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The Effect of Unobservable Efforts on Contractual Efficiency: Wholesale Contract vs. Revenue-Sharing Contract

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ABSTRACT

An interesting puzzle in business practices is that although many researchers emphasize the benefits of a revenue-sharing contract, a wholesale contract has remained to be the most common contractual form. By introducing the concept of unobservable efforts, we examine the contractual efficiency of a wholesale contract and a revenue-sharing contract. The multi-task agency model and experimental design approach are used to analyze the relationship between the contractual efficiency and parameters. A major finding of our study is that a wholesale contract coordinates unobservable efforts, while it fails to coordinate the order quantity decision. Because unobservable efforts have mixed effects on the contractual efficiency, the superiority of contract type depends on parameters. This finding implies that a wholesale contract can be a competitive contract, especially when unobservable efforts are heavily involved. Our conclusion is that the current popularity of a wholesale contract is manager's rational response to complex supply chain environments rather than irrational behaviors.

Keywords: Unobservable Efforts, Contractual Efficiency, Wholesale Contract, Revenue-Sharing Contract, Multi-Task Agency Model

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1. INTRODUCTION

Supply chain coordination through contracts has been one of the important research topics in operations management discipline. Among various supply chain contracts, a revenue-sharing contract is considered as one of the competitive contractual forms in coordinating the supply chain (Cachon and Lariviere, 2005). A success story of Blockbuster Inc. is a famous example to show the potential of this contract. According to Mortimer (Mortimer, 2008), video rental stores with a revenue-sharing contract show 10% higher profits than those without a revenue-sharing contract. As such, a revenue-sharing contract has been widely used in several industries such as video rental industry, franchise industry and online retailing (Qin and Yang, 2008; Wang, 2002).

One interesting 'puzzle' in business practices is that except for some industries, most firms are using a 'simple' contract, wholesale contract (Corbett *et al.*, 2004; Gerchak and Wang, 2004; Yao *et al.*, 2008). Some researchers explain this phenomenon in the following ways. First, a wholesale contract is easy to manage so that administrative costs are relatively low. Second, a more academic explanation is that some efficient contract such as a revenue-sharing contract may fail to coordinate the supply chain when there are unobservable efforts (Cachon and Lariviere, 2005).

Unobservable efforts refer to behaviors which cannot be measured objectively and reflected in the formal contract (Gibbons, 2005). For example, consider a supply chain with an auto manufacturer and a car dealer. Sales promotion efforts by a dealer have a significant effect on the total sales amount. However, relevant costs are the composite of various activities so that it is difficult to convince a manufacturer to share costs. Although salesperson's time and efforts are used in the promotion, a manufacturer tends to refuse paying salesperson's salary. In this sense, sales promotion efforts cannot be formally considered and observable in the supply chain contract. Fund manager's customer service or Walmart employee's sales promotion can be an example of unobservable efforts.

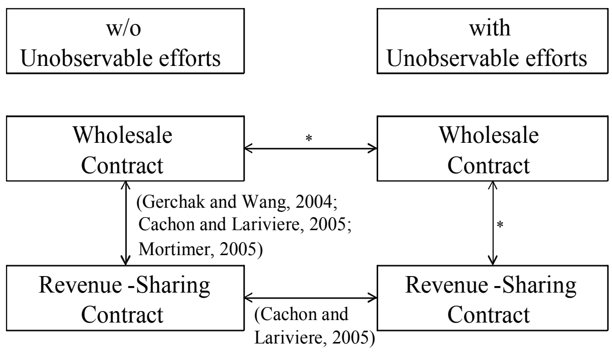
'Unobservable efforts' have not been thoroughly examined in the context of supply chain contracts, because they are unmeasurable and difficult to appropriately reflect in the model. Nevertheless, unobservable efforts are pretty common in business practices and may distort the efficiency of supply chain contracts developed in analytic approaches (Poppo and Zenger, 2002). One interesting point of view allows us to analyze unobservable efforts in a rigorous research setting. According to the relational contract approach, unobservable efforts include not only unmeasurable behaviors, but also behaviors non-enforceable by the court (Bull, 1987; Gibbons, 2005; Heide, 1994). That is, when contractual behaviors are based on the subjective assessment, it is difficult to enforce them by the court. Under this circumstance, measurable but non-enforceable contractual behaviors have the same effects as unmeasurable behaviors.

In an effort to answer the above puzzle in the real business, we examine contractual efficiencies of two popular supply chain contracts, a wholesale contract and a revenue-sharing contract. Specifically, we address two research questions, (1) which contract is more efficient, a wholesale contract or a revenue-sharing contract? and (2) what is the effect of unobservable efforts on the contractual efficiency?

Regarding the methodology, we adopt the multi-task agent model (Bull, 1987; Baker *et al.*, 2002; Gibbons, 2005) developed in the relational contract approach. The multi-task agent model is an extension of the traditional agent model and allows us to examine simultaneous effects of two managerial decision variables, order quantity decision and unobservable efforts. After deriving optimal decisions with/without unobservable efforts, we conducted a numerical analysis in order to show how contractual efficiencies are changed.

The major contributions of this study can be summarized in the following ways. First, we explain a puzzle in business practice, the current conflict between academic proposal and business practices. Many researches support the effectiveness of a revenue-sharing contract. For example, Cachon and Lariviere (2005) conducted an extensive analysis and concluded that a revenue-sharing contract coordinates the supply chain in various settings and has a lot of strengths. Mortimer (2008) examined the video-rental industry and shows that a revenue-sharing contract plays an important role in coordinating the supply chain. Yao *et al*. (2008) compared two contracts considering price-setting issue. Contrary to these academic recommendations, most firms have adapted relatively easy wholesale contracts.

Researchers explain this issue by the easiness of use and low administrative costs. Such an explanation implies that the current popularity of a revenue-sharing contract results from irrational behaviors in business practices. However, our study shows that a wholesale contract, in fact, is an efficient contract to coordinate unobservable efforts. Therefore, a firm needs to consider environmental factors influencing contractual efficiency and to choose a contractual form that fits with business conditions. Given that business activities are related to a wide range of unobservable or subjective factors, the popularity of a wholesale contract is manager's rational decision rather than irrational one.



Note) * refers to missing gaps in the literature. Our study attempts to fill those gaps.

Figure 1. Research Streams

Second, this study fills the gap in the literature by presenting a framework on the effect of unobservable efforts on the contractual efficiency. Many studies have studied the contractual efficiencies of a wholesale contract and a revenue-sharing contract. A dominant conclusion is that a revenue-sharing contract coordinates the supply chain, while a wholesale contract fails to do so (Chopra and Meindl, 2010; Gerchak and Wang, 2004). An interesting analysis on the contractual efficiency is Cachon and Lariviere (2005). This paper pointed out that when there are unobservable efforts, a revenue-sharing contract does not coordinate the supply chain. However, this paper does not show how the contractual efficiency of a wholesale contract is changed under the effect of unobservable efforts. By analyzing both the wholesale contract and revenue-sharing contract, we present a comprehensive framework on the effect of unobservable efforts on the supply chain contracts. Figure 1 illustrates how our work is placed in the literature and what is our contribution.

This study is organized in the following ways. Chapter 2 explains the multi-task agent model and major research settings. Next chapter addresses major procedures on deriving optimal solutions. Numerical analysis appears at Chapter 4. Chapter 5 discusses major results and implications of our study.

2. MODEL

The multi-task agency model is an extension of the traditional agency model. Some studies have adapted this approach in analyzing the contract between a principal and an agency (Bull, 1987; Baker *et al*., 2002; Gibbons, 2005). While the agency model is generally used to examine the relationship within a firm, we apply this concept into the supply chain context. We start from a single-task agency model and extend to the multi-task model.

2.1 Single-Task Model

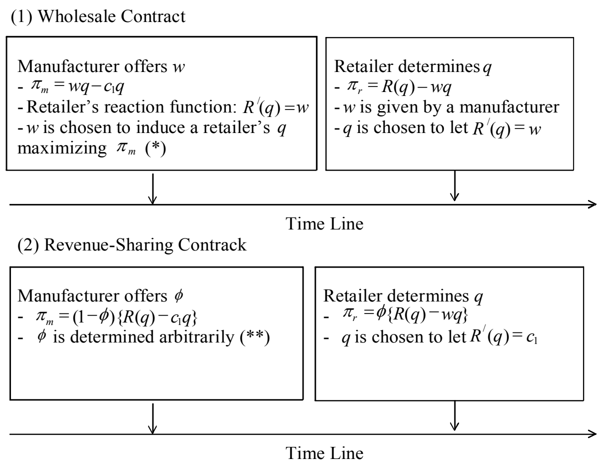
Consider a supply chain composed of two players, a manufacturer and a retailer. In our setting, a manufacturer offers a contract (w) and a retailer makes a managerial decision, order quantity decision (q). Therefore, a manufacturer plays a role of a principal, while a retailer takes a role of an agency.

In a wholesale contract case, a manufacturer and a retailer follows several stages. First, a manufacturer offers a flat contract value, w to maximize his profit, $\pi_m = qw - qc_1$, where c_1 is production cost per unit. A manufacturer is assumed to know a retailer's reaction function, $R'q - w = 0$. w is chosen to induce a retailer's q maximizing π_m. Second, a retailer makes an order quantity decision (q) to maximize her profit, $\pi_r = R(q) - wq$, where *R(q)* is revenue. A retailer is assumed to consider w as a given value. This procedure is the same as Stackelberg approach.

In a revenue-sharing contract case, the contract between a manufacturer and a retailer is revenue-sharing ratio, ϕ. Therefore, a manufacturer offers a revenue-sharing ratio to a retailer and a retailer chooses to accept or reject the offer. Lastly, a retailer determines an order quantity to maximize $\pi_r = \phi[R(q) - c_1 q]$.

Regarding the value of w and ϕ, we assume the arbitrary splitting. The arbitrary splitting means that the specific ratio of sharing the supply chain profit is determined arbitrarily. Contract values such as w and ϕ are directly related to how much portion one party takes. For example, if W is high or ϕ is low, a manufacturer will take a larger portion of the supply chain profit. In many researches on the supply chain contract, the major focus is whether certain contractual form can achieve the supply chain coordination rather than which party takes extra profits from the contract. Therefore, extra profits from the supply chain contract are assumed to be shared arbitrarily between two parties. This approach appears in other papers such as Cachon and Lariviere (2005), Yao *et al*. (2008a, 2008b) and we follow this assumption.

Regarding the shape of the revenue function *R(q)*, we use $R(q) = q\left(1 - \frac{q^{\theta}}{(\theta-1)}\right)$. Cachon and Lariviere (2005) used this demand function in order to illustrate the relationship between the shape of demand function and contractual efficiency. A major advantage of this demand function is that it is relatively easy to show the linkage between parameter (θ) and the marginal revenue. For example, when $\theta < 1$, the marginal revenue curve is convex. Because their study is one of the representative articles to examine the contractual efficiency, we borrow this revenue function for the purpose of comparison with previous literatures. Figure 2 describes the event timing and the information used in each stage.



Note) *: Assuming that $R'(q) + qR''(q)$ is decreasing in q, a manufacturer's profit can be expressed by the function of q. This condition is discussed in 3.1.
**: Assuming arbitrary splitting, ϕ is considered as a given constant.

Figure 2. Event Timing and the Information Used: Case w/o Efforts

2.2 Multi-Task Model

In the multi-task model, a retailer's managerial decisions include not only order quantity decision (q) but also unobservable efforts level (e). In our study, unobservable efforts refer not to unmeasurable effort, but to efforts not enforceable by the court. The relational contract theory states that transactions or activities between firms range from objectively measurable behaviors to subjectively measurable behaviors (Bull, 1987; Gibbons, 2005; Macneil, 1985; Poppo and Zenger, 2002). If business activities are only able to be measured by subjective criteria, they will be very difficult to enforce by the court.

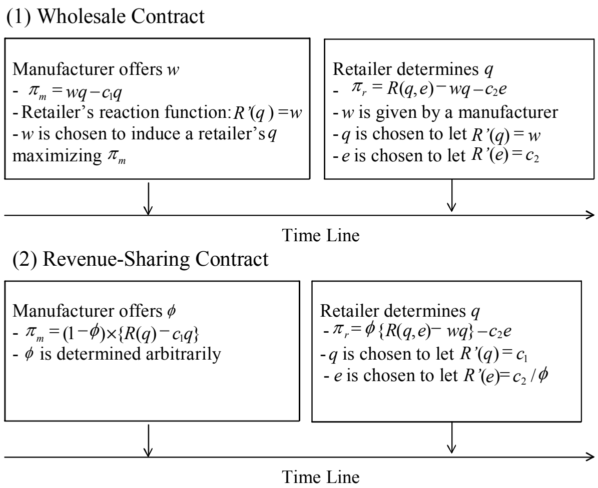


Figure 3. Event Timing and the Information Used: Case with Efforts

Table 1. Major Notations and Equations

		w/o Unobservable effort (Single-task model)	With Unobservable effort (Multi-task model)
WS[1]	R[3]	$\pi_r(q) = R(q) - wq$	$\pi_r(q, e) = R(q, e) - wq - c_2e$
	M[4]	$\pi_m = q[w - c_1]$	$\pi_m = q[w(q, e) - c_1]$
RS[2]	R	$\pi_r(q) = \phi[R(q) - c_1q]$	$\pi_r(q, e) = \phi[R(q, e) - c_1q] - c_2e$
	M	$\pi_m = (1-\phi)[R(q) - c_1q]$	$\pi_m = (1-\phi)[R(q, e) - c_1q]$
Supply Chain Profit		$\Pi_s(q) = R(q) - c_1q$	$\Pi_s(q) = R(q, e) - c_1q - c_2e$
Demand function		$R(q) = q\left(1 - \frac{q^\theta}{(\theta+1)}\right)$	$R(q, e) = q\left(1 - \frac{q^\theta}{(\theta+1)}\right) + e\left(1 - \frac{e^\tau}{(\tau+1)}\right)$

Note) [1] WS: wholesale contract
[2] RS: revenue-sharing contract
[3] R: Retailer's profit
[4] M: Manufacturer's profit
q: order quantity
e: unobservable efforts level
w: wholesale price
ϕ : revenue-sharing ratio
c_1 : unit cost for a product
c_2 : unit cost for efforts
θ : shape factor of revenue from quantity
τ : shape factor for revenue from efforts

For example, fund manager's tasks are comprised of the market return and the customer service. Because both the tasks play an important role in fund managing, they needs to be appropriately measured. Regarding the market return, managers can craft a contract with the exact market return and it is enforceable by the court. Regarding the customer service, the performance measurement can be only based on the subjective assessment so that it is very difficult to enforce specific behaviors related to customer service.

Recognizing behaviors which can be measured but cannot be enforced by the court, some studies have examined unobservable efforts in analytic models (Baker *et al*., 2002; Gibbons, 2005). In line with those studies, we define unobservable efforts as behaviors which can be measured but may not be forced by the court. Walmart employees' participation in product promotion is an example of unobservable efforts in the setting of supply chain contract.

A major structure of the multi-task model is similar to that of single-task model, except for parameters corresponding to unobservable efforts. c_1 and c_2 represents unit cost for quantity and effort, respectively. Figure 3 illusrtates the event timing and information used at the multi-task model. And Table 1 summarizes major notations and equations used in our study.

3. MAJOR RESULTS

3.1 Optimal Decisions at Single-Task Case

Using the equations at Table 1, we can derive optimal decisions of manufacturer and retailer. At centralized (or coordinated) supply chain, order quantity, $q_0 = (1-c_1)^{\frac{1}{\theta}}$, is derived by plugging demand function, $R(q) = q(1 - \frac{q^\theta}{(\theta+1)})$, into equation (2).

$$\max_q \Pi_s(q) = R(q) - cq \quad (1)$$

$$\frac{\partial \Pi_s(q)}{\partial q} = R'(q) - c = 0 \quad (2)$$

Major procedures in deriving optimal decisions under a wholesale contract and a revenue-sharing contract follows Cachon and Lariviere (2005). The sequence of events follows the Stackelberg approach. A retailer is a follower who determines q based on w. A manufacturer is a leader who determines w, considering a retailer's reaction. An optimal decision under a wholesale contract is derived in the following way. In terms of a retailer, order quantity (q) is determined by a manufacturer's offer, w. A retailer considers w as a given constant.

$$\frac{\partial \pi_r(q)}{\partial q} = R'(q) - w = 0 \quad (3)$$

Expecting that a retailer will determine q satisfying

$R'(q) = w$, a manufacturer determines w maximizing π_m. From equation (3), a manufacturer can control q by choosing w. Because $R'(q) = w$, a manufacturer's profit can be expressed by equation (4).

A manufacturer's profit is unimodal in q if $R'(q) + qR''(q)$ is decreasing in q. This condition refers to the elasticity of the retailer's order decreases in q. This assumption allows us to express a manufacturer's revenue function in terms of q. This assumption has been used in researches comparing the supply chain contracts. For example, Cachon and Lariviere (2005) and Yao *et al.* (2008a, 2008b) adapted this approach.

Assuming that a manufacturer's profit is unimodal in q, a manufacturer wants a retailer to order q^* satisfying $\frac{\partial \pi_m}{\partial q} = 0$. w, is chosen to induce q^*. Eventually, equation (5) shows a retailer's order quantity under a wholesale contract.

$$\pi_m = q(w-c) = q(R'(q)-c) \tag{4}$$

$$\frac{\partial \pi_m}{\partial q} = R'(q) + qR''(q) - c = 0 \tag{5}$$

As shown in equation (6), plugging the demand function, into equation (5) allows us to derive retailer's optimal order quantity, $q_r^* = \left(\frac{1-c}{1+\theta}\right)^{1/\theta}$, under the wholesale contract.

$$1 - q^\theta + q(-\theta q^{\theta-1}) - c = 0 \tag{6}$$

Regarding a revenue-sharing contract, retailer's profit function is the affine transformation of the supply chain's profit function (Cachon and Lariviere, 2005). Therefore, the order quantity decision is the same as that under the centralized decision. By plugging demand function into Equation (7), we can derive the retailer's optimal order quantity, $q_r^* = (1-c)^{1/\theta}$, which is the optimal order quantity under the coordinated supply chain.

$$\frac{\partial \pi_r(q)}{\partial q} = \phi(R'(q)-c) = 0 \tag{7}$$

3.2 Optimal Decisions at Multi-Task Case

A major difference between the single-task model and the multi-task model is that a retailer's decisions include effort level (e) as well as order quantity (q). For the purpose of simplicity and comparison, we assume that an effort level affects revenue but does not affect order quantity. Optimal order quantity, $q_0 = (1-c_1)^{\frac{1}{\theta}}$, and optimal effort level, $e_0 = (1-c_2)^{\frac{1}{\tau}}$ are derived by plugging demand function, $R(q,e) = q\left(1 - \frac{q^\theta}{(\theta+1)}\right) + e\left(1 - \frac{e^\tau}{(\tau+1)}\right)$, into equation (9) and (10), respectively.

$$\max_{q,e} \Pi_s(q, e) = R(q, e) - c_1 q - c_2 e \tag{8}$$

$$\frac{\partial \Pi_s(q)}{\partial q} = R'(q, e) - c_1 = 0 \tag{9}$$

$$\frac{\partial \Pi_s(q)}{\partial e} = R'(q, e) - c_2 = 0 \tag{10}$$

Optimal decisions under a wholesale contract are derived in the following ways. First, a retailer determines order quantity (q) and effort level (e), based on a manufacturer's decision, w.

$$\frac{\partial \pi_r(q)}{\partial q} = \frac{\partial R(q, e)}{\partial q} - w = 0 \tag{11}$$

$$\frac{\partial \pi_r(e)}{\partial e} = \frac{\partial R(q, e)}{\partial e} - c_2 = 0 \tag{12}$$

Therefore, $\frac{\partial R(q,e)}{\partial q} = w$ and $\frac{\partial R(q,e)}{\partial e} = c_2$ hold. One notion is that in our setting, an effort level is only related to a retailer so that a manufacturer has no influence on an effort level. That is, w is function of q, while c_2 remains a constant. A rationale behind this assumption is that because we consider an effort level as unobservable efforts (which cannot be forced by the court), a manufacturer cannot play any role in determining an effort level.

Similar to the single-task case, a retailer's order quantity decision satisfies equation (13).

$$\pi_m = q(w(q) - c_1) = q(R'(q, e) - c_1) \tag{13}$$

$$\frac{\partial \pi_m}{\partial q} = w(q) - c_1 + q\frac{\partial_w(q, e)}{\partial q}$$
$$= \frac{\partial R(q, e)}{\partial q} = q\frac{\partial^2 R(q, e)}{\partial q^2} - c_1 = 0 \tag{14}$$

By plugging demand function into equation (14), we can derive optimal order quantity decision, $q_r^* = \left(\frac{1-c_1}{1+\theta}\right)^{1/\theta}$. An optimal effort level, $e_r^* = (1-c_2)^{1/\tau}$ is directly derived from equation (12).

Optimal decisions under a revenue-sharing contract are derived in the following ways. A retailer's decisions satisfy equation (15) and (16).

$$\frac{\partial \pi_r(q)}{\partial q} = \phi\left(\frac{\partial R(q, e)}{\partial q} - c_1\right) = 0 \tag{15}$$

$$\frac{\partial \pi_r(e)}{\partial e} = \phi\frac{\partial R(q, e)}{\partial e} - c_2 = 0 \tag{16}$$

Therefore, $\frac{\partial R(q, e)}{\partial q} = c_1$ and $\frac{\partial R(q, e)}{\partial e} = c_2/\phi$ hold. By plugging demand function into equation (15) and (16), we get optimal decisions on order quantity level, $q_r^* = (1-c)^{1/\theta}$, and an effort level, $e_r^* = (1-\frac{c_2}{\phi})^{1/\tau}$.

Optimal decisions for each case are summarized in

Table 2. Some interesting finding is that at the single-task model, an order quantity decision under a revenue-sharing contract is same as that under centralized decision, which means that a revenue-sharing contract coordinates the supply chain. On the other hand, at the multi-task model, a revenue-sharing contract coordinates the order quantity decision but fails to coordinate the effort level decision. However, wholesale contract coordinate the effort level while it fails to coordinate the order quantity decision.

Table 2. Optimal Decisions

		w/o Unobservable effort (Single-task)	With Unobservable effort (Multi-task)
q	W-S	$q_r^* = \left(\frac{1-c}{1-\theta}\right)^{1/\theta}$	$q_r^* = \left(\frac{1-c_1}{1-\theta}\right)^{1/\theta}$
	R-S	$q_r^* = (1-c)^{1/\theta}$	$q_r^* = (1-c_1)^{1/\theta}$
	Centralized decision	$q_0 = (1-c)^{1/\theta}$	$q_0 = (1-c_1)^{1/\theta}$
e	W-S	N/A	$e_r^* = (1-c_2)^{1/\tau}$
	R-S	N/A	$e_r^* = (1-\frac{c_2}{\phi})^{1/\tau}$
	Centralized decision	N/A	$e_0 = (1-c_2)^{1/\tau}$

3.3 Contractual Efficiency

Contractual efficiency is defined as the ratio of the supply chain profits under certain contract to the coordinated supply chain profit, $\frac{\pi_r(q_r^*, e_r^*)+\pi_m(q_r^*, e_r^*)}{\Pi r(q_0, q_0)}$. Using optimal decisions at Table 2. we can derive each player's profit and contractual efficiency.

In order to simplify equations, we introduce several notations.

α : Retailer's profit when the supply chain is coordinated

β : Manufacturer's profit when the supply chain is coordinated

α^* : Retailer's profit under wholesale contract, single-task

β^* : Manufacturer's profit under wholesale contract, single-task

γ : Incremental profit increase from unobservable effort, wholesale contract

γ^* : Incremental profit increase from unobservable effort, revenue-sharing contract

$\alpha+\beta$: supply chain profit under the centralized decision, single-task

$\alpha+\beta+\gamma$: supply chain profit under the centralized decision, multi-task

$\alpha^* < \alpha$, $\beta^* < \beta$ and $\gamma^* < \gamma$ hold. Simplified contractual efficiency for each case appears in Table 3.

Table 3. Contractual Efficiency for Each Case

	w/o Unobservable effort (Single-task model)	With Unobservable effort (Multi-task model)
W-S	$\frac{\alpha^*+\beta^*}{\alpha+\beta}$	$\frac{\alpha^*+\beta^*+\gamma}{\alpha+\beta+\gamma}$
R-S	$\frac{\alpha+\beta}{\alpha+\beta}$	$\frac{\alpha+\beta+\gamma^*}{\alpha+\beta+\gamma}$

Figure 4 shows a more intuitive relationship between the contractual efficiency and contractual forms. When unobservable efforts are not considered, a revenue-sharing contract coordinates the supply chain (contractual efficiency = 1) and a wholesale contract fails to coordinate the supply chain (contractual efficiency < 1). The contractual efficiency without unobservable efforts has been well examined in the previous literature (Cachon and Lariviere, 2005; Gerchak and Wang, 2004).

Some interesting finding is that the existence of unobservable efforts can significantly distort the contractual efficiency. As examined in section 3.2., a wholesale contract coordinate unobservable efforts level, while a revenue-sharing contract fails to do so. Therefore, the contractual efficiency of a wholesale contract increases when unobservable efforts are considered. That is, $\frac{\alpha^*+\beta^*}{\alpha+\beta}$ is always smaller than $\frac{\alpha^*+\beta^*+\gamma}{\alpha+\beta+\gamma}$. On the other hand, that of a revenue-sharing contract decreases when we consider the multi-task model. That is, $\frac{\alpha+\beta}{\alpha+\beta}=1$ is always larger than $\frac{\alpha+\beta+\gamma^*}{\alpha+\beta+\gamma}$.

Because unobservable efforts have opposite effects on the contractual efficiencies of a wholesale contract and a revenue-sharing contract, we cannot say which contract is better under the multi-task model. At some parameter setting, a wholesale contract will show a better contractual efficiency. At the other setting, a revenue-sharing contract will show a better efficiency. In order to understand how the contractual efficiencies are changed, we conduct some numerical analysis in the next section.

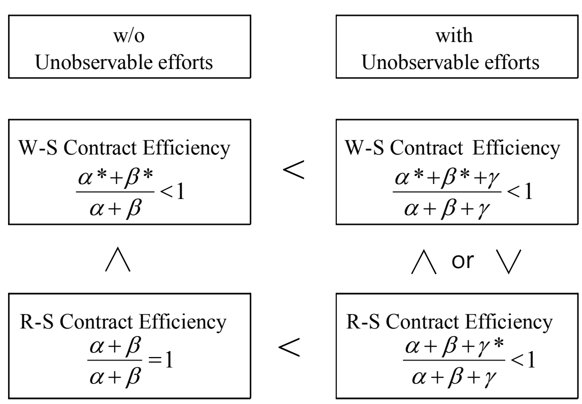


Figure 4. Relationship between Contractual Efficiency and Contractual Form

4. NUMERICAL ANALYSIS

We conduct some numerical analysis in order to illustrate the relationship between parameters and the contractual efficiency. We adapt experimental design approach from Law (Chopra and Meindl, 2010). 2^5 factorial design is used to reflect five parameters in our model.

First, θ and τ are shape factors of the demand function. Both the parameters can exist at (0, ∞). If shape factor = 1, marginal revenue function will be flat. If shape factor > 1, marginal revenue function will be concave. Cachon and Lariviere (2005) used 0.25 and 10 to compare concave marginal revenue function with convex one. We follow their approach and select 0.25 and 10 as design points.

Second, ϕ is revenue sharing ratio between retailer and manufacturer. It can exist at [0, 1]. If ϕ > .5, retailer will take a more portion from the total revenue. 0.4 and 0.6 are chosen in order to compare retailer's dominance with manufacturer's dominance.

Lastly, c_1 and c_2 refer to unit cost related to order quantity and effort level. Due to the characteristics of the revenue function, the ranges of q and e are restricted at [0, 1]. Therefore, corresponding costs, c_1 and c_2, are restricted to at [0, 1]. 0.3 and 0.7 are chosen in order to contrast low cost case with high cost case.

Major results from the experimental design appear in Table 4 and Table 6. At Table 4, a negative (positive) sign for each factor means that a small (large) value from two design points is used in the experiment. For example, the first response illustrates that the contractual efficiency of wholesale (revenue-sharing) is 0.741 (0.986) when parameter values for F1(θ), F2(τ), F3(ϕ), F4(c_1) and F5(c_2) are 0.25, 0.25, 0.4, 0.3 and 0.7, respectively.

Table 4. Response for Individual Design Points

F1	F2	F3	F4	F5	Response WS	Response RS	F1	F2	F3	F4	F5	Response WS	Response RS
-	-	-	-	+	0.741	0.986	+	-	-	-	+	0.858	0.999
-	-	-	-	-	0.869	0.529	+	-	-	-	-	0.866	0.951
-	-	-	+	+	0.869	0.500	+	-	-	+	+	0.859	0.998
-	-	-	+	-	0.996	0.072	+	-	-	+	-	0.876	0.885
-	-	+	-	+	0.741	0.986	+	-	+	-	+	0.858	0.999
-	-	+	-	-	0.869	0.779	+	-	+	-	-	0.866	0.977
-	-	+	+	+	0.869	0.500	+	-	+	+	+	0.859	0.998
-	-	+	+	-	0.996	0.564	+	-	+	+	-	0.876	0.946
-	+	-	-	+	0.968	0.122	+	+	-	-	+	0.898	0.717
-	+	-	-	-	0.986	0.962	+	+	-	-	-	0.929	0.980
-	+	-	+	+	0.999	0.002	+	+	-	+	+	0.929	0.500
-	+	-	+	-	1.000	0.960	+	+	-	+	-	0.960	0.971
-	+	+	-	+	0.968	0.122	+	+	+	-	+	0.898	0.717
-	+	+	-	-	0.986	0.995	+	+	+	-	-	0.929	0.997
-	+	+	+	+	0.999	0.002	+	+	+	+	+	0.929	0.500
-	+	+	+	-	1.000	0.995	+	+	+	+	-	0.960	0.996

At Table 5, the main effect of certain factor is the average change in the response due to moving factor from its '-' level to its '+' level while holding all other factors fixed (Law, 2007). Because a main effect is computed relative to the current design and factor levels only, results may not be extrapolated. Nevertheless, it can provide us with some insights on the effects of parameter changes on responses, which are the contractual efficiencies in our study.

Table 5. Main Effects of Factors on Contractual Efficiency

Variable		Experiment Point	Main Effect on Efficiency W-S	Main Effect on Efficiency R-S
F1(θ)	S-F* of revenue from q decision	(0.25, 10)*	(0.032)	0.316
F2(τ)	S-F of revenue from e decision	(0.25, 10)*	0.092	(0.133)
F3(ϕ)	Ratio of revenue-sharing	(0.4, 0.6)*	0.000	0.059
F4(c_1)	Unit cost of quantity	(0.3, 0.7)*	0.046	(0.152)
F5(c_2)	Unit cost of effort	(0.3, 0.7)*	(0.045)	(0.244)

Note) * S-F: Shape Factor.

Table 5 shows the main effects of individual factors on the contractual efficiencies. The change in θ (from 0.25 to 10) decreases the contractual efficiency of a wholesale contract by 0.032, whereas it increases that of a revenue-sharing contract by 0.316. It means that if a marginal revenue function in terms of order quantity decision is convex, the contractual efficiency of a wholesale contract will be higher when a marginal revenue function (in terms of order quantity) is convex. The shape of a marginal revenue function has an opposite effect on the contractual efficiency of a revenue-sharing contract. An interesting fact is that the absolute size of effect is much larger in a revenue-sharing contract than a wholesale contract.

Unlike θ, a change in τ has a positive effect on the contractual efficiency of a wholesale contract. Also, it decreases the contractual efficiency of a revenue-sharing contract by (0.133). Similar to θ, the absolute magnitude of effect is much larger in a revenue-sharing contract than in a wholesale contract.

Figure 5~Figure 7 graphically show the relationship between the contractual efficiency and parameters. At Figure 5, the contractual efficiencies of two contracts are compared, in the perspective of shape factor, τ. In wholesale contract, a decision on an effort level is always coordinated. That is, an effort level under wholesale contract (e_r^*) is always the same as an effort level under coordinated supply chain (e_0). Therefore, the change in the shape (τ) of marginal revenue from effort decision does not influence an effort level, although the relative portion of revenue from effort decision may change the overall contractual efficiency of the wholesale contract.

In a revenue-sharing contract, an effort level is not coordinated. That is, an effort level under a revenue-sharing contract (e_r^*) is smaller than an effort level under the coordinated supply chain (e_0). Because the distance between e_r^* and e_0 is affected by parameters, the shape (τ) of the marginal revenue from effort decision influences the contractual efficiency through the decision on e_r^* , as well as the relative portion of the revenue from effort decision.

The above interpretation implies that the contractual efficiency of a wholesale contract is relatively robust to parameter changes, whereas that of a revenue-sharing contract is relatively sensitive. Three dimensional graphs at Figure 6 and Figure 7 support our observations. Figure 6 and Figure 7 illustrate the relationship between θ, τ, and contractual efficiency. The contractual efficiency of a wholesale contract (Figure 6) has a relatively smooth surface, while that of revenue-sharing contract (Figure 7) has a relatively steep surface.

Results from the experimental design support our interpretation. Table 5 shows the effect of each factor. In a wholesale contract, the shape factors of q and e on contractual efficiency are (0.032) and 0.092. In a revenue-sharing contract, they are 0.316 and (0.133). This result implies that the change of contractual efficiency in the revenue-sharing contract is three times more than that in a wholesale contract.

In addition, we examined four different cost settings, two costs of products (0.3 and 0.7) and two costs of efforts (0.3 and 0.7). Similar to the effects of shape factors, contractual efficiency of revenue-sharing contract is more sensitive to the change of costs.

Due to inherent characteristics of the experimental design approach, we cannot say that our extrapolation or the main effects of individual factors rigorously represents the relationship among variables. Nevertheless, we can observe some interesting findings on features of a wholesale contract and a revenue-sharing contract through experimental design approach and present some intuitions on contractual efficiencies of supply chain contracts.

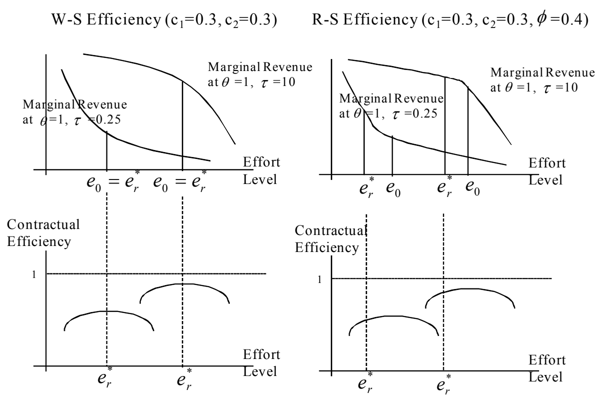


Figure 5. The Effect of Shape Factor, τ, on Contractual Efficiency

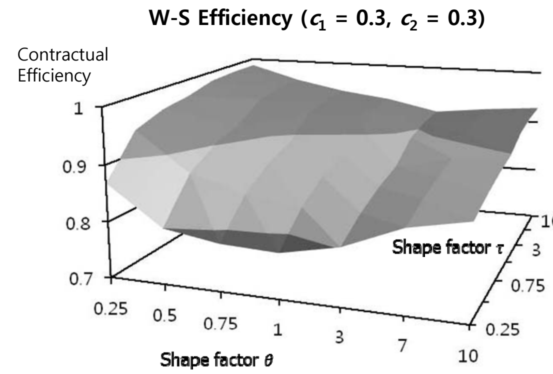


Figure 6. The Relationship Among θ, τ and Contractual Efficiency: Wholesale Contract

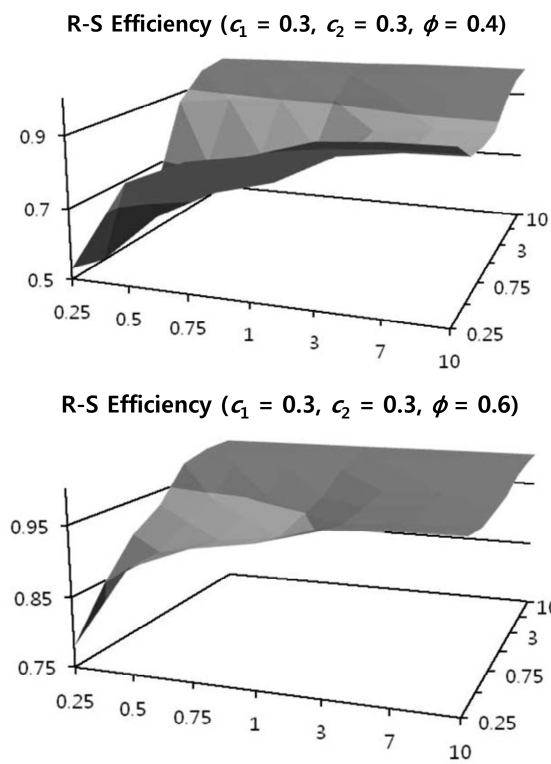


Figure 7. The Relationship Among θ, τ and Contractual Efficiency: Revenue-Sharing Contract

5. DISCUSSION

From the previous analysis, we show that if unobservable efforts are considered, the contractual efficiencies of two popular supply chain contracts will depend on parameters, and that under certain conditions, a wholesale contract may have a better efficiency than a revenue-sharing contract. Major findings and implications of our study can be summarized in three ways.

First, our analysis shows the relationship between unobservable efforts and contractual efficiencies. On the one hand, a revenue-sharing contract coordinates order quantity decision, whereas it fails to coordinate unobservable efforts. On the other hand, a wholesale contract coordinates unobservable efforts, although it does not coordinate the order quantity decision. Such mixed effects provide us with answers for the current popularity of wholesale contracts.

Pointing out the superiority of a revenue-sharing contract, many researchers tend to explain the popularity of the wholesale contract as manager's irrational behaviors or negligible random factors. However, our analysis shows that when unobservable efforts play an important role in the relationship between supply chain members, a wholesale contract can have a better contractual efficiency.

When there is no unobservable effort, a revenue-sharing contract coordinates the supply chain. But as the effect of unobservable effort increases, contractual efficiency continues to decrease. On the Contrary, contractual efficiency of wholesale contract continues to increase, as the effect of unobservable effort increases.

Such a relationship sheds an interesting implication on the contemporary supply chain management. These days, the globalization and diversified customer demands require a firm to compete not only through internal resources, but also through coordinated supply chain (Chen and Paulraj, 2004; Dyer and Singh, 1998). Researchers and practitioners agree that the relationship management among supply chain members result in amplified complexities in business. Under this environment, contractual behaviors between supply chain members have extended from traditional observable activities to unobservable behaviors. As such, the effect of supply chain contracts needs to be revisited. Under this notion, we state that the current popularity of wholesale contract is, indeed, a firm's rational endeavor to reflect current complexities of supply chain.

Second, our analysis sheds us a new avenue for the contingency on adaptation of contract types. Although many papers have rigorously examined the features of supply chain contracts and proposed various incentive schemes to coordinate the supply chain, relatively few papers have specifically addressed the linkage between business environments and contract types. Another implication of this study is to reveal the relationship between business environments and contract types. As stated above, the supply chain relationship with low unobservable efforts (or uncertainty) may prefer a revenue-sharing contract, because the contractual efficiency is better. On the other hand, if unobservable efforts are heavily involved, a wholesale contract will be preferred.

For example, video rental or online shopping industry may have relatively low unobservable efforts involved in the contracts so that revenue-sharing contract can be widely used. In addition, a revenue-sharing contract may fit with firms belonging to 'service factory.' On the other hand, automobile sales or insurance involves a wide range of unobservable behaviors such as customized services. Therefore, a wholesale contract will be a better choice for those industries. Firms such as 'professional service' will prefer a wholesale contract.

Lastly, from numerical analysis, we observe that a wholesale contract is more robust to parameter changes than revenue-sharing contract. Because an experimental design approach is used to numerically examine the model, we may not state that the robustness of a wholesale contract holds all over the response surface. However, within our experiment setting, a wholesale contract turns out to be robust to parameter changes. This observation reinforces our stance on the current popularity of a wholesale contract. Our analysis states that the contractual efficiency of a wholesale contract is improved as unobservable efforts become more common. In addition to this effect, the robustness of a wholesale contract provides a firm with a more flexibility in managing the contract. In that rapid environmental changes and uncertainties are a sort of the trade-mark of current business environments, the robustness from adapting a wholesale contract allows firm to more comfortably choose a contract type.

6. CONCLUSION

This study examines two research questions, the comparison of contractual efficiencies and the effect of unobservable efforts on the contractual efficiency. Our analysis answers those research questions in the following ways. Unobservable efforts have a positive effect on the contractual efficiency of a wholesale contract, while they have a negative effect on that of a revenue-sharing contract. Due to Such mixed effects, the superiority among contractual forms depends on parameters. A natural interpretation is that a wholesale contract is likely to be better than a revenue-sharing contract, when unobservable efforts play an important role in the relationship between supply chain members. An additional observation from numerical analysis shows that a wholesale is more robust to parameter changes.

A theoretical contribution of our study is to fill the gap in the literature by presenting a comprehensive framework on the relationship between unobservable efforts and the contractual efficiency. Although many supply chain papers have thoroughly examined features of supply chain contracts, unobservable efforts have not been generally reflected in the research because they are regarded as negligible random factors or unmeasurable factor. Some papers attempted to consider unobservable efforts in the contractual study but did not incorporate unobservable efforts with the contractual efficiency under a comprehensive framework. On the other hand, the relational contract theory presents a theoretical foundation on how to reflect unmeasurable factors in the contract by introducing the concept of 'non-enforceable' behaviors in the contract. However, relational contract theory has only examined behaviors within a single firm or general contract setting so that the effect of unobservable efforts on specific supply chain contracts has remained to be unexplored. Integrating those research streams, we develop a comprehensive model reflecting unobservable efforts under the context of the supply chain contracts.

Our contribution to business manager is to explain an interesting puzzle in business practices, the popularity of a wholesale contract. Many researchers have emphasized benefits of a revenue-sharing contract and proposed a wide adaptation of a revenue-sharing contract. Unlike such an academic proposal, many managers have commonly used a 'simple' wholesale contract. Although this puzzle tends to be explained by low administrative cost or easiness in use, our analysis shows that a seemingly inefficient wholesale contract can be a competitive contractual form especially when supply chain relationship is heavily affected by unobservable efforts. That is, the current popularity of a wholesale contract is a manager's rational response to complex environments rather than an irrational behavior.

A limitation of our study is that due to the characteristics of experimental design approach, our numerical analysis may not be extensively applied into the response surface. We conducted experimental design approach in order to understand the relationship between contractual efficiency and parameter changes. A future study may implement a more thorough investigation on the relationship between contractual efficiency and parameters.

Our study may be extended in the following way. First, we proposed some contingency between contractual efficiency and industry type, through the observation from numerical analysis. For example, we conjecture that industries such as service factory will prefer a revenue-sharing contract, while industries such as professional service will prefer wholesale contract. An empirical investigation may confirm our conjecture and provide managers with a more concrete guideline on the choice of contract type. Second, our analysis may be applied into other supply chain contract such as quantity discount contract. In this study, we narrowed down the scope of the study and focused on two types of supply chain contracts. A further study may examine the applicability of our model into the context of our supply chain contracts. Lastly, some ideas from the relational contract theory may be examined. For example, the relational contract theory states that the contractual efficiency can be decomposed into alignment effect and scaling effect, when there are multiple tasks involved in the contract. An alignment effect refers to whether agency's tasks go in the same directions as principal's intentions, while scaling effect refers to how strong is the contract to motivate agency's tasks. Decomposing the contractual efficiency of current supply chain contracts may provide us for interesting findings.

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