding strategies, I introduce two scenarios as follows:

Case I: the vendor is keen to gain the renewal. While the vendor is actually bidding for the outsourcing contract over (T, T+D), its bidding strategy extends to the next contract duration ($T + D$, $T + 2D$). As a result, the vendor considers a long-term bidding strategy over (T, $T + 2D$):

$$V_T = E_T\left[\int_T^{T+2D}(P - C_t)e^{-\rho(t-T)}dt\right]$$

$$= P\frac{1-e^{-\rho\cdot 2D}}{\rho} - C_T\frac{1-e^{-(\rho-\mu)\cdot 2D}}{\rho} \tag{4.10}$$

Case II: the vendor's bidding strategy only covers one period (T, $T + D$). As a result, under this short-term bidding strategy, the renewal over the next period ($T + D$, $T + 2D$) is an option—renew or not—in the future rather than a scheduled event in Case I.

$$V_{II} = E_T\left[\int_T^{T+D}(P - C_t)e^{-\rho(t-(T))}dt + \left(\int_{T+D}^{T+2D}(P - C_t)e^{-\rho(t-(T+D))}dt\right)^+\right]$$

At T+D, define $V_{T+D} = \int_{T+D}^{T+2D}(P - C_t)e^{-\rho(t-(T+D))}dt$

$$= P\frac{1-e^{-\rho D}}{\rho} - C_{T+D}\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}$$

$$V_{II} = E_T\left[\int_T^{T+D}(P - C_t)e^{-\rho(t-T)}dt + V_{T+D}^+\right]$$

$$= P\frac{1-e^{-\rho D}}{\rho} - C_T\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu} + E_T\left[V_{T+D}^+\right]$$

$$E_T\left[V_{T+D}^+\right] = E_T\left[\left(P\frac{1-e^{-\rho D}}{\rho} - C_{T+D}\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}\right)^+ \middle| C_T\right]$$

$$= \int_{-\infty}^{x^*} \left(P \frac{1-e^{-\rho D}}{\rho} - C_{T+D} \frac{1-e^{-(\rho-\mu)D}}{\rho-\mu} \right) \frac{1}{\sqrt{2\pi D}} e^{-\frac{x^2}{2D}} dx$$

Where $x^* = \left\{ x : P \frac{1-e^{-\rho D}}{\rho} - C_{T+D}(x) \frac{1-e^{-(\rho-\mu)D}}{\rho-\mu} = 0 \right\}$

At t=D;

$$x^* = \frac{\ln C_{t+T} - \ln C_T - (\mu - \frac{1}{2}\sigma^2)t}{\sigma},$$

$$= \frac{\ln\left(P \frac{1-e^{-\rho D}}{\rho} \frac{\rho-\mu}{1-e^{-(\rho-\mu)D}} \right) - \ln C_T - (\mu - \frac{1}{2}\sigma^2)D}{\sigma}$$

Notice $x_0 = 0$; $dx_t = dB_t$, which implies $X_t \sim N(0,t)$

Hence:

$$P \frac{1-e^{-\rho D}}{\rho} \int_{-\infty}^{x^*} \frac{1}{\sqrt{2\pi D}} e^{-\frac{x^2}{2D}} dx$$

$$= P \frac{1-e^{-\rho D}}{\rho} \phi(\frac{x^*}{\sqrt{D}})$$

Where $\phi(\cdot)$ is the cumulative distribution function for the standard normal distribution.

In addition, $C_{T+D} = C_T e^{(\mu - \frac{1}{2}\sigma^2)D + x_D \sigma}$; Hence:

$$\int_{-\infty}^{x^*} C_{T+D} \frac{1}{\sqrt{2\pi D}} e^{-\frac{x^2}{2D}} dx = \int_{-\infty}^{x^*} C_T e^{(\mu - \frac{1}{2}\sigma^2)D + x\sigma - \frac{x^2}{2D}} \frac{1}{\sqrt{2\pi D}} dx$$

$$= \int_{-\infty}^{x^*} C_T e^{(\mu - \frac{1}{2}\sigma^2)D + \frac{\sigma^2}{2}D} \frac{1}{\sqrt{2\pi D}} e^{-\frac{(x-\sigma D)^2}{2D}} dx = C_T e^{\mu D} \phi(\frac{x^* - \sigma D}{\sqrt{D}})$$

Thus:

$$E_T\left[V_{T+D}^{+}\right]=P\frac{1-e^{-\rho D}}{\rho}\phi(\frac{x^*}{\sqrt{D}})-\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}C_T e^{\mu D}\phi(\frac{x^*-\sigma D}{\sqrt{D}})$$

$$V_{II}=E_T\left[\int_T^{T+D}(P-C_t)e^{-\rho(t-(T))}dt+\left(\int_{T+D}^{T+2D}(P-C_t)e^{-\rho(t-(T+D))}dt\right)^{+}\right]$$
$$=P\frac{1-e^{-\rho D}}{\rho}-C_T\frac{1-e^{-(\rho-\mu)D}}{\rho}+P\frac{1-e^{-\rho D}}{\rho}\phi(\frac{x^*}{\sqrt{D}})-\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}C_T e^{\mu D}\phi(\frac{x^*-\sigma D}{\sqrt{D}})$$

$$\Delta V=V_{II}-V_I$$

$$=E_T\left[\left(P\frac{1-e^{-\rho D}}{\rho}-C_{T+D}\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}\right)^{+}\middle|C_T\right]-E_T\left[\left(P\frac{1-e^{-\rho D}}{\rho}-C_{T+D}\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}\right)\middle|C_T\right]$$
$$=E_T\left[\left(P\frac{1-e^{-\rho D}}{\rho}-C_{T+D}\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}\right)^{-}\middle|C_T\right]$$

$$\geq 0 \tag{4.11}$$

Where

$$x^{-}=(-x)^{+}$$

$$\Delta V=E_T\left[\left(P\frac{1-e^{-\rho D}}{\rho}-C_{T+D}\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}\right)^{-}\middle|C_T\right]$$

$$=-\int_{x^*}^{+\infty}\left(P\frac{1-e^{-\rho D}}{\rho}-C_{T+D}\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}\right)\frac{1}{\sqrt{2\pi D}}e^{-\frac{x^2}{2D}}dx$$

$$-\left\{P\frac{1-e^{-\rho D}}{\rho}\left(1-\phi(\frac{x^*}{\sqrt{D}})\right)-\frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}C_T e^{\mu D}\left(1-\phi(\frac{x^*-\sigma D}{\sqrt{D}})\right)\right\}$$

$$= -\left\{ P\frac{1-e^{-\rho D}}{\rho}(-1)\frac{1}{\sqrt{2\pi D}}e^{-\frac{(x^*)^2}{2D}}\frac{1}{\sqrt{D}}\frac{\partial x^*}{\partial x^*}\left(1-\phi(\frac{x^*}{\sqrt{D}})\right) - \frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}C_T e^{\mu D}\left(1-\phi(\frac{x^*-\sigma D}{\sqrt{D}})\right)\right\}$$

$$\geq 0$$

$$\frac{\partial \Delta V}{\partial \sigma} = -\left\{ P\frac{1-e^{-\rho D}}{\rho}(-1)\frac{1}{\sqrt{2\pi D}}e^{-\frac{(x^*)^2}{2D}}\frac{1}{\sqrt{D}}\frac{\partial x^*}{\partial \sigma} - \frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}C_T e^{\mu D}(-1)\frac{1}{\sqrt{2\pi D}}e^{-\frac{(x^*-\sigma D)^2}{2D}}\frac{1}{\sqrt{D}}\frac{\partial (x^*-\sigma D)}{\partial \sigma}\right\}$$

Where $x^* = \dfrac{\ln\left(P\dfrac{1-e^{-\rho D}}{\rho}\dfrac{\rho-\mu}{1-e^{-(\rho-\mu)D}}\right) - \ln C_T - (\mu - \frac{1}{2}\sigma^2)D}{\sigma}$

Hence:

$$\frac{\partial \Delta V}{\partial \sigma} = -\left\{ P\frac{1-e^{-\rho D}}{\rho}(-1)\frac{1}{\sqrt{2\pi D}}e^{-\frac{(x^*)^2}{2D}}\frac{1}{\sqrt{D}}\frac{\partial x^*}{\partial \sigma} - \frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}C_T e^{\mu D}(-1)\frac{1}{\sqrt{2\pi D}}e^{-\frac{(x^*-\sigma D)^2}{2D}}\frac{1}{\sqrt{D}}\frac{\partial (x^*-\sigma D)}{\partial \sigma}\right\}$$

$$= -\left\{ P\frac{1-e^{-\rho D}}{\rho}(1-1)\frac{1}{\sqrt{2\pi D}}e^{-\frac{(x^*)^2}{2D}}\frac{1}{\sqrt{D}}\frac{\partial x^*}{\partial \sigma} - \frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}C_T e^{\mu D}(-1)\frac{1}{\sqrt{2\pi D}}e^{-\frac{(x^*-\sigma D)^2}{2D}}\frac{1}{\sqrt{D}}(-D)\right\}$$

$$= \frac{1-e^{-(\rho-\mu)D}}{\rho-\mu}C_T e^{\mu D}\frac{1}{\sqrt{2\pi}}e^{-\frac{(x^*-\sigma D)^2}{2D}} \geq 0$$

Equation (4.11) reveals that Case II brings a higher value to the vendor than Case I does. The managerial relevance is that when facing an outsourcing contract opportunity, the vendor should bid this opportunity by focusing on a single period and treat the renewal as an option instead of an obligation. The higher value of Case II comes from more information or knowledge and options the vendor possesses. During the first period (T, T + D), the vendor usually establishes the learning-curve for the client's special requirements or demands, so that it can use the learning from the first period to revamp itself more knowledgeable of the operational cost over the second period (T + D, T + 2D). The higher the future uncertainty is, the higher the value of Case II is (see equation (3.15)). In Case II, based on its new knowledge, the vendor can more wisely decide to accept the client's renewal invitation or withdraw from the client's outsourcing business at the end of the first period. In Case I, however, the vendor does not have such an option, because it has to follow its original strategy to carry on the outsourcing contract over the second period.

4.5 Conclusions

The outsourcing literature has addressed the vendor's problem of valuating outsourcing contracts from the standard NPV approach, which often results in the notorious winner's curse. This study evaluates the outsourcing contracts from the vendor's perspective and uses the real option approach to explain the phenomenon of the winner's curse. The real option approach considers the uncertainty in the vendor's cost and the vendor's managerial flexibility of when to exercise the contract. This approach considers the vendor's option to wait and provides new decision-making criteria for the vendor (the "strike price" P_{ROT} and C_{ROT}) to bid and exercise the contract if winning the contract.

The vendors' lowest bidding price P_{ROT} (the highest operating cost C_{ROT}) resulting from the real option approach is significant higher (lower) than its counterpart P_{NPV}(C_{NPV}) from the standard *NPV* approach, in which the so-called winner's curse exists. This is attributed to the fact that the vendors have to exercise outsourcing contracts at client's giving time and lost the option to wait. Such a compensation- oriented model yields new insights about the vendors' valuation of outsourcing opportunities. Such findings show that the vendor will bid more aggressively under the standard NPV approach, which would result in the winner's curse. The conservative thresholds under the real option approach may protect vendors again the aggressive bidding which in turn decreases the risk of the so-called winner's curse. This study also examines the difference in the decision thresholds under the NPV approach and the real option approach and investigates how they are affected by the influential factors (ρ, μ, and σ) analytically and numerically. Furthermore, this research analyzes vendors' learning effects within the context of outsourcing contract renewal. The result also reflects the value of vendors' option: the vendors' benefits from treating renewal as an option are higher than an otherwise identical outsourcing contract that treats renewal as an obligation. A vendor should not simply pursue long-term outsourcing opportunities, but pay attention to establish its dynamic learning curve under uncertainties.

This research could be further enriched in many ways. First, a fixed-price outsourcing contract which is the commonly used contract in outsourcing is assumed in this study. However, in practice there could be many other contract such as cost plus contracts, revenue sharing contracts etc. Future research should cover other contracts and investigate the bidding strategy used in different contracts. Second, future research should investigate how the multiple uncertainties affects the vendor's outsourcing contract evaluation where the market, cost and technology uncertainty coexist and evolve. Last this study assumes that the vendor is risk-neural. However, in proactive some vendors might be risk-seeking or risk-averse. Therefore, future research should extend to other risk tolerance to best approximate the outsourcing practice for different decision makers.

Chapter 5

Conclusions

This Chapter concludes this dissertation and summarizes the contributions of my studies. Possible future research directions are covered as well.

The remainder of this chapter is structured as follows. The next section states the contributions of this dissertation. Section 5.2 presents the conclusions of this dissertation, points out the limitations and suggests the future research directions.

5.1 Contributions

In this dissertation, I propose to examine outsourcing in Emerging Market under uncertainty. By modeling three important and fruitful topics in outsourcing, this dissertation contributes to supply chain management in general and to the relatively sparse, but growing, outsourcing literature in particular in several ways.

First, this dissertation studies a new contract, gainsharing contract, in the emerging markets using a continuous-time analytical approach. I establish the key elements of the gainsharing contracts for risk-averse decision makers and provide guidelines on how to negotiate these elements based on the negotiation powers.

Second, this dissertation develops an incentive outsourcing contract for technology adoption. In doing so, it equips scholars with a model of how the client could stimulate the vendor to adopt a new technology when they have already been cooperating under an outsourcing contract. It is a new challenge in outsourcing where the client and vendor need to promote the technology adoption which is crucial for both parties to survive in the competitive global business environment. This dissertation recognizes that such technology adoption involves cost uncertainty, agency conflicts and information asymmetries and provides an incentive contract for the vendor based on the investment timing. Such incentive contract could provide incentives to the vendor to both exert costly efforts and truthfully disclose private information and could be used to guide the outsourcing practice when appropriate.

Last, the outsourcing literature to date has investigated the valuation of the outsourcing contract from the client's point of view to minimize cost and enhance outsourcing performance which often results the notorious "winner's curse" to the vendors. This dissertation, on the other hand, acknowledges the pivotal role of the vendor in outsourcing and provides a contract evaluation tool for the vendor. This new evaluation method is based on the real option theory and recognizes how the managerial flexibility can affect the vendor's decision making. Hence, the vendor could use the evaluation tool to avoid the notorious "winner's curse" upon bidding. Furthermore, this dissertation also analyzes vendors' learning effect within the context of outsourcing contract renewal. This learning effect indicates that a vendor should not simply pursue long-term outsourcing opportunities, but instead, need to pay attention to establish its dynamic learning curve under uncertainties.

5.2 Conclusions

My dissertation analyzes three topics in outsourcing under uncertainty and provides decision support guidelines for the scholars and practitioners.

My ultimate goal is to foster the development of knowledge in outsourcing under uncertainty. Toward this end, I intend to use analytical methods rigorously to gather insights of the coordination and competition in outsourcing under uncertainty. I aim to enrich the operations management literature and to stimulate future research directions which serve to accelerate development of outsourcing broadly.

Specifically, in this dissertation I first develop an analytical model of how the client, vendor, and spot market interact and co-evolve in a complex and non-linear manner over time under a gainsharing contract. I show how to determine the key elements, and specifically, the gainsharing ratio and the target price of the gainsharing contract. I generate useful and novel guidelines for the decision makers to implement and negotiate the gainsharing contract in practice.

Then starting from an outsourcing contract, I investigate how the client should promote the vendor to adopt a new technology which is crucial for the client and vendor to remain competitive in the global business environment. Such technology adoption in outsourcing involves agency issues and information asymmetry. I derive an incentive outsourcing contract for the client to both promote the vendor to incur costly effort and truly reveal his private information. I show that the cost-saving ratio plays a pivot role in demining the parameters of the optimal parameters of contract. I further discover the hidden information and hidden actions of the vendor will lead to lower investment threshold or delayed investment timing when compared to the first-best solutions.

Finally, in recognizing the importance of vendors in enhancing the outsourcing performance, I explore the outsourcing contact evaluation problem from the vendor's perspective by using the real option approach. The outsourcing literature to date has investigated the valuation of the outsourcing contract from the client's point of view to minimize cost and enhance outsourcing performance which, however, often results the notorious "winner's curse" to the vendors. Little research provides practical guidance to vendors for outsourcing contract valuation, helping them avoid the risk of the winner's curse. In this dissertation, I study outsourcing from the vendors' perspective by proposing a new valuation tool for the vendors to avoid the "winner's curse". Specifically, I incorporate the vendor's managerial flexibility and cost uncertainty into the evaluation problem and find that the vendors bid more regressively under the standard NPV approach than under the real option approach. I further examine the difference in the decision thresholds under the NPV approach and the real option approach and investigate how they are affected by the influential factors. I also analyze vendors' learning effects within the context of outsourcing contract renewal and conclude that a vendor should not simply pursue long-term outsourcing opportunities, but should pay attention to establish its dynamic learning curve under uncertainties.

Some limitations of this research need to be addressed. These limitations also raise a number of questions for future research. First, this dissertation only covers two types of outsourcing contracts: the fixed-price contract and the market-based gainsharing contract. Other contracts such as the revenue-sharing and cost-plus outsourcing contracts should be investigated as well to explore how the uncertainty drives the decisions for both the client and the vendor. Second, this dissertation only investigates the outsourcing problems when only one client and one vendor are participating in the outsourcing. Future studies are encouraged to explore the situations involving multiple clients and vendors by incorporating the interactions among the clients and the vendors when designing the outsourcing contracts.

This dissertation contributes to the outsourcing literature by focusing on three specific topics. There are many other promising aspects of outsourcing that deserve future investigation. One topic is how to model the increasing power of the vendors which might tighten the competition for the clients. As the trend of outsourcing grows, the vendor have grown fast in size thereby they can affect the client from other aspects which are not expected at the signing of outsourcing contracts. For instance, the contract manufacturers are growing rapidly in China because a large number of overseas companies currently are taking advantages of the low-cost labor and material in China. The results of this trend are as follows: The clients become more and more dependent on the vendor and the vendors are more and more powerful with regards to their size, capability and ambition. Consequently, the vendors would want to move up in the supply chain and engage in activities that are more profitable. Arrunada and colleagues (2006) discussed an interesting phenomenon where the contract manufacturers become the competitors of the originally equipment Manufacturers by creating a new company or new brand. Contract manufacturer Solectron (acquired by Flextronics International Ltd.

in 2007) developed its manufacturing expertise in the course of working for IBM, Hewlett-Packard, and Mitsubishi. Later, distributor Ingram Micro asked Solectron to customer build PCs, servers, and other computer equipment under its own and retailer's brand. Therefore, the vendor Solectron has become a competitor in PC industry to IBM, Hewlett-Packard etc. Future research should investigate the triggers of such strategic role change in the outsourcing process and examine the underlying mechanisms of such trend to provide guidance for the managers to adapt to such changes.

As emerging markets start to play important roles in world economy and outsourcing continues to be a growing area of research, it is important to uncover the various mechanisms influencing the different aspects of outsourcing in emerging market under uncertainty. This dissertation models three such important topics of outsourcing in emerging market, and hopefully will spur more research in this direction.

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