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Research on Coordinating Cloud Service Supply Chain Considering Service Disruption

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ABSTRACT

The risk of the implementation of cloud service and the worry about the failure of projects or strategies caused by service disruption is an important reason of low adoption rates of the cloud service. Service disruption not only directly affects the cloud service free trial results, but also leads to compensation to the consumers. The coordination problem between a CFP (cloud function provider) and a CIP (cloud integration provider) in a cloud supply chain is investigated, in which service demand is determined by the application free trial. Coordination Contracts are discussed in two kinds of situations, linked respectively to the information symmetry and information asymmetry. The results show that the cost and risk-sharing coordination contracts we proposed can realize optimal supply chain performance, and Pareto improvement of supply chain members' profits. Reducing the service disruption probability and improving the level of service reliability are the key to the free trial. Besides, the compensation cost allocation enhances the scalability of cost allocation. Through numerical exploration analysis, effectiveness of the model is demonstrated and some managerial insights are obtained.

Keywords: Service Disruption, Cloud Service Supply Chain, Free Trial, Coordination.

INTRODUCTION

With the development of the theory and the technology of cloud computing, the cloud service mode shows the tendency of the enterprise strategic alliance. In 2014, HP and Cisco, as the world's top cloud service integration providers, announced that they would establish Helion and Intercloud cloud computing service supply chain networks respectively. Both of the networks covered cloud service function providers, such as cloud computing provider, telecom operators and data centers. Domestic Internet giant Alibaba also announced the launch of Ali Cloud Cooperation Plan in August 2014. He planned to recruit more than 10000 cloud service partners to build the cloud ecological system adapting to the processing technology in the DT era and provide one-stop cloud service for more customers.

As more enterprise strategic alliances established, the demand for cooperation among members of the supply chain grows accordingly. Recently IT service market design and coordination have been a theme of many studies. Dorsch (2014) [5] pointed out that the coordination of this kind supply chain paid more attention to service, effort and ability coordinating. Scholars[2][3] have proposed some collaborative method of normal service condition (Demirkan and Cheng, 2008 and 2010), such as revenue sharing contract, cost sharing contract, laying sufficient theoretical model for the research on cloud service supply chain coordination. Demirkan and Cheng studied an application services supply chain consisting of one application service provider (ASP) and one application infrastructure provider (AIP). They found that it is better to let the player closer to the market coordinate the supply chain. This research provided a good reference for the subsequent research about the relationship of new IT service model from the perspective of service supply chain. On this basis, Demirkan et al. (2010)[3] introduced the queuing model constraints and studied the coordination strategies about time cost and service ability in SaaS service supply chain.

There exist lots of research addressing issues related to the ASP field. Lin (2009)[10] analyzed the establishment and coordination of outsourcing relationship between ASP and customers. He discussed opportunism, interdependence, trust and relationship coordination, etc. Based on the intangibility and unverifiability of contributed resources resulting in double moral hazard, Dan et al.[1] analyzed the effect of different membership in the supply chain on the risk sharing (Dan et al., 2010). In order to solve the problems involving ASP providers' capability construction and motivation, Ren and Zhang(2012)[12] built a multi-task principal-agent model. Based on three kinds of capability constructing models, the incentive contacts for the ASP providers that provide critical business application service and execute the two tasks involving the system operation service and the business consultant service are analyzed. Li et al. (2011)[7] studied the coordination problem between a network service provider (NSP) and an application service provider (ASP) from the perspective of application service supply chain based on the ASP model. In this paper, they proposed a method that introduced the risk sharing of ASP's over and under-capacity into the revenue sharing contract to coordinate the application service supply chain.

With the development of theory and technology of cloud computing, the service platform dominated by new carriers of value such as cloud computing, Internet of things and big data became one new business development model. At the same time, cloud service supply chain has gradually been a hot research on the emerging supply relationship (Jula et al., 2014[6]; Dha, 2012 [4]; Song et al., 2010[12]). The Software as a Service (SaaS), as the marketing front of cloud service delivery, got extensive concern of scholars and industry. In domestic research field, most coordination research on SaaS service supply chain focused on the coordination among SaaS function providers, SaaS service providers and SaaS service agents. For instance, the team leading by Yan analyzed incentive and risk control problems of SaaS service supply chain, which includes both the upstream enterprise (namely SaaS function provider) and the downstream enterprise (namely SaaS service distributors) (Yan et al., 2012, 2014 and 2015[13][14][15]). Li et al. (2013)[8] investigated the coordination problem between an AIP and an ASP in a SaaS supply chain, in which the service demand is determined by the application free trial. Additionally, they discussed the opportunism in ability cooperation under asymmetrical information.

However, few scholars analyzed incentive, allocation and compensation problems of interruptible service. While one important reason leading to the low cloud adoption rate is customers' worry about implement risk and project failure causing by service disruption. Most studies don't explicitly take into account the effect of service disruption and failure on the supply chain coordination, and don't pay attention to the change of the risk and benefits in ASP or SaaS model of the cloud platform. The important role of behavior efforts for supply chain coordination under the features of super-large scale and non-inventory of the cloud service have also been ignored.

Our model is similar in vein to the one studied in Liang and Ye (2015)[9]. However, Liang's model does not explicitly consider the effects of exogenous risk of service failure. Instead, Liang first specifies coordination of cloud service supply chain based on the cost distributions of efforts cost and compensation costs. We depart from the Liang's model by explicitly taking into account the service interruption causing the low adoption rate of cloud service and by allowing the demand determined by the application free trial. The major contributions of this paper include that service disruption affect free trial result, which in turn affect the market demand. When facing with asymmetrical information problems, we discuss the opportunism behavior in cooperation and coordination. Further managerial insights are also derived from extensive numerical exploration where the results indicate that the decentralized "cost and risk sharing" mechanism achieves the same supply chain performance as a centralized system. Several insights not reported in prior literature are discussed in Section 5.

The paper is organized as follows. In Section 2, we present the problem description and model assumption. In Section 3 and 4, we model decision-makers and their behavior and the coordination contracts among decision makers under symmetrical and asymmetrical information respectively. In Section 5, we conduct numerical simulation and analysis. In the concluding Section 6, we summarize our results and suggest directions for future research.

PROBLEM DESCRIPTION AND MODEL ASSUMPTION

Before using cloud computing, a lot of customers have some doubts, especially worry about the stability, security of cloud service. So most of them choose to try before they buy. And most CIP (Cloud Integration Provider) are also glad to provide free trial for customers, such as Amazon, he announced to provide one-year free cloud service for AWS new users in 2011. This event promotes the standard of "free" business model, thus customers can try the suppliers' service first and then decide to buy or not. CCW Research points that "try before they buy" is a big advantage of SaaS to the traditional software. In this model, customers could enjoy free trial before formal purchase for a period of time, thereby reducing the risk and cost of supplier's selection process. Therefore, in this paper, we consider the actual market demand is to rely on the free trial implementation, which is different from the product supply chain assuming the demand is dependent on price or random. As the core enterprise on the supply chain, on one hand, CIP needs to incent CFP's (Cloud Function Provider's) joint by cooperation, win-win and information environment construction to build internal cooperation platform and business model. On the other hand, CIP needs to provide compensation to improve customers' satisfaction, encourage more demand to become partners and expand the market share.

With the development of the theory and the technology of cloud computing, the cloud service mode shows the tendency of the enterprise strategic alliance. In 2014, HP and Cisco, as the world's top cloud service integration providers, announced that they would establish Helion and Intercloud cloud computing service supply chain networks respectively. Both of the networks covered cloud service function providers, such as cloud computing provider, telecom operators and data centers. Domestic Internet giant Alibaba also announced the launch of Ali Cloud Cooperation Plan in August 2014. He planned to recruit more than 10000 cloud service partners to build the cloud ecological system adapting to the processing technology in the DT era and provide one-stop cloud service for more customers. We develop a stylized model to study the cloud service supply chain. Fig. 1 shows the cloud service supply chain model.

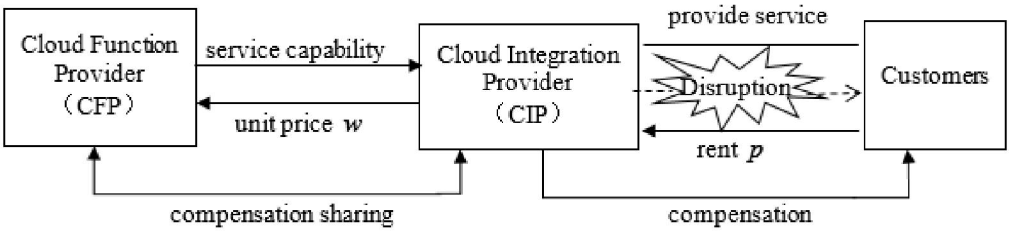

Figure 1: The cloud service supply chain model

In order to make the study more representative and easily quantify the decision process of CFP and CIP, we make the following assumptions.

Assumption 1. There is only one CFP, one CIP and many potential customers in the market. The CFP provides service capability for the CIP, on this basis, the CIP provides value-added service for customers (The specific supply chain model is shown in Fig. 1). Potential customers decide whether to rent the cloud service after free trial. The actual market demand depends on the effect of free trial, which is also the bright spot of this article.

Assumption 2. The adoption probability of cloud service of potential customers is $\varphi = 1 - r^{\delta}\ (0 \le r \le 1)$. Here we mainly consider two factors affecting customer adoption intention. One is the interruption risk probability, which is unchangeable and uncontrollable by the CIP in a short term due to various factors of the nature (such as extreme weather), human factors and cost budget. The other one is the effort level during free trial period, which is quantitative investment and the decision variable of the CIP.

Figure 2 shows the relationship between the cloud service adoption rate and the CIP's effort level. As is shown in Fig.2, along with the increase of the CIP's effort level, the adoption rate of cloud service rises while marginal effects of the effort decreases. For the same effort level, the smaller the service disruption probability is, the higher the adoption rate is. service disruption. Otherwise, the lower the adoption rate is and the easier the CIP loses customers.

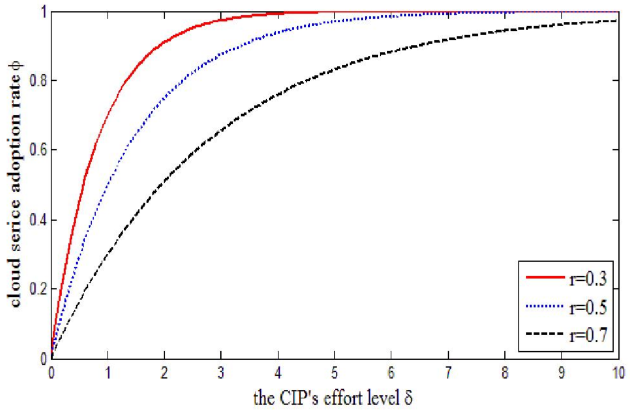

Figure 2: The relationship between the CIP's effort level and cloud service adoption rate

Assumption 3. In one contract period, the cost of unit service ability of the CFP is c, and the according price is w. After the free trial, if the potential customers adopt the service, then they will sign a service contract with the CIP and the service fee will be p.

During the free trial period of cooperation of the CFP and the CIP, the cost of the CFP is $c_0 N$, where c_0 is the unit service ability of the CFP, N is the number of all customers. The effort cost of the CIP is $c(\delta) = b\delta$ (referred Li's research, 2013[8]), where b is cost factor. It is worth noting that we assume the effort cost of the CIP is the linear function instead of quadratic function. Adoption rate has already been set nonlinear and reflects marginal utility diminishing. So linear function could depict the effect of marginal effort diminishing in reality.

Assumption 4. The expected number of customers in contract period is $N(1 - r^{\delta})$. Because of the uncertainty of the market, the number of customer is uniformly distributed over $[\mu - a, \mu + a]$, where $\mu = N(1 - r^{\delta})$. We use $f(x)$ to denote the probability density function and $F(x)$ to denote the cumulative distribution function.

Assumption 5. Faced with customer dissatisfaction with service interruption, the CIP attract customers through the compensation strategy in order to improve the customer satisfaction and increase market share. The amount of compensation is $r(\Delta - \delta)$, which is related to the risk probability r and insufficient efforts $(\Delta - \delta)$. Here we use Δ to denote the maximum of the effort level, however it is difficult to achieve this maximum value because the CIP can't pay all effort to meet customer requirements for the sake of cost control and idle resources. The unit compensation price is β times of the market price p, where β is compensation coefficient. When $\beta = 1$, the unit compensation price is $\beta p = 1 \cdot p = p$, that is free. This compensation strategy is based on market price, which is common in reality and measured easily and conveniently. The variables used throughout this model are summarized in Table 1.

Table 1: Variables used throughout the model

Notation	Definition
N	the number of potential customers
p	price of cloud service
w	price of per unit of capacity paid by CFP to CIP
r	service disruption probability
δ	the effort level of CIP
φ	Customer adoption rate after the trial， and $\varphi = 1 - r^{\delta}$
c_0	Service cost coefficient of CFP
$c(\delta)$	the effort cost of CIP, and $c(\delta) = b\delta$, where b is cost coefficient, $b > 0$
Δ	the maximum of effort level
β	compensation multiple relative to the p
$\alpha, \alpha^{'}$	Allocation proportion of effort cost and compensation cost, allocation proportion of effort cost
γ	risk sharing proportion
$\Pi^{s}_{CFP}, \Pi^{s}_{CFP,\alpha}$	the expected return of CFP in symmetrical information situation, the expected return of CFP under the cost sharing contract in symmetrical information situation
$\Pi^{s}_{CIP}, \Pi^{s}_{CIP,\alpha}$	the expected return of CIP in symmetrical information situation, the expected return of CIP under the cost sharing contract in symmetrical information situation
$\Pi^{a}_{CFP}, \Pi^{a}_{CFP,\alpha,\gamma}$	the expected return of CFP in asymmetrical information situation, the expected return of CFP under the cost and risk sharing contract in asymmetrical information situation
$\Pi^{a}_{CIP}, \Pi^{a}_{CIP,\alpha,\gamma}$	the expected return of CIP in information asymmetry situation, the expected return of CIP under the cost and risk sharing contract in asymmetrical information situation
$\Pi^{s}_{SC}, \Pi^{a}_{SC}$	the expected return of cloud service supply chain in symmetrical information situation and asymmetrical information situation respectively

CLOUD SERVICE SUPPLY CHAIN COORDINATION UNDER SYMMETRICAL INFORMATION

In asymmetrical information situation, the service reliability of CIP (service disruption probability, denoted by r) is the knowledge shared by both sides of the cooperation, that is to say, the CFP knows the service disruption probability of the CIP. In this case, the actual needs of customers are influenced by service disruption probability and the CIP's effort level. For the CIP, the major costs include effort cost and compensation cost. For the CFP, there is only the service capacity cost to be considered. The expected revenue function of CFP, CIP and the whole cloud service supply chain are

$$\Pi^{s}_{CFP} = (w - c) N \left(1 - r^{\delta}\right) - c_0 N \tag{1}$$

$$\Pi^{s}_{CIP} = (p - w) N \left(1 - r^{\delta}\right) - b\delta - r(\Delta - \delta)\beta p \tag{2}$$

$$\Pi^{s}_{SC} = (p - c) N \left(1 - r^{\delta}\right) - c_0 N - b\delta - r(\Delta - \delta)\beta p \tag{3}$$

Centralized Decision-making

In the centralized supply chain, the CFP and the CIP form a joint venture to achieve the goal of optimizing the supply chain as a whole. The whole supply chain's expected profit is the sum of the expected profit functions of the CFP and the CIP described in Eq. (3). The first order and the second order of Eq. (3) leads to

$$\frac{\partial \Pi^{s}_{SC}}{\partial \delta} = -(p - c) N r^{\delta} \ln r - b + r\beta p \tag{4}$$

$$\frac{\partial^2 \Pi^s_{SC}}{\partial \delta^2} = -(p-c) N r^{\delta} (\ln r)^2 < 0 \tag{5}$$

Because the second order of Eq. (3) is less than zero, the objective function in Eq. (3) is strictly concave, thereby ensuring the existence of a unique optimal solution. To find the optimal effort level, first order conditions require $\frac{\partial \Pi^s_{SC}}{\partial \delta} = 0$. After some algebra, first order conditions lead to

$$\delta^{s\ *}_{SC} = \log_r \frac{b - r\beta p}{(c-p) N \ln r} \tag{6}$$

In order to make the results conform to reality, $b > r\beta p$ need to meet. This constraint shows that the effort cost coefficient is greater than the compensation cost coefficient.

In centralized decision-making, the whole supply chain's expected profit is

$$\Pi^s_{SC} = (p-c) N \left(1 - r^{\delta^{s\ *}_{SC}}\right) - c_0 N - b\delta^{s\ *}_{SC} - r\left(\Delta - \delta^{s\ *}_{SC}\right)\beta p \tag{7}$$

Decentralized Decision-making

In reality, the CFP and the CIP are independent of the benefit. Most of time, they will just consider their own interests, regardless of the other party and the whole supply chain. In this scenario, the CIP make the independent decision to maximize his own profit in a dominant position. The first order and the second order of Eq. (2) leads to

$$\frac{\partial \Pi^s_{CIP}}{\partial \delta} = -(p-w) N r^{\delta} \ln r - b + r\beta p \tag{8}$$

$$\frac{\partial^2 \Pi^s_{CIP}}{\partial \delta^2} = -(p-w) N r^{\delta} (\ln r)^2 < 0 \tag{9}$$

Because the second order of Eq. (2) is less than zero, the objective function in Eq. (2) is strictly concave, thereby ensuring the existence of a unique optimal solution. To find the optimal supply chain profit, first order conditions require $\frac{\partial \Pi^s_{CIP}}{\partial \delta} = 0$. After some algebra, first order conditions lead to

$$\delta^{s\ *}_{CIP} = \log_r \frac{b - r\beta p}{(w-p) N \ln r} \tag{10}$$

In order to make the results conform to reality, $b > r\beta p$ need to meet. This constraint shows that the effort cost coefficient is greater than the compensation cost coefficient.

In decentralized decision-making, the whole supply chain's expected profit is

$$\Pi^{s\ '}_{SC} = (p-c) N \left(1 - r^{\delta^{s\ *}_{CIP}}\right) - c_0 N - b\delta^{s\ *}_{CIP} - r\left(\Delta - \delta^{s\ *}_{CIP}\right)\beta p \tag{11}$$

Proposition 1. In decentralized supply chain, the optimal effort level of the CIP's independent decision making is lower than that in centralized decision-making, that is to say, $\delta^{s\ *}_{CIP} < \delta^{s\ *}_{SC}$, and $\Pi^{s\ '}_{SC} < \Pi^s_{SC}$, the cloud service supply chain cannot achieve coordination.

Proof. See the Appendix.

Proposition 1 implies that there is double marginalized effect under the decentralized decision, which is similar to products supply chain. Because the CIP make more effort in integration supply chain, centralized decision increases the profits of the whole supply chain. However, it's shown that the CIP does not make enough effort to maximized the supply chain's total profit because the CIP ignores the impact of his action on the CFP's profit. Hence, coordination requires that the CIP be given an incentive to increase his effort.

Cost Sharing Coordination Mechanism

The above analysis shows that under the certain service disruption probability, when the CIP increases his effort level, the number of customers winning through the free trial grows. Because the CIP bears all effort and compensation costs, conversely, the CFP only benefit without sharing any cost, which causing the distortion of the CIP's independent decision. As an effective coordination approach of supply chain, contracts have been widely used. This study intends to adopt cost sharing contract, in which the effort costs and compensation costs are shared by both the CFP and the CIP. Assume the cost ratio hold by CIP is α , while the cost ratio hold by CFP is $1-\alpha$. The expected revenue function of CFP, CIP are

$$\Pi^{s}_{CFP,\alpha}=\left(w-c\right)N\left(1-r^{\delta}\right)-c_0N-\left(1-\alpha\right)\left[b\delta+r\left(\Delta-\delta\right)\beta p\right] \tag{12}$$

$$\Pi^{s}_{CIP,\alpha}=\left(p-w\right)N\left(1-r^{\delta}\right)-\alpha\left[b\delta+r\left(\Delta-\delta\right)\beta p\right] \tag{13}$$

Because the second order of Eq. (13) is less than zero, the objective function in Eq. (13) is strictly concave, thereby ensuring the existence of a unique optimal solution. To find the optimal effort level, first order conditions require $\frac{\partial\Pi^{s}_{CIP,\ \alpha}}{\partial\delta}=0$. After some algebra, first order conditions lead to

$$\delta^{s}_{CIP,\alpha}{}^{*}=\log_r\frac{\alpha\left(b-r\beta p\right)}{\left(w-p\right)N\ln r} \tag{14}$$

To achieve coordination, $\delta^{s}_{CIP,\alpha}{}^{*}=\delta^{s}_{SC}{}^{*}$ only when

$$\alpha=\frac{p-w}{p-c} \tag{15}$$

Proposition 2. To enable cloud service supply chain to achieve the coordination, the cost sharing ratio is $\alpha:\left(1-\alpha\right)=\left(p-w\right):\left(w-c\right)$. The proportion of cost-sharing is equal to the proportion allocating the marginal profit of supply chain, which reflecting consistency of costs and benefits in supply chain coordination.

Proof. $\frac{\alpha}{1-\alpha}=\frac{p-w}{p-c}\cdot\frac{p-c}{w-c}=\frac{p-w}{w-c}$

Proposition 2 implies that when the unit service capacity price is fixed and the cloud service supply chain achieves coordination, the CFP and the CIP 's allocation proportions are unique and fixed. If the unit service capacity price is variable, we can get proposition 3.

Proposition 3. Under the cost sharing contract, if w is variable and meets the condition $w^{*}=\alpha c+\left(1-\alpha\right)p$, cost sharing contract can achieve supply chain coordination, and at this time the effect of free trial is optimal. In addition, the relationship between the profits (including the CFP's and the CIP's) and α are linear respectively. We can change the ratio of sharing the maximum profit of the supply chain by adjusting α .

Proof. See the Appendix.

Proposition 3 illustrates that in cost sharing contract, if w is variable, the scope of the contract will be expanded. When the cloud service supply chain reaches coordination, they can freely choose cost-sharing ratio and share maximum profits of the supply chain in any proportion.

Lemma 1. If only sharing the effort cost, not sharing compensation cost in the coordination of the supply chain, the coordination parameter is $\alpha^{'}=\frac{p-w}{p-c}+\frac{(w-c)r\beta p}{(p-c)b}$, and the allocation of compensation enhances the intuitiveness and scalability of the cost allocation.

Proof. See the Appendix.

Easy to know $\alpha^{'}>\alpha$ from Lemma1. It implies that if not sharing the compensation cost, more effort cost needs to be shared to achieve the supply chain coordination. However, the effort cost is difficult to measure compared to the compensation cost, which is based on the price with better scalability and intuitiveness. So the implementation of the policy of compensation cost sharing increases visualization and impartiality of the sharing mechanism, and more easily accepted by supply chain members.

CLOUD SERVCIE SUPPLY CHAIN COORDINATION UNDER ASYMMETRICAL INFORMATION

In the case of asymmetrical information, the service reliability capacity (service disruption probability) is a private information of the CIP. Because the CFP cannot detect the service reliability ability of the CIP, the CIP with poor service reliability (higher risk of service) also hopes to cooperate with the CFP under the opportunism motivation. If the CFP cooperate with the CIP with low reliability, the free trial may not be able to attract sufficient numbers of potential customers, and even cannot offset costs during the free trial period, which is a cooperation of relatively high risk.

In order to avoid the risk of opportunism, the CFP needs to take corresponding measures to distinguish the service reliability ability of the CIP through some information before cooperation. The above analysis shows that the higher the service reliability of the CIP (the lower the service disruption probability), the higher the customer adoption rate, and the more ultimate customers through free trial, which leading to more service ability. Thus, the amount of the required service ability is a kind of signal which reflects the service level and the size of the effort of the CIP. Therefore, this paper proposes a service capacity reservation strategy, that is to say the CFP could reveal hidden service reliability information by the amount of reservation service ability during the cooperation period before free trail. Through this order quantity, the CFP can judge the service reliability of the CIP and weigh his own input costs to determine whether to achieve his expected return and whether to cooperate with the CIP.

Game process is as follows, first, the CIP orders service ability during contract from the CFP according to his own circumstance. Secondly, the CFP determines his profitability and decides whether to cooperate with the CIP to provide free trial according to the order quantity. If they cooperate, the CIP will win clients by effort and realize the market demand, If they do not cooperate, the market demand faced by the CIP is random distribution on the interval $[0,N]$, the order of the service ability of the CIP is similar to a typical newsboy model.

Under the capacity reservation strategy, the expected revenue function of the CFP is

$$\Pi_{CFP}^{a}=(w-c)q-c_{0}N \tag{16}$$

For the CIP, the capacity reservation strategy requires to order before the contract. Therefore, he will face the excessive or deficient order risk. We use $M(q,\delta)$ to denote the expected number of customers when the CIP's order quantity is q and effort level during free trail is δ. Then

$$\begin{aligned}M(q,\delta)&=E[\min(q,x)]=\int_{N(1-r^{\delta})-a}^{N(1-r^{\delta})+a}\min(q,x)f(x)dx\\&=\int_{N(1-r^{\delta})-a}^{q}xf(x)dx+\int_{q}^{N(1-r^{\delta})+a}qf(x)dx\\&=\frac{q^{2}-\left[N(1-r^{\delta})-a\right]^{2}+2q\left[N(1-r^{\delta})+a-q\right]}{4a}\end{aligned} \tag{17}$$

The CIP's expected revenue function is

$$\Pi_{CIP}^{a}=\left(p-w\right)M\left(q,\delta\right)-b\delta-r\left(\Delta-\delta\right)\beta p-\left(w-g\right)\left[q-M\left(q,\delta\right)\right]-k\left[\mu-M\left(q,\delta\right)\right] \tag{18}$$

Where g is unit residual value of excess capacity, and k is unit opportunity cost lost by insufficient service ability.

The expected revenue function of the whole cloud service supply chain is

$$\begin{aligned}\Pi_{SC}^{a}&=\Pi_{CFP}^{a}+\Pi_{CIP}^{a}\\&=\left(w-c\right)q-c_0N+\left(p-w\right)M\left(q,\delta\right)-b\delta-r\left(\Delta-\delta\right)\beta p\\&-\left(w-g\right)\left[q-M\left(q,\delta\right)\right]-k\left[\mu-M\left(q,\delta\right)\right]\\&=\left(p-c\right)M\left(q,\delta\right)-\left(c-g\right)\left[q-M\left(q,\delta\right)\right]-k\left[\mu-M\left(q,\delta\right)\right]-c_0N-b\delta-r\left(\Delta-\delta\right)\beta p\end{aligned} \tag{19}$$

Centralized Decision-making

There are little literatures proposed the approach responding to cloud service security risk under the insurance perspective, the cloud insurance in this paper covers the business interruption caused by sudden accidents of cloud service, and it's similar to the traditional business interruption insurance.

Similar to the analysis under symmetrical information, we discuss centralized supply chain system, in which the CFP and the CIP is a community of interests. However, under asymmetrical information, the CIP do not only decide effort level δ, but also decide order quantity q of service ability. To find the optimal decision of the whole supply chain system, first order conditions require $\frac{\partial \Pi_{SC}^{a}}{\partial \delta}=0$ and $\frac{\partial \Pi_{SC}^{a}}{\partial q}=0$. After some algebra, first order conditions lead to

$$\delta_{SC}^{a\ *}=\log_r\frac{b-r\beta p}{\left(c-p\right)N\ln r} \tag{20}$$

$$q_{SC}^{a\ *}=N-\frac{b-r\beta p}{\left(c-p\right)\ln r}+\frac{a\left(p+g+k-2c\right)}{p-g+k} \tag{21}$$

And

$$\frac{\partial^2\Pi_{SC}^{a}}{\partial\delta^2}=Nr^{\delta}\left(\ln r\right)^2\left[c-p-\frac{\left(p-g+k\right)Nr^{\delta}}{2a}\right]<0 \tag{22}$$

$$\frac{\partial^2\Pi_{SC}^{a}}{\partial q^2}=-\frac{p-g+k}{2a}<0 \tag{23}$$

$$\frac{\partial^2\Pi_{SC}^{a}}{\partial\delta\partial q}=\frac{\partial^2\Pi_{SC}^{a}}{\partial q\partial\delta}=-\frac{\left(p-g+k\right)Nr^{\delta}\ln r}{2a} \tag{24}$$

So Hessian Matrix is：

$$H=\frac{\partial^2\Pi_{SC}^{a}}{\partial\delta^2}\frac{\partial^2\Pi_{SC}^{a}}{\partial q^2}-\frac{\partial^2\Pi_{SC}^{a}}{\partial\delta\partial q}\frac{\partial^2\Pi_{SC}^{a}}{\partial q\partial\delta}=\frac{\left(Nr^{\delta}\ln r\right)^2\left(p-c\right)\left(p-g+k\right)}{2a}>0 \tag{25}$$

So the expected profit function of supply chain system is joint concave, that is to say the solution above is the only combination to get the maximum profit of the supply chain.

Decentralized Decision-making

In reality, the CFP and the CIP are separate interests in cloud service supply chain. They often only consider their own interests and make independent decision regardless of the other party. In this case, the CIP in the dominant position make independent decision according to his own profit maximization principle, so to get the optimal effort level and service capacity of the CIP, first order conditions require

$$\begin{aligned}\frac{\partial \Pi_{CIP}^{a}}{\partial \delta} &= (p-w+w-g+k)\frac{\partial M(q,\delta)}{\partial \delta} - k\frac{\partial \mu}{\partial e} - b + r\beta p \\ &= (p-g+k)\frac{Nr^{\delta}\ln r\left[N(1-r^{\delta})-a-q\right]}{2a} + kNr^{\delta}\ln r - b + r\beta p = 0\end{aligned} \tag{26}$$

$$\begin{aligned}\frac{\partial \Pi_{CIP}^{a}}{\partial q} &= (p-w+w-g+k)\frac{\partial M(q,\delta)}{\partial q} - (w-g) \\ &= (p-g+k)\frac{N(1-r^{\delta})+a-q}{2a} - w + g = 0\end{aligned} \tag{27}$$

After some algebra, first order conditions lead to

$$\delta_{CIP}^{a\ *} = \log_r \frac{b-r\beta p}{(w-p)N\ln r} \tag{28}$$

$$q_{CIP}^{a\ *} = N - \frac{b-r\beta p}{(w-p)\ln r} + \frac{a(p+g+k-2w)}{p-g+k} \tag{29}$$

Contrast Eq.(20) and Eq.(21) with Eq. (28) and Eq. (29), we assert Proposition 4.

Proposition 4. In decentralized supply chain, $\delta_{CIP}^{a\ *} < \delta_{SC}^{a\ *}$ and $q_{CIP}^{a\ *} < q_{SC}^{a\ *}$, that is to say, both the optimal effort level and the optimal service ability ordering quantity of the CIP in independent decision are lower than those in cloud service supply chain system. Thus the cloud service supply chain cannot be coordinated.

Proof. See the Appendix.

Cost and Risk Sharing Coordination Mechanism

In the case of symmetrical information, the cost sharing contract is testified to be a proper solution. If we still use the cost sharing contract under asymmetrical information, set the contract parameter equal to α. Then the cost ratio borne by the CIP is α, and the cost ratio borne by the CFP is $1-\alpha$. The expected revenue function of CFP, CIP and the whole cloud service supply chain are

$$\Pi_{CFP,\alpha}^{a} = (w-c)q - c_0 N - (1-\alpha)\left[b\delta + r(\Delta-\delta)\beta p\right] \tag{30}$$

$$\Pi_{CIP,\alpha}^{a} = (p-w)M(q,\delta) - \alpha\left[b\delta + r(\Delta-\delta)\beta p\right] - \left\{(w-g)\left[q-M(q,\delta)\right] + k\left[\mu - M(q,\delta)\right]\right\} \tag{31}$$

$$\begin{aligned}\Pi_{SC,\alpha}^{a} &= \Pi_{CFP,\alpha}^{a} + \Pi_{CIP,\alpha}^{a} \\ &= (p-c)M(q,\delta) - (c-g)\left[q-M(q,\delta)\right] - k\left[\mu - M(q,\delta)\right] - c_0 N - b\delta - r(\Delta-\delta)\beta p\end{aligned} \tag{32}$$

Under the cost sharing contract, to get the optimal decision of the CIP, first order conditions require

$$\frac{\partial \Pi^{a}_{CIP,\ \alpha}}{\partial \delta}=\left(p-g+k\right)\frac{Nr^{\delta}\ln r\left[N(1-r^{\delta})-a-q\right]}{2a}+kNr^{\delta}\ln r-\alpha\left(b-r\beta p\right)=0 \tag{33}$$

$$\frac{\partial \Pi^{a}_{CIP,\alpha}}{\partial q}=\left(p-g+k\right)\frac{N(1-r^{\delta})+a-q}{2a}-\left(w-g\right)=0 \tag{34}$$

After some algebra, first order conditions lead to

$$\delta^{a}_{CIP,\alpha}{}^{*}=\log_{r}\frac{\alpha\left(b-r\beta p\right)}{\left(w-p\right)N\ln r} \tag{35}$$

$$q^{a}_{CIP,\alpha}{}^{*}=N-\frac{\alpha\left(b-r\beta p\right)}{\left(w-p\right)\ln r}+\frac{a\left(p+g+k-2w\right)}{p-g+k} \tag{36}$$

The results should be equal to the optimal results under centralized decision-making, which requires $\delta^{a}_{CIP,\alpha}{}^{*}=\delta^{a}_{SC}{}^{*}$ and $q^{a}_{CIP,\alpha}{}^{*}=q^{a}_{SC}{}^{*}$. But because of $c<w$, we can't get $q^{a}_{CIP,\alpha}{}^{*}=q^{a}_{SC}{}^{*}$, so the cost sharing contract cannot achieve cloud service supply chain coordination under asymmetrical information.

The past researches show that when the risk is borne by one party alone in the supply chain, the double marginalized effect will lead to low performance of the whole supply chain. Studies of Dan (2010) and Lin (2010) have shown that risk-sharing can solve this problem and achieve supply chain coordination. So we intend to adopt the combination of cost and risk sharing contract in this paper. Contract parameters are $\{\alpha,\ \gamma\}$, where the CIP's cost ratio and risk ratio are α and γ respectively, and the CFP's cost ratio and risk ratio are $1-\alpha$ and $1-\gamma$ respectively. Under the cost and risk sharing contract, the expected revenue function of CFP, CIP and the whole cloud service supply chain are

$$\begin{aligned}\Pi^{a}_{CFP,\alpha,\gamma}&=\left(w-c\right)q-c_{0}N-\left(1-\alpha\right)\left[b\delta+r\left(\Delta-\delta\right)\beta p\right]\\&-\left(1-\gamma\right)\left\{\left(w-g\right)\left[q-M\left(q,\delta\right)\right]+k\left[\mu-M\left(q,\delta\right)\right]\right\}\end{aligned} \tag{37}$$

$$\begin{aligned}\Pi^{a}_{CIP,\alpha,\gamma}&=\left(p-w\right)M\left(q,\delta\right)-\alpha\left[b\delta+r\left(\Delta-\delta\right)\beta p\right]\\&-\gamma\left\{\left(w-g\right)\left[q-M\left(q,\delta\right)\right]+k\left[\mu-M\left(q,\delta\right)\right]\right\}\end{aligned} \tag{38}$$

$$\begin{aligned}\Pi^{a}_{SC,\alpha,\gamma}&=\Pi^{a}_{CFP,\alpha,\gamma}+\Pi^{a}_{CIP,\alpha,\gamma}\\&=\left(p-c\right)M\left(q,\delta\right)-\left(c-g\right)\left[q-M\left(q,\delta\right)\right]-k\left[\mu-M\left(q,\delta\right)\right]-c_{0}N-b\delta-r\left(\Delta-\delta\right)\beta p\end{aligned} \tag{39}$$

Under the cost and risk sharing contract, to get the optimal decision of the CIP, first order conditions require

$$\frac{\partial \Pi^{a}_{CIP,\ \alpha,\gamma}}{\partial \delta}=\left[p-w+\gamma\left(w-g+k\right)\right]\frac{\partial M\left(q,\delta\right)}{\partial \delta}-\gamma k\frac{\partial \mu}{\partial \delta}-\alpha\left(b-r\beta p\right)=0 \tag{40}$$

$$\frac{\partial \Pi^{a}_{CIP,\alpha,\gamma}}{\partial q}=\left[p-w+\gamma\left(w-g+k\right)\right]\frac{\partial M\left(q,\delta\right)}{\partial q}-\gamma\left(w-g\right)=0 \tag{41}$$

After some algebra, first order conditions lead to

$$\delta^{a}_{CIP,\alpha,\gamma}{}^{*}=\log_{r}\frac{\alpha\left(b-r\beta p\right)}{\left(w-p\right)N\ln r} \tag{42}$$

$$q_{CIP,\alpha,\gamma}^{a}{}^{*} = N - \frac{\alpha(b - r\beta p)}{(w-p)\ln r} + \frac{a\left(p - w - \gamma(w-g-k)\right)}{p - w + \gamma(w-g+k)} \tag{43}$$

The results should be equal to the optimal results under centralized decision-making, which requires $\delta_{CIP,\alpha,\gamma}^{a}{}^{*} = \delta_{SC}^{a}{}^{*}$ and $q_{CIP,\alpha,\gamma}^{a}{}^{*} = q_{SC}^{a}{}^{*}$. So we can obtain the cost and risk sharing contract parameters are

$$\alpha = \frac{p-w}{p-c} \tag{44}$$

$$\gamma = \frac{(p-w)(c-g)}{(w-g)(p-c+k)+k(g-c)} \tag{45}$$

Proposition 5. In the cost and risk sharing contract, the coordination parameters only determined by coefficient parameters and has nothing with the CIP's effort level, service capacity reservation decision, service reliability and market uncertainty. The cost sharing ratio α is equal to the proportion under the symmetrical information, while risk sharing ratio γ has positive correlation with the cost sharing ratio α, and $\gamma = \dfrac{\alpha(c-g)(p-c)}{\left(\alpha c + (1-\alpha)p - g\right)(p-c+k)+k(g-c)}$

Proof. See the Appendix.

Proposition 5 implies that the coordination parameters only determined by objective parameters of the market, and has nothing with subjective decision. It shows that this coordination contract has stronger adaptability and not easily influenced by subjective factors. When unit service capacity price w is fixed and cloud service supply achieves coordination, the cost sharing ratio is unique and fixed. If w is variable, we can get proposition 6.

Proposition 6. Under the cost and risk sharing contract, if w is variable and meets the condition $w^{*} = \alpha c + (1-\alpha)p$, the risk sharing parameter will meet the condition $\gamma = \dfrac{\alpha(c-g)(p-c)}{\left(\alpha c + (1-\alpha)p - g\right)(p-c+k)+k(g-c)}$. The cost and risk sharing contract can achieve supply chain coordination, and at this time the effect of free trial is optimal. In addition, we can change the ratio of sharing the maximum profit of the supply chain by adjusting α, γ.

Proof. See the Appendix.

Proposition 6 illustrates that in cost and risk sharing contract, if w is decision variable, the scope of the contract will be expanded. When the cloud service supply chain reaches coordination, they can freely choose sharing ratio and share maximum profits of the supply chain in any proportion. The contract has good flexibility.

NUMERICAL SIMULATION AND ANALYSIS

In this section, we make some numerical examples to demonstrate our findings. We compare information both symmetrical and asymmetrical circumstances, in terms of the expected revenue of CFP, CIP and the whole cloud service supply chain. Then, we discuss the effects of some key parameters in the model.

The Performance Comparison of Cloud Service Supply Chain Under Symmetrical Information

We set $N=100$, $r=0.5$, $c=12$, $w=15$, $c_0=0.5$, $p=20$, $b=100$, $\beta=0.5$, $\Delta=10$. Parameter setting meets assumed condition, and results are presented in Table 2.

Table 2: The performance of cloud service supply chain under symmetrical information

	δ^{*}	μ	α	w	Π_{CFP}	Π_{CIP}	Π_{SC}
Centralized Decision-making	2.54	82.9	——	——	——	——	321.1

Decentralized Decision-making	1.87	72.6	——	15.0	167.8	135.6	303.3
Cost Sharing (w is fixed)	2.54	82.9.	0.63	15.0	89.2	231.9	321.1
Cost Sharing (w is variable)	2.54	82.9	0.4	16.8	172.7	148.4	321.1

Table 2 compares the expected revenue of CFP, CIP and the whole cloud service supply chain under symmetrical information. The results show that first, both the optimal effort level and the whole supply chain profit in decentralized decision are lower than those in centralized decision. The cloud service supply chain cannot achieve coordination. Secondly, in cost sharing contract, if w is fixed, both the CIP's profit (from 135.6 to 231.9) and the expected profit of the whole supply chain (from 303.3 to 321.1) will increase, which is equal to the profit in centralized decision. So cloud service supply chain can achieve coordination, but compared to decentralized decision, the CFP's profit decreases (from 167.8 to 89.2), which cannot achieve pareto optimality. Thirdly, if w is variable and meets the condition $w^* = \alpha c + (1-\alpha) p$, we can change the ratio of sharing the maximum profit of the supply chain by adjusting α. In this case, when $\alpha=0.4$ and $w^* = 16.8$, the expected profit of CFP, CIP and the whole cloud service supply chain are improved. And the cloud service supply chain coordination and pareto optimality can be achieved.

The Performance Comparison of Cloud Service Supply Chain Under Asymmetrical Information

Similarly, we set $N=100$, $r=0.5$, $c=12$, $w=15$, $c_0=0.5$, $p=20$, $b=100$, and $g=10$, $k=2$. Parameter setting meets assumed condition, and results are presented in Table 3.

Table 3: The performance of cloud service supply chain under asymmetrical information

	δ^*	q^*	α	γ	w	Π_{CFP}	Π_{CIP}	Π_{SC}
Centralized Decision-making	2.54	89.5	——	——	——	——	——	304.5
Decentralized Decision-making	1.87	74.3	——	——	15.0	172.8	106.4	279.2
Cost Sharing (w is fixed)	2.54	84.5	0.63	——	15.0	94.2	202.8	297.0
Cost and Risk Sharing (w is fixed)	2.54	89.5	0.63	0.22	15	81.6	222.9	304.5
Cost and Risk Sharing (w is variable)	2.54	89.5	0.33	0.1	17.4	186.7	117.8	304.5

Table 3 compares the expected revenue of CFP, CIP and the whole cloud service supply chain under asymmetrical information. The results show that first, similarly with symmetrical information, both the optimal effort level, service capacity ordering quantity and the whole supply chain profit in decentralized decision are lower than those in centralized decision. The cloud service supply chain cannot achieve coordination. Secondly, the cost sharing contract cannot achieve cloud service supply chain coordination under asymmetrical information. Thirdly, in cost and risk sharing contract, if w is fixed, both the CIP's profit (from 106.4 to 222.9) and the expected profit of the whole supply chain (from 279.2 to 304.5) will increase, which is equal to the profit in centralized decision. So cloud service supply chain can achieve coordination, but compared to decentralized decision, the CFP's profit decreases (from 172.8 to 81.6), which cannot achieve pareto optimality. Finally, if w is variable and meets the condition $w^* = \alpha c + (1-\alpha) p$, we can change the ratio of sharing the maximum profit of the supply chain by adjusting α. In this case, when $\alpha=0.33$, $\gamma=0.1$ and $w^* = 17.4$, the expected profit of CFP, CIP and the whole cloud service supply chain are improved. And the cloud service supply chain coordination and pareto optimality can be achieved.

In addition, some results can be found in the comparison of table 3 and table 2. First, the supply chain system performance under symmetrical information is higher than those under asymmetrical information (321.1 > 304.5), which is due to the low efficiency of asymmetrical information. Secondly, if there is no contract, the CIP's profit under asymmetrical information decreases (from 135.6 to 135.6), while the expected profit of CFP rises (increased from 167.8 to 172.8). It is mainly due to the capacity reservation strategy used by the CFP to prevent opportunistic risk of the CIP. It can avoid opportunism behavior of CIP with high interruption risk, but the disadvantage is that it will bring losses for CIP with low interruption risk.

The impact of Service Reliability Parameter (Service Disruption Probability) on the Profit
Service interruption probability is an important exogenous variable in free trial. It affects the adoption rate of customers, thus affects the actual demand of the market. Here we discuss the role of interruption probability r .

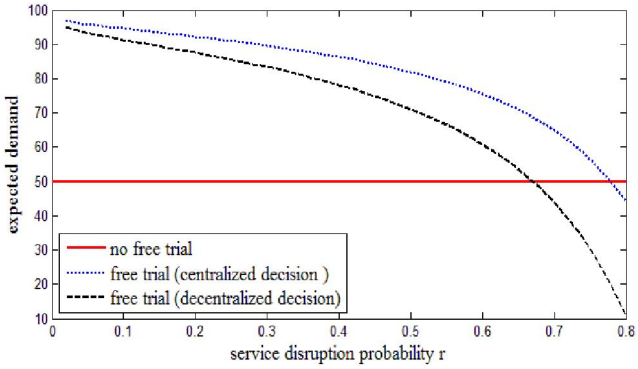

Figure 3: The relationship between the expected demand and service disruption probability

Figure 3 shows the relationship between the expected demand and service disruption probability. As is shown in Fig.3, free trial stimulates the demand of cloud service, and the effect of the free trail is closely related to service disruption probability (service reliability level) of the CIP. Along with the increase of service disruption probability, the expected demand will be less than no free trial. Thus, service reliability level is one of the key elements for free trail. CIP must constantly improve his technological capabilities, reduce service disruption probability, then play a better effect of free trail.

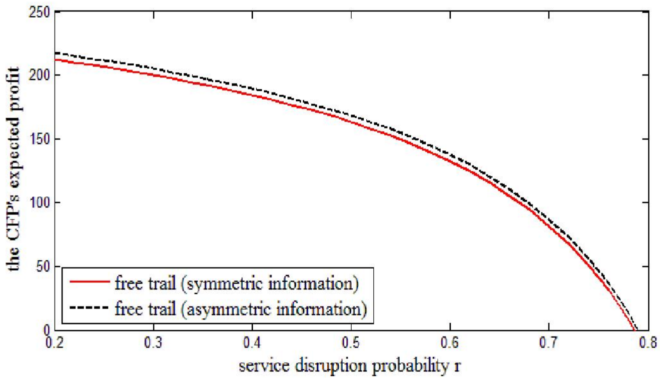

Figure 4: The relationship between the CFP's expected profit and service disruption probability

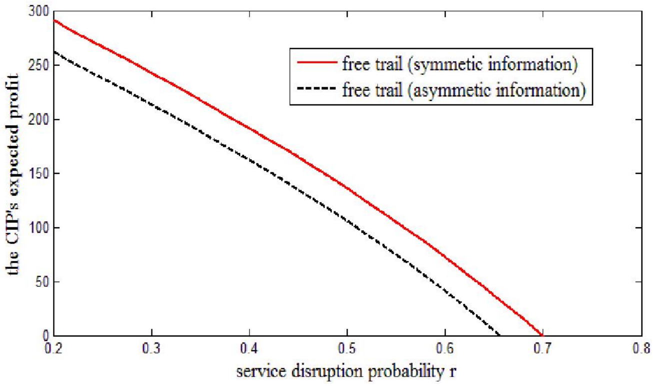

Figure 5: The relationship between the CIP's expected profit and service disruption probability

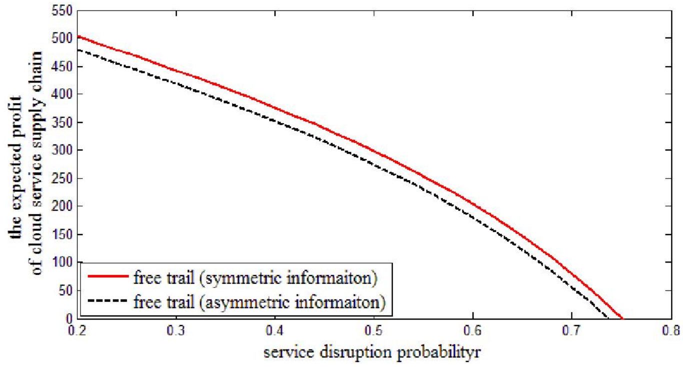

Figure 6: The relationship between the expected profit of cloud service supply chain and service disruption probability

Fig. 4, 5 and 6 give the expected profit of CFP, CIP and the whole cloud service supply chain comparisons, and all of parameter input values are the same. We can draw the following conclusions. Firstly, the effect of the free trail is closely related to service disruption probability (service reliability level) of the CIP. The smaller the service disruption probability, the higher the expected profit. Thus, service reliability level is one of the key elements for free trail. CIP must constantly improve his technological capabilities and reduce service disruption probability.

Secondly, asymmetrical information will lower the performance of cloud service supply chain. Although service capacity reservation strategy can guarantee CFP's profit do not be damaged by asymmetrical information (as shown in Fig.4). But the profit of both CIP and the whole supply chain will decrease (as shown in Fig. 5 and 6). The service capacity reservation strategy can avoid opportunism behavior of CIP with high interruption risk, but the disadvantage is that it will bring losses for CIP with low interruption risk.

Finally, the sensitivity of expected profit of CFP, CIP and the whole cloud service supply chain to interruption probability is different. For CFP, when service interruption probability is low, his profit changes in a small range. When service interruption probability becomes higher, the profit will significantly descend. So CFP should cooperate with CFP with high service reliability to ensure stable benefit. For CIP, his expected profit almost shows a linear correlation of service interruption probability. Thus CIP must continually reduce interruption probability and improve his service reliability level to improve earnings. The changes of the profit of cloud service supply chain is somewhere between CFP and CIP.

The impact of Compensation Ratio on the Decision Variables and the Target

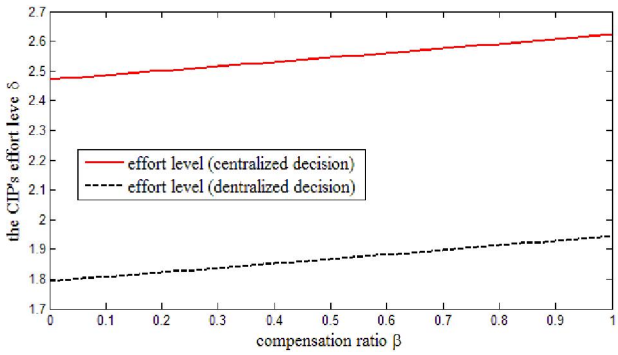

Figure 7: The relationship between the CIP's effort level and compensation ratio

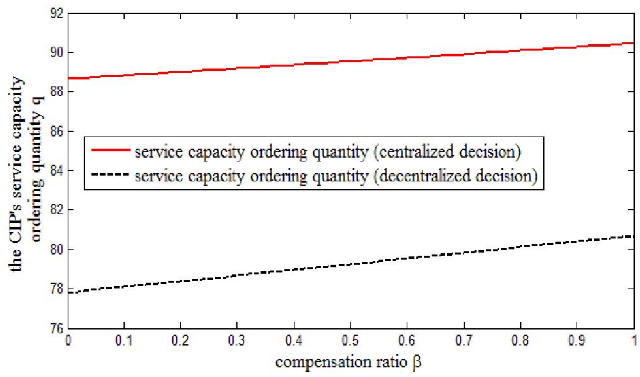

Figure 8: The relationship between the CIP's service capacity ordering quantity and compensation ratio

Fig. 7 and 8 shows the relationship between the CIP's two decision variables (effort level and service capacity ordering quantity) and compensation ratio respectively. As compensation ratio grows, both of the effort level and service capacity ordering quantity increases. This is because the compensation value related to inadequate effort. On one hand, the CIP can reduce the amount of compensation through improving his effort level. On the other hand, he can also improve customer satisfaction and increase sales.

Fig. 9 and 10 shows the relationship between the expected profit and compensation ratio in decentralized decision and cost and risk sharing contract respectively.

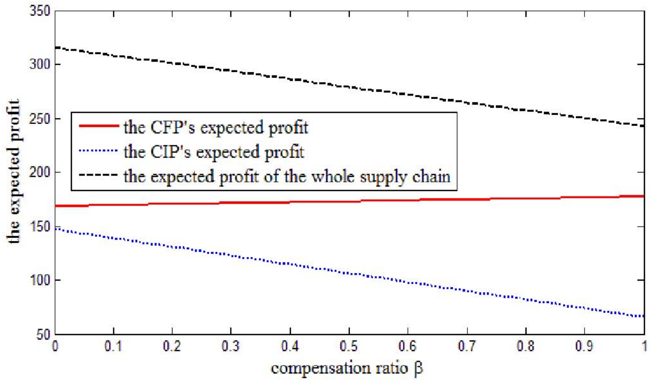

Figure 9: The relationship between the expected profit and compensation ratio in decentralized decision

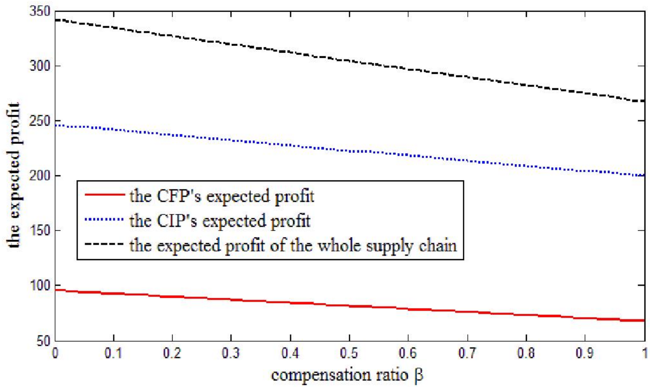

Figure 10: The relationship between the expected profit and compensation ratio in cost and risk sharing contract

Comparing Fig. 9 and 10, both the CIP's profit and cloud services supply chain profit increase with compensation ratio growing. Differently, the CFP's profit increases in decentralized decision making but decreases in cost and risk sharing contract. This is because in decentralized decision making, all compensation costs are borne by CIP alone. With the increase of compensation ratio, expected sales will increase, while CFP benefits without bearing any cost. In cost and risk sharing contract, CFP needs to share effort and compensation costs with CIP, so its profits changed trend is the same as CIP and the whole supply chain. In practice, CIP should carefully set compensation ratio referring to the industry standard.

The impact of Cost-sharing Ratio on the Profits

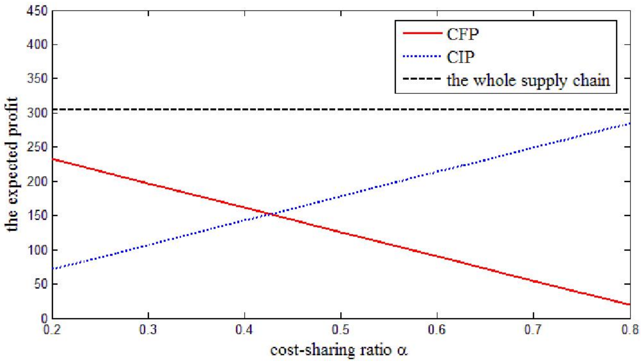

Figure 11: The relationship between the expected profit and cost-sharing ratio

Fig.11 shows the relationship between the expected profit and cost-sharing ratio. The cost sharing ratio α can adjust percentage of sharing profits of cloud service supply chain when achieving coordination. As is shown in Fig. 11, with the increase of cost sharing ratio, CFP's expected profit will decreases while CIP's expected profit rises. In reality, the two sides can determine the corresponding α according to their own game ability, thus striving for respective profit share proportion for their own interests.

CONCLUSION

As more and more enterprise strategy alliances established, cooperation demand between members of cloud service supply chain upstream and downstream is increasing. One of the reasons causing low adoption rate is the worry about implement risk of cloud services, as well as service disruption. Therefore, considering service failure compensation strategy, this paper builds a new three-level supply chain including CFP, CIP and customers. Coordination Contracts are discussed in two kinds of situations, linked respectively to the information symmetry and information asymmetry. The results show that the cost and risk sharing contract we proposed can realize optimal supply chain performance. Our findings have managerial implications. We discuss them and offer some recommendations, beginning with:

Recommendation 1.

Reducing service disruption probability and improving service reliability level are the key to a free trial, which plays a decisive role no the effect of free trial and overall supply chain performance. As the focus of enterprise customers, service reliability must get enough attention in order to improve the adoption rates and the performance of the whole supply.

Recommendation 2.

In cost sharing mechanism, compensation cost allocation enhances the scalability of cost allocation because it is based on the price. So introducing compensation cost sharing can increase visualization and impartiality of the sharing mechanism in supply chain coordination, and is also more acceptable by the chain members.

Recommendation 3.

The supply chain members between upstream and downstream should strengthen information exchange and communication to avoid the distortion caused by information asymmetry. To avoid losing profit, CIP with high service reliability should actively prove their ability in communication with the upstream CFP through conveying useful signal to CFP. In addition, how to eliminate or reduce the negative effects causing by the information asymmetry to cloud services supply chain is worth further study.

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APPENDIX

Appendix A.

This work is supported by China Postdoctoral Science Foundation Funded Project "Risk Transfer and Sharing of Cloud Service Supply Chain Based on Uncontrollable Service Interruption" and National Natural Science foundations of China " Research on the Incentive and Risk Control of IT Service Supply Chain Based on the SaaS" (Grant No.71172072).

Appendix B. Mathematical results and proofs

B.1. Proof of proposition 1

Because of $w > c$, yields, $p - w < p - c$,

$0 < -(p-w)N\ln r < -(p-c)N\ln r$, $\log_r \dfrac{b - r\beta p}{-(p-w)N\ln r} < \log_r \dfrac{b - r\beta p}{-(p-c)N\ln r}$, that is to say ${\delta_{CIP}^s}^* < {\delta_{SC}^s}^*$.

So $r^{{\delta_{SC}^s}^*} - r^{{\delta_{CIP}^s}^*} < 0$, $(p-c)N\left(r^{{\delta_{SC}^s}^*} - r^{{\delta_{CIP}^s}^*}\right) < 0$. Consequently, $(b - r\beta p)\left({\delta_{CIP}^s}^* - {\delta_{SC}^s}^*\right) < 0$,

$\Pi_{SC}^{s\,'} - \Pi_{SC}^s = (p-c)N\left(r^{{\delta_{SC}^s}^*} - r^{{\delta_{CIP}^s}^*}\right) - (b - r\beta p)\left({\delta_{CIP}^s}^* - {\delta_{SC}^s}^*\right) < 0$.

B.2. Proof of proposition 3

Substituting $w^* = \alpha c + (1-\alpha)p$ into ${\delta_{CIP,\alpha}^s}^* = \log_r \dfrac{\alpha(b - r\beta p)}{(w-p)N\ln r}$, we can get ${\delta_{CIP,\alpha}^s}^* = {\delta_{SC}^s}^*$, which meets the conditions of the coordination of the supply chain. After $w^* = \alpha c + (1-\alpha)p$ is sent to the expected profit function of the CFP and the CIP respectively, we can get $\Pi_{CFP,\alpha}^s = (1-\alpha)\Pi_{SC}^s - \alpha c_0 N$ and $\Pi_{CIP}^s = \alpha\Pi_{SC}^s + \alpha c_0 N$. So the relationship between the profits (including the CFP's and the CIP's) and α are linear respectively.

B.3. Proof of Lemma 1

If only considering to share effort cost, the profit of the CIP is $\Pi_{CIP,\alpha'}^s = (p-w)N(1-r^\delta) - \alpha' b\delta - r(\Delta - \delta)\beta p$, and the first order is $\dfrac{\partial \Pi_{CIP,\alpha'}^s}{\partial \delta} = -(p-w)Nr^\delta \ln r - \alpha' b + r\beta p$. Because of $\dfrac{\partial^2 \Pi_{CIP,\alpha'}^s}{\partial \delta^2} = -(p-w)Nr^\delta (\ln r)^2 < 0$, the first order conditions require $\dfrac{\partial \Pi_{CIP,\alpha}^s}{\partial \delta} = 0$. So we can get ${\delta_{CIP,\alpha'}^s}^* = \log_r \dfrac{\alpha' b - r\beta p}{(w-p)N\ln r}$. To achieve coordination, ${\delta_{CIP,\alpha'}^s}^* = {\delta_{SC}^s}^*$ only when $\alpha' = \dfrac{p-w}{p-c} + \dfrac{(w-c)r\beta p}{(p-c)b}$.

B.4. Proof of proposition 4

Because of $w > c$, yields $0 > w - p > c - p$, $\log_r \dfrac{b - r\beta p}{(w-p)N\ln r} < \log_r \dfrac{b - r\beta p}{(c-p)N\ln r}$, that is to say ${\delta_{CIP}^a}^* < {\delta_{SC}^a}^*$.

Because $\dfrac{b - r\beta p}{(w-p)\ln r} > \dfrac{b - r\beta p}{(c-p)\ln r}$ and $\dfrac{a(p+g+k-2w)}{p-g+k} < \dfrac{a(p+g+k-2c)}{p-g+k}$, it is easily to know

$N - \dfrac{b - r\beta p}{(w-p)\ln r} + \dfrac{a(p+g+k-2w)}{p-g+k} < N - \dfrac{b - r\beta p}{(c-p)\ln r} + \dfrac{a(p+g+k-2c)}{p-g+k}$. Consequently ${q_{CIP}^a}^* < {q_{SC}^a}^*$.

B.5. Proof of proposition 5

Because of $\alpha = \dfrac{p-w}{p-c}$, $\gamma = \dfrac{(p-w)(c-g)}{(w-g)(p-c+k) + k(g-c)}$, yields $p - w = \alpha(p-c)$, $w = p - \alpha(p-c)$, it is easily to know $\gamma=\dfrac{\alpha(p-c)(c-g)}{(\alpha c+(1-\alpha)p-g)(p-c+k)+k(g-c)}$ by substituting w into expressions.

B.6. Proof of proposition 6

Substituting $w^{*}=\alpha c+(1-\alpha)p$ and $\gamma=\dfrac{\alpha(p-c)(c-g)}{(\alpha c+(1-\alpha)p-g)(p-c+k)+k(g-c)}$ into Eq.(42) and Eq.(43), it is easily to know ${\delta_{CIP,\alpha,\gamma}^{a}}^{*}=\log_r\dfrac{\alpha(b-r\beta p)}{(w-p)N\ln r}=\log_r\dfrac{b-r\beta p}{(c-p)N\ln r}={\delta_{SC}^{s}}^{*}$,

and ${q_{CIP,\alpha,\gamma}^{a}}^{*}=N-\dfrac{\alpha(b-r\beta p)}{(w-p)\ln r}+\dfrac{a(p-w-\gamma(w-g-k))}{p-w+\gamma(w-g+k)}=N-\dfrac{b-r\beta p}{(c-p)\ln r}+\dfrac{a(p+g+k-2c)}{p-g+k}={q_{SC}^{a}}^{*}$. The conditions to achieve the supply chain coordination are meet.