
Service capacity procurement in logistics service supply chain with demand updating and reciprocal behaviour

Weihua Liu*, Wanying Wei and Donglei Zhu

College of Management and Economics,
Tianjin University,
No. 92, Weijin Road, Nankai District,
Tianjin, 300072, China
Email: lwhliu@tju.edu.cn
Email: weiwanying@tju.edu.cn
Email: dongleizhu234@163.com
*Corresponding author

Abstract: This paper builds a logistics service supply chain consisting of a logistics service integrator (LSI) and a functional logistics service provider (FLSP), where they collaborate with a reciprocity contract. We aim to analyse the impact of reciprocity on the supply chain members' two-stage service capability procurement decisions under demand updating through a multi-method, combining game theory and a case study. We find that a reciprocity contract could provide a win-win situation and coordinate the supply chain when reciprocity factors are in an appropriate range. Moreover, the reciprocal behaviour of LSI can promote the reduction of wholesale prices, and the reciprocal behaviour of FLSP will increase the purchasing quantity as well as bring forward the purchasing time point of LSI. Lastly, the reciprocal behaviour of both parties is mutually reinforcing; that is, when one party increases its own reciprocity factor, the other party also increases its reciprocity factor as a return. [Received: 30 September 2018; Accepted: 11 February 2020]

Keywords: service capacity procurement; reciprocity contract; demand updating; case study.

Reference to this paper should be made as follows: Liu, W., Wei, W. and Zhu, D. (2021) 'Service capacity procurement in logistics service supply chain with demand updating and reciprocal behaviour', *European J. Industrial Engineering*, Vol. 15, No. 1, pp.35–66.

Biographical notes: Weihua Liu is a Professor of Department of Logistics and Supply Chain Management at the College of Management and Economics, Tianjin University, China. He obtained his Doctor degree from the Shanghai Jiaotong University majoring in Enterprise Management in 2007. He specialises in logistics enterprise development and management and has published more than 40 international research papers including *International Journal of Production Economics*, *International Journal of Production Research*, *Supply Chain Management: An International Journal*, *Journal of Purchasing and Supply Management*, *Production Planning & Control*, *Transportation Research Part E: Transportation and Logistics Review*, *Annals of Operation Research*, etc.

Wanying Wei is a PhD student majored in Management Science and Engineering at the Tianjin University in China. She obtained her Bachelor's from the Tianjin University and focused on the research topic of service operations management. Her current research interests are in the field of logistics service supply chain and behavioural economics. She has published her research in *International Journal of Production Research*, *Transportation Research Part E: Transportation and Logistics Review* and others.

Donglei Zhu received her Bachelor's from the Department of Logistics Management, College of Management and Economics, Tianjin University China. Currently, she is a Master's student at the College of Management and Economics, Tianjin University, China. Her research interesting focuses on the behavioural operations of logistics service supply chain. She has published his research in *International Journal of Production Economics*, *Transportation Research Part E: Transportation and Logistics Review*, *Applied Mathematical Modelling*, *Asia-Pacific Journal of Operational Research*, etc.

1 Introduction

With intensifying market competition and increasing customer expectations, supply chain members start to mitigate the traditional competitive barriers with reciprocal behaviour and create close cooperation relationships to improve their profitability (Maloni and Benton, 1997). Fehr and Gächter (2000) define reciprocity as “the ability to respond to friendly actions”, because people are frequently much nicer and much more cooperative than predicted by the self-interest model. Reciprocal behaviour is quite common in practice. For example, on the contract signed by GE Aviation and its New York suppliers, the suppliers provided a backup source to GE, and reciprocally, GE paid a premium on a lot-size basis to the suppliers. This kind of reciprocal cooperation helps GE to maintain continuous operations in its facility and satisfy customer demand on time (Zeng and Xia, 2015). Similar case is also happened between Wal-Mart and Warner-Lambert (Simatupang and Sridharan, 2005).

In a logistics service supply chain (LSSC), a logistics service integrator (LSI) purchases service capacity from the functional logistics service providers (FLSPs) and then provide services to customers. The LSI and the FLSP also benefit from the reciprocal cooperation. For instance, Shanghai YTO Express (Logistics) Co. Ltd., a leading LSI with 60 branches in China, collaborates with the FLSPs in numerous ways, such as providing pricing discounting, awarding subsidies and carrying out express service training to FLSPs. In return, these FLSPs run image stores to enhance the brand influence of YTO Express. In this respect, reciprocal cooperation helps to decrease the transaction cost and offers higher profits to both parties.

However, compared with the prevalence of reciprocity, the effects of reciprocity on firms have not been explored systematically in the LSSC. While LSSC members are already cooperating with each other in a reciprocal way, there is much to learn about how to design reasonable reciprocity factors. Operating under a complicated environment of accurate demand updating (Fisher and Raman, 1996; Liu et al., 2015a), misaligned reciprocity can result in a misalignment of interest or stifle cooperation among LSSC members.

Many of YTO Express's branches suffer from these problems, especially during the annual sales promotions on 11 November. To cope with the surging demand of promotions, YTO Express pre-orders service capacity, such as renting the distribution centre site and warehouses, booking personnel and vehicles from FLSPs in advance based on forecasted demand (Sina News, 2017). By the time the promotion season approaches, YTO Express will have more accurate market information to update the demand, and then determine the final service capacity quantity purchased from FLSPs according to the newest forecasted demand. In this demand update environment, the reciprocal cooperation between YTO Express and the FLSPs has encountered many problems. Warehouse overflows, delayed deliveries, and goods damaged in transit are frequent (Zhang and Xiao, 2011; Sohu, 2017), and some FLSPs even stop cooperating with YTO Express (ECRC, 2018). The reason for these problems is that the FLSPs' marginal profits have been decreasing due to intense market competition and higher customer expectations. At the same time, YTO Express has not improved its reciprocal cooperation with some of the FLSPs, which has led to the loss of FLSPs. This loss is more serious when faced with a demand update. Anecdotal evidence suggests that Tianjin SND Logistics Company and STO Express suffer from similar problems.

Reciprocity is an important facet of social fairness preferences in behavioural economics, which emphasises that both parties in the supply chain support each other and eventually achieve an increase in both parties' utilities. Some scholars have studied reciprocity and built related models (Du et al., 2014; Xia et al., 2018). The traditional reciprocal model mainly focuses on the reciprocal decision-making process. It not only considers the inequity aversion toward outcomes of decision makers but also takes intention into account as an important decision criterion (Du et al., 2014). Different from the traditional reciprocal model, we consider that both parties in the supply chain have positive reciprocal preferences which are reflected in the contract. We refer to this contract as a reciprocity contract. Reciprocity contracts are similar in structure to revenue-sharing contracts, but are still significantly different from them. For example, revenue-sharing contracts are often limited to one member in the supply chain sharing its revenue with the other members under the incentive of Pareto improvement or channel coordination (Sluis and Giovanni, 2016), while reciprocity contracts emphasise that both parties in the supply chain are providing revenue-sharing to each other. In this paper, we study the conditions necessary for using a reciprocity contract in the service capacity procurement in LSSC and explore the impact of reciprocity on the supply chain members' decisions.

From a theoretical point of view, many scholars have studied reciprocity and demand updating in the supply chain individually. To date, studies on reciprocity focus on the effects of reciprocal behaviour on supply chain performance (Zhu et al., 2016; Luo and Zheng, 2013; Simatupang and Sridharan, 2005), but not on service capacity procurement decisions in the LSSCs. As for the literature about demand updating, production problems (Donohue, 2000; Kogan and Herbon, 2008; Qin, 2011; Zheng et al., 2016) and inventory problems (Gurnani and Tang, 1999; So and Zheng, 2003; Özen et al., 2012; Ma et al., 2012) in manufacturing supply chains have also been thoroughly studied. However, the literature has not considered the combined influence of reciprocity and demand updating. Further, these studies mostly deal with manufacturing supply chains, not LSSCs. Indeed, the typical properties of service, such as the non-storage property (Nie and Kellogg, 1999), make the service capacity procurement problem more

challenging than that of the manufacturing supply chain. This is because the non-storage of services makes it impossible for service companies to use secure inventory to buffer when there is a huge change in demand. In this case, if the LSI cannot make accurate demand updates, it will be more likely to cause huge sales losses. Therefore, in the context of demand updating, we urgently need to combine the characteristics of a service supply chain to carry out targeted research.

Based on the above background, this paper mainly studies the following three questions:

- 1 In the context of demand updating, does the reciprocity contract increase the profits of both the LSI and FLSP to enable supply chain coordination?
- 2 How does reciprocity affect the two-stage purchasing decisions of LSI and the wholesale price of FLSP before and after the demand updating?
- 3 When the reciprocity factors of LSI and FLSP are decision variables, what is their interaction?

To answer these questions, we build a two-echelon LSSC consisting of a LSI and a FLSP. Prior to the promotion season, the LSI will pre-order logistics service capability from the FLSP based on the forecasted demand, and the FLSP provides logistics services to the integrator's customers during the promotion season according to the integrator's purchasing quantity. Market demand is uncertain, but the closer to the promotion season one gets, the more accurate the demand forecasted by the LSI will be. The LSI will update the demand based on the collected market information before the promotion season and has two opportunities to subscribe to service capabilities before and after the demand update. In this context, we have established three models: decentralised decision setting, centralised decision setting, and reciprocal cooperation setting. By comparing these three models, we study the impact of reciprocal behaviour of LSI and FLSP on the two-stage service capability procurement decisions in the context of demand updating and use a case study of Tianjin SND Logistics Company to demonstrate our results.

Our main findings are as follows. In response to the first research question, we find that reciprocity contract can coordinate the supply chain. When the reciprocity factors of LSI and FLSP meet a certain range, the profits of both parties are improved compared to the profits under decentralised decision setting. In response to the second research question, we find that the reciprocal behaviour of FLSP will definitely increase the purchasing quantity in the first stage and will also promote the total purchasing quantity under certain conditions. Besides, the optimal purchasing time point becomes earlier the reciprocity factor of FLSP increases. At the same time, our research also shows that the wholesale prices in two stages will decrease as the reciprocity factor of LSI increases. In response to the third research problem, we find that when the reciprocity factors are decision variables, the reciprocal behaviour between the LSI and the FLSP is mutually reinforcing; that is, as the reciprocity factor of the LSI increases, the reciprocity factor of the provider FLSP will also increase, and vice versa.

This paper makes three contributions to both literature and practice. First, different from previous studies considering the reciprocal behaviour in the decision-making process (Du et al., 2014; Xia et al., 2018), we model the reciprocal behaviour of supply chain members through contracts and propose the reciprocity contract, which enriches the research on reciprocity. Second, our results show that the reciprocity benefits the supply chain by lowering the wholesale price as well as boosting purchasing quantity, which can

provide many insights for managers when signing a reciprocity contract. Lastly, we adopted the multi-method research of game theory modelling and case study (Given, 2008), which not only theoretically obtains the influence of reciprocal behaviour on the procurement decisions in a LSSC under demand update but also verifies it using practical cases. Therefore, the results provide not only a theoretical direction for subsequent research but also an effective guide for practice.

The rest of this paper is organised as follows. Section 2 reviews the extant literature on supply chain capacity procurement under demand updating and reciprocal cooperation. Section 3 sets forth some key assumptions and the decision-making process. Section 4 builds three two-stage models under decentralised, centralised, and reciprocal cooperation settings, respectively. Section 5 is model analysis, which compares the solutions of three models to determine whether the reciprocity contract can coordinate the LSSC, and analyse the effects of reciprocity on procurement decisions. Section 6 contains the case study of Tianjin SND Logistics used to validate our proposed models. Section 7 concludes with some limitations and provides research directions for future study.

2 Literature review

We now review the literature on supply chain capacity procurement under demand updating and reciprocal cooperation.

2.1 Supply chain procurement under demand updating

Decision making under demand updating is common in practice. As the demand realisation time point nears, decision makers continuously collect market information and update the demand in order to make better decisions based on the newly updated market demand. The common demand updating methods are the Bayesian updating method (Lee et al., 2012), conditional distribution method (Zhang et al., 2013), and the AR(1) process (So and Zheng, 2003). In supply chain procurement problems, demand updating has also been thoroughly studied, especially in terms of products with long lead times and short selling seasons, such as in the fashion (Yang et al., 2011), semiconductors (So and Zheng, 2003), and the telecommunication and automobile industries (Özen et al., 2012). As demand updating can alter procurement decisions, we review the demand updating literature for the single and two-stage ordering policies.

Studies on a single ordering policy often pay attention to procurement, inventory and optimal procurement time point problems. For example, Iyer and Bergen (1997) studied a single ordering policy which allows the retailer to observe market signals to improve demand updating in a shortened lead time. Choi et al. (2004) found the optimal single ordering policy for a retailer and proposed that the use of multiple delivery modes can help to increase the flexibility of inventory decisions. Based on Choi et al. (2004, 2006) studied a quick response (QR) policy using two information update models and showed that an effective QR policy depended on a precise information update model as well as on the selection of an appropriate pre-seasonal product as the observation target. Expanding the newsvendor model, Zheng et al. (2016) explored the effects of two kinds of supply constraints: limited ordering time scale and decreasing maximum ordering quantity. Comparing the two modes, Zheng et al. (2016) found that demand forecast updating is

negatively affected by increased purchasing cost, ordering lead time, and quantity restrictions.

The study of the more complex two-stage ordering policy based on demand information update has two branches: supply chain contract design and procurement. At the same time, service constraint and service level are taken into consideration. Sethi et al. (2007) discussed a two-stage service-constrained supply chain with an information update and service level guarantee. They found that the critical market signal, the optimal first-stage purchasing quantity, and the optimal expected profit are monotone and increase with service level. Zhou and Wang (2012) focused on the supply chain of a manufacturer and buyer and showed that an improved revenue-sharing contract can coordinate the supply chain. Considering service levels, Liu et al. (2015b) studied the influence of demand uncertainty revelation and quality guarantee change cost on the supply chain members' optimal decision making. Liu et al. (2018) investigated the impacts of a LSI's overconfidence behaviour on supply chain decisions under demand surge.

More complicated factors, especially some common behavioural factors such as risk factors and loss-aversion factors, are taken into consideration to make the studies more practical. For example, by comparing risk-neutral and risk-averse situations, Yan and Wang (2014) considered a capital constraint and showed that target safety capital can affect the optimal ordering policy. In addition to risk-averse factors, loss-averse factors are also studied (Qin, 2011; Ma et al., 2012). Although demand updating has been widely studied, there is no study on joint demand updating and reciprocity.

2.2 Reciprocal behaviour in supply chain management

Reciprocal cooperation is commonly used in a buyer-supplier relationship to improve supply chain performance (Maloni and Benton, 1997). However, the literature on the theoretical study on reciprocity is scant. For example, Simatupang and Sridharan (2005) proposed an integrative framework for supply chain collaboration based on the reciprocal approach. Luo and Zheng (2013) considered corporate social responsibility (CSR) (such as work conditions, child labour, environment, and forestry management), pointing out that CSR reciprocity between buyer and seller firms in a supply chain affects channel tie intensity and channel sales performance. Zhu et al. (2016) focused on green supply chain management and studied the influence of customer relational governance on the environment and economic performance. They found that cooperation and reciprocity with customers are needed for firms to gain economic performance through green innovation.

Next, some scholars have tried to model how reciprocal behaviour can affect supply chain decision making. For example, Du et al. (2014) modelled the effects of reciprocity on supply chain decision making and coordination. Comparing two scenarios where only the retailer or both sides have a preference for reciprocity, their research showed that intention plays an important role in the decision making of the supply chain and will significantly change the equilibrium. Different from Du et al. (2014), we determine the optimal condition and factors of the reciprocity contract by comparing the optimal strategies of decentralised, centralised, and reciprocal cooperation settings. In Zeng and Xia (2015), both the supplier and the buyer prefer reciprocity and guaranteed a backup supply by reciprocity. To maintain the backup supply partnership, the buyer bought constant small amounts of products from a backup supplier; reciprocally, the

backup supplier reserved production capacity for the buyer. Xia et al. (2018) studied the impact of reciprocal preferences on supply chain carbon emissions and pricing strategies in a cap-and-trade system and found that supply chain efficiency increases with supply chain members' reciprocal preferences. These studies mainly focused on manufacturing supply chains, and not on LSSCs under demand updating.

From the literature review, we find that scholars have studied supply chain capacity procurement under demand updating and reciprocal cooperation separately. However, there remain two limitations. On the one hand, research has not considered the combination of demand updating and reciprocity, which may give rise to more fundamental questions: how will reciprocity factors affect supply chain decision making? On the other hand, current studies on demand updating and reciprocity mainly focus on the manufacturing supply chain but not on the LSSCs. The properties of service, such as the non-storage property, make two-opportunity procurement problems under demand updating in LSSCs quite different from those of a manufacturing supply chain. The LSI places a pre-order in the first stage, instead of an actual purchase. In the second stage, the LSI places the order and receives the service capacity provided by the FLSP. Our study fills these research gaps.

3 Problem description and assumptions

This paper studies a two-echelon LSSC consisting of a LSI and a FLSP. The LSI integrates the functional logistics service capacity purchased from the FLSP and sells the integrated service capacity to customers. The mutability and intangibility of service (Nie and Kellogg, 1999) make it more important for the LSI to improve the accuracy of the market demand forecast and perform demand updating. Thus, the FLSP gives the LSI two ordering opportunities before the start of the selling season to avoid the loss from the mismatch of supply and demand. Long before the selling season, the LSI places a pre-order based on its market demand forecast. As the selling season draws near, the LSI could collect more accurate market information, based on which he updates the demand and decides the procurement time point and total purchasing quantity in the second stage (Liu et al., 2015a).

In the procurement process of service capacity, both the LSI and the FLSP have preferences for reciprocity. That is, they both do something good for each other. For example, in practice, SND (the LSI) often provides a flexible work arrangement and free professional training for its FLSPs. The FLSPs take the initiative to set lower wholesale prices. In our model, the LSI and the FLSP share a fraction of their revenue (including their sales income and revenue of the resale of integrated capacity at the end of the second stage) with each other to cooperate reciprocally. At $t = 0$, the LSI and the FLSP sign a reciprocity contract, which sets both parties' reciprocity degrees, including the LSI's reciprocity factor φ and the FLSP's reciprocity factor η , wholesale price w_0 in the first stage and wholesale price increasing speed k . Next, the LSI places a pre-order in the first stage.

In the second stage, the LSI observes the actual market signal and updates the demand. Because of the purchasing lead time, the LSI must place the actual order before time T_1 , which is considered as the latest procurement time point allowed by the FLSP. Considering reciprocal behaviour and market demand uncertainty, the LSI will share

demand information with the FLSP to ensure that the FLSP can provide sufficient functional logistics service capacity (Chen and Wang, 2014). In addition, the FLSP gives the LSI two purchasing opportunities and offers a lower w_0 in the first stage. Thus, in the second stage, this paper only considers two situations: the LSI keeps the initial purchasing quantity decided in the first stage or purchases more capacity.

3.1 Decision-making process

The decision process is as follows.

First, before $t = 0$, the LSI and the FLSP sign a reciprocity contract. The parameters' reciprocity factors φ and η , time points T_1 and T_2 , wholesale price w_0 in the first stage and wholesale price increasing speed k , are set in the reciprocity contract. In addition to the wholesale price charged by the FLSP, the LSI must pay costs in order to guarantee a certain level of service. These costs may cover organising providers, maintaining customer relationships, route optimisation and so on. We assume that the guaranteed service level is γ and the service cost of the LSI is $\rho\gamma$, where ρ is the cost coefficient. Therefore, the total unit service cost paid by the LSI in the first stage is $w_0 + \rho\gamma$.

Second, at $t = 0$, the LSI makes a demand forecast of the coming selling season and decides the purchase quantity Q_1 in the first stage.

Third, during $[0, T]$, the LSI observes a market signal, updates market demand at t , and makes procurement decisions in the second stage based on the newly updated market demand. The procurement decisions include the total purchasing quantity Q_2 and the optimal purchasing time point t .

Last, at T_2 , the FLSP hands over functional logistics service capacity Q_2 to the LSI. Different from the manufacturing supply chain, logistics services cannot be stored. Thus, although the LSI does purchase capacity before T_2 , the FLSP does not hand over the capacity to the LSI until the market demand realisation time point T_2 . At T_2 , the LSI can resell the surplus service capacity to the FLSP, as an FLSP often serve more than one LSI (Liu et al., 2015a). The decision process is shown in Figure 1.

Figure 1 Decision making process

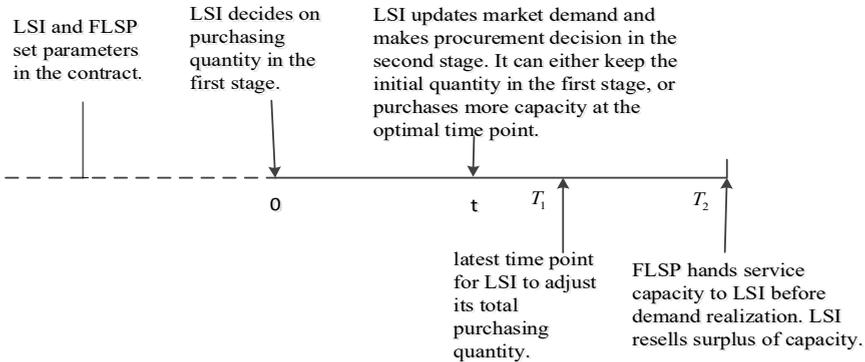


Table 1 Notations for the model

<i>Notation</i>	<i>Description</i>
c	Unit operating cost of the FLSP, $w_0 > c$.
X	Market demand for integrated service capacity.
μ_i	Mean of market demand in stage i ($i = 1, 2$).
σ_0	Standard deviation of market demand in the first stage.
σ_t	Standard deviation of market demand at time t in the second stage.
$f(x)$	Market demand distribution in the first stage, $X \sim N(\mu_1, \sigma_0^2)$.
$F(x)$	Cumulative distribution function of demand in the first stage, strictly monotone increasing function and $0 \leq F(x) \leq 1$.
g	Unit stock-out costs of the LSI.
$g(x)$	Market demand distribution in the second stage, $X \sim N(\mu_2, \sigma_t^2)$.
$G(x)$	Cumulative distribution function of demand in the second stage, strictly monotone increasing function and $0 \leq G(x) \leq 1$.
k	Wholesale price increasing speed $k > 0$.
p	Market price of integrated service capacity.
Q_1	LSI's purchasing quantity in the first stage. Q_1^d, Q_1^c, Q_1^r are purchasing quantities under decentralised, centralised and reciprocal cooperation settings.
Q_2	LSI's total purchasing quantity. Q_2^d, Q_2^c, Q_2^r are the total purchasing quantities under decentralised, centralised, and reciprocal cooperation settings.
t	LSI's purchasing time point in the second stage, $0 < t < T_1$.
T_1	Latest allowed procurement time point for LSI in the second stage.
T_2	The demand realisation time point.
v	Unit revenue of reselling surplus capacity.
w_0	Wholesale price in the first stage.
w_t	Wholesale price in the second stage $w_t = w_0 + kt$.
γ	Service guarantee level of LSI.
ρ	Logistics service level guarantee cost factor.
φ	Reciprocity factor of the LSI.
η	Reciprocity factor of the FLSP.
Π_I	LSI's total profit in the two stages. $\Pi_I^d, \Pi_I^c, \Pi_I^r$ are the total profits of the LSI under decentralised, centralised, and reciprocal cooperation settings. Π_{I1} is LSI's profit in the first stage.
Π_F	FLSP's total profit in the two stages. $\Pi_F^d, \Pi_F^c, \Pi_F^r$ are total profits of the FLSP under decentralised, centralised, and reciprocal cooperation settings. Π_{F1} is FLSP's profit in the first stage.

Notes: Superscripts d, c, r denote decentralised, centralised, and reciprocal cooperation settings, respectively.

3.2 Assumptions and notations

For the convenience of modelling, we make the following assumptions:

Assumption 1: The LSI and FLSP cooperate reciprocally through revenue sharing. All revenue, including sales and revenue of reselling surplus capacity, will be shared (Alaei and Setak, 2015). The LSI keeps a fraction $(1 - \varphi)$ of its revenue and shares φ with the FLSP. At the same time, defining $(1 - \eta)$ as the fraction of the FLSP's revenue kept by itself, the LSI earns a fraction of η . Accordingly, φ and η are the reciprocity factors of the LSI and FLSP, respectively.

Assumption 2: Market demand is normally distributed, with random variable $X \sim N(\mu_1, \sigma_0^2)$ in the first stage and $X \sim N(\mu_2, \sigma_t^2)$ in the second stage. As the forecast error decreases when it approaches the demand realisation time point, we assume $\sigma_t(t) = \frac{T_2 - t}{T_2} \sigma_0$, where σ_0 is the demand standard deviation at time point $t = 0$ (Chen and Chuang, 2000).

Assumption 3: Similar to Zheng et al. (2016), we assume the wholesale price in the second stage to be linear increasing with the LSI's purchasing time point, that is, $w_t = w_0 + kt$, $k > 0$. This is because, if the LSI has a longer purchasing lead time, the FLSP will have more time to prepare the service capacity and thus offers its capacity to the LSI at a lower price (w_0 in the first stage). However, with the shortening of the lead time in the second stage, the cost of FLSP will increase and the bargaining power of LSI decreases, so wholesale price in the second stage is linear increasing with the LSI's purchasing time point.

Assumption 4: The LSI and FLSP will cooperate only if the profit thresholds are satisfied. In short, the unit market price p of the integrated service capacity should be larger than the sum of the FLSP's unit wholesale price and service level guarantee cost, $p > w_0 + \rho\gamma$. For the FLSP, its unit operating cost should not be larger than the unit wholesale price in the first stage, i.e., $w_0 > c$. Similar to Liu et al. (2015a, 2015b), as $w_0 > c$ is already satisfied, this paper will focus on the LSI's procurement decision-making problem. The decision variables of LSI are the purchasing quantity in the first stage Q_1 , the total purchasing quantity decided in the second stage Q_2 and purchasing time point t . Table 1 shows the parameters and variables used.

4 Model building

We now build the three two-stage logistics service procurement models under decentralised setting (model 1), centralised setting (model 2) and reciprocal cooperation setting in Sections 4.1, 4.2 and 4.3, respectively. The following are some expressions that will be used in models 1 to 3.

LSI's expectation of the logistics service capacity sales quantity in the first stage:

$$S(Q_1) = Q_1 - \int_0^{Q_1} F(X) dX$$

LSI's expectation of total logistics service capacity sales quantity:

$$S(Q_2) = Q_2 - \int_0^{Q_2} G(X) dX$$

Expectation of insufficient capacity in the first stage:

$$\max(X - Q_1, 0) = \mu - Q_1 + \int_0^{Q_1} F(X) dX$$

Expectation of insufficient capacity in the second stage:

$$\max(X - Q_2, 0) = \mu - Q_2 + \int_0^{Q_2} G(X) dX$$

Expectation of surplus capacity at the end of the first stage:

$$\max(Q_1 - X, 0) = \int_0^{Q_1} F(X) dX$$

Expectation of surplus capacity at the end of the second stage:

$$\max(Q_2 - X, 0) = \int_0^{Q_2} G(X) dX$$

4.1 Model under decentralised setting (model 1)

Under a decentralised setting, the LSI and FLSP make their decisions independently to maximise individual profits.

4.1.1 Procurement model in the first stage

The LSI decides on the purchasing quantity Q_1 in the first stage based on demand forecast. Its profit function in the first stage is:

$$\Pi_{F1}^d(Q_1^d) = pS(Q_1^d) - (w_0 + \rho\gamma)Q_1^d - g \max(X - Q_1^d, 0) + v \max(Q_1^d - X, 0) \quad (1)$$

where $pS(Q_1^d)$ is the LSI's sales revenue in the first stage, $(w_0 + \rho\gamma)Q_1^d$ is the LSI's procurement cost and service level guarantee cost, $g \max(X - Q_1^d, 0)$ is the stock-out cost, $v \max(Q_1^d - X, 0)$ is the revenue of reselling the surplus capacity. With the development and diffusion of new technologies, it is more convenient and cheaper for the LSIs to observe and collect customer demand information. For example, Shanghai YTO Express (Logistics) Co., Ltd. can use the radar warning system of the Alibaba novice network to update market demand and pay a very low demand updating cost. Thus, this paper does not consider any demand updating cost (Youth News, 2015).

The profit function of the FLSP in the first stage is:

$$\Pi_{F1}^d(Q_1) = (w_0 - c)Q_1^d \quad (2)$$

where $w_0Q_1^d$ is the FLSP's sales revenue in the first stage and cQ_1^d is the FLSP's operating cost.

4.1.2 Procurement model in the second stage

In the second stage, the LSI decides the optimal purchasing time point t^d and the total purchasing quantity Q_2^d to maximise its profit. According to Assumption 2, the forecasted demand is closely related to the t^d . The closer the order point is to T_2 , the more accurate the demand forecast. Therefore, in the second stage, the LSI must first determine the purchasing point t^d , and judge whether the purchasing quantity must be updated according to the forecasted demand at the optimal order point, and then determine the total purchasing quantity Q_2^d . The LSI's total profit function is:

$$\begin{aligned} \Pi_l^d(Q_2^d, t) &= pS(Q_2^d) - (w_0 + \rho\gamma)Q_1^d - (w_t^d + \rho\gamma)(Q_2^d - Q_1^d) \\ &- g \max(X - Q_2^d, 0) + v \max(Q_2^d - X, 0) \end{aligned} \quad (3)$$

where Q_2^d is the LSI's total purchasing quantity, $Q_2^d - Q_1^d$ is the LSI's purchasing quantity in the second stage, and $(w_t^d + \rho\gamma)(Q_2^d - Q_1^d)$ is the LSI's procurement costs and service level guarantee costs in the second stage.

The total profit function of the FLSP is:

$$\Pi_F^d(Q_1^d, Q_2^d) = (w_0 - c)Q_1^d + (w_t^d - c)(Q_2^d - Q_1^d) \quad (4)$$

where $(w_t^d - c)(Q_2^d - Q_1^d)$ is the FLSP's profit in the second stage.

4.2 Model under centralised setting (model 2)

Model 2 is built under a centralised setting and the decision variables are the purchasing quantity Q_1^c in the first stage, the total purchasing quantity Q_2^c and the optimal purchasing time point t^c in the second stage. The LSI decides the t^c first and then decides the Q_2^c in the second stage. The channel profit in the first stage is:

$$\Pi_1^c(Q_1^c) = pS(Q_1^c) - (\rho\gamma + c)Q_1^c - g \max(X - Q_1^c, 0) + v \max(Q_1^c - X, 0) \quad (5)$$

where $\rho\gamma Q_1^c$ is the service level guarantee cost and cQ_1^c is the operation cost.

The total channel profit in the second stage is:

$$\Pi^c(Q_2^c, t) = pS(Q_2^c) - (\rho\gamma + c)Q_2^c - g \max(X - Q_2^c, 0) + v \max(Q_2^c - X, 0) \quad (6)$$

4.3 Model under reciprocal cooperation setting (model 3)

Unlike the traditional reciprocal model which emphasises the decision process and considers both outcomes and intentions, we study the reciprocal cooperation between the two parties in the contract and propose the concept of reciprocity contract. In the reciprocal cooperation model, the LSI and FLSP make decisions independently. However, they will not only try to maximise their own profit but also consider the profit of the other party.

4.3.1 Procurement model in the first stage

From Assumption 1, we know that all revenue will be shared. Thus, the LSI keeps a fraction $1 - \varphi$ of its revenue and shares φ with the FLSP. At the same time, the FLSP keeps a fraction $1 - \eta$ of its revenue and shares η with the LSI.

The LSI's profit function in the first stage is as follows:

$$\begin{aligned} \Pi_{l1}^r(Q_1^r) = & (1 - \varphi) [pS(Q_1^r) + v \max(Q_1^r - X, 0)] \\ & - (w_0 + \rho\gamma)Q_1^r - g \max(X - Q_1^r, 0) + \eta w_0 Q_1^r \end{aligned} \quad (7)$$

where $(1 - \varphi)[pS(Q_1^r) + v \max(Q_1^r - X, 0)]$ is the LSI's remaining revenue in the first stage, $\eta w_0 Q_1^r$ is the revenue shared by the FLSP.

The profit function of the FLSP in the first stage is:

$$\Pi_{f1}^r(Q_1^r) = (1 - \eta)w_0 Q_1^r - cQ_1^r + \varphi [pS(Q_1^r) + v \max(Q_1^r - X, 0)] \quad (8)$$

where $(1 - \eta)w_0 Q_1^r$ is the FLSP's revenue retained in the first stage, $\varphi [pS(Q_1^r) + v \max(Q_1^r - X, 0)]$ is the revenue shared by the LSI.

4.3.2 Procurement model in the second stage

In the second stage, the LSI updates the market demand and decides on the optimal total purchasing quantity and optimal purchasing time point t^r to maximise its profit. Similar to Section 4.1.2, the LSI first decides the optimal purchasing time point t^r and the total purchasing quantity Q_2^r . The LSI's total profit function is:

$$\begin{aligned} \Pi_l^r(Q_2^r, t) = & (1 - \varphi) [pS(Q_2^r) + v \max(Q_2^r - X, 0)] \\ & - (w_0 + \rho\gamma)Q_1^r - (w_t^r + \rho\gamma)(Q_2^r - Q_1^r) \\ & - g \max(X - Q_2^r, 0) + \eta [w_0 Q_1^r + w_t^r (Q_2^r - Q_1^r)] \end{aligned} \quad (9)$$

The total profit function of the FLSP is thus:

$$\begin{aligned} \Pi_f^r(Q_1^r, Q_2^r) = & (1 - \eta) [w_0 Q_1^r + w_t^r (Q_2^r - Q_1^r)] \\ & - cQ_2^r + \varphi [pS(Q_2^r) + v \max(Q_2^r - X, 0)] \end{aligned} \quad (10)$$

5 Model analysis

In this section, we analyse the models and advance four propositions. In Section 5.1, the optimal solutions under the three models of decentralised decision setting, centralised decision setting and reciprocal cooperation setting are given. Section 5.2 discusses the conditions under which the reciprocity contract can coordinate the supply chain. Section 5.3 analyses the impact of reciprocal behaviour on supply chain decisions. Section 5.4 explores the interaction between the reciprocity factors when they are decision variables.

Table 2 Optimal solutions of models 1–3

Model	Purchase more	Purchasing quantity in first stage	Total purchasing quantity	Conditions satisfied by optimal purchasing time point
1	Yes	$Q_1^{d*} = F^{-1}\left(\frac{p+g-w_0-p\gamma}{p+g-v}\right)$	$Q_2^{d*} = G^{-1}\left(\frac{p+g-w_0^{d*}-p\gamma}{p+g-v}\right)$	$\frac{(p+g-v)\sigma_0}{T_2} - \phi(z^d(t^{d*})) - kz^d(t^{d*}) \frac{T_2-t^{d*}}{T_2} - \sigma_0 - \mu_2k + kQ_1^{d*} = 0$
	No	$\underline{Q}_1^{d*} = F^{-1}\left(\frac{p+g-w_0-p\gamma}{p+g-v}\right)$	$\underline{Q}_2^{d*} = F^{-1}\left(\frac{p+g-w_0-p\gamma}{p+g-v}\right)$	–
2	Yes	$\underline{Q}_1^{d*} = F^{-1}\left(\frac{p+g-p\gamma-c}{p+g-v}\right)$	$\underline{Q}_2^{d*} = G^{-1}\left(\frac{p+g-p\gamma-c}{p+g-v}\right)$	$t^{d*} = T_1$
	No	$\underline{Q}_1^{d*} = F^{-1}\left(\frac{p+g-p\gamma-c}{p+g-v}\right)$	$\underline{Q}_2^{d*} = F^{-1}\left(\frac{p+g-p\gamma-c}{p+g-v}\right)$	–
3	Yes	$\underline{Q}_1^{d*} = F^{-1}\left(\frac{(1-\varphi)p+g-(1-\eta)w_0-p\gamma}{(1-\varphi)(p-v)+g}\right)$	$\underline{Q}_2^{d*} = G^{-1}\left(\frac{(1-\varphi)p+g-(1-\eta)w_0^{d*}-p\gamma}{(1-\varphi)(p-v)+g}\right)$	$\frac{[(1-\varphi)(p-v)+g]\sigma_0}{T_2} - \phi(z^r(t^{r*})) - kz^r(t^{r*}) \frac{T_2-t^{r*}}{T_2} - \sigma_0 - \mu_2(1-\eta)k + (1-\eta)kQ_1^{r*} = 0$
	No	$\underline{Q}_1^{d*} = F^{-1}\left(\frac{(1-\varphi)p+g-(1-\eta)w_0-p\gamma}{(1-\varphi)(p-v)+g}\right)$	$\underline{Q}_2^{d*} = F^{-1}\left(\frac{(1-\varphi)p+g-(1-\eta)w_0-p\gamma}{(1-\varphi)(p-v)+g}\right)$	–

Notes: The demand distributions are different in the three models, as the LSI's optimal purchasing time points are different. $\phi(\bullet)$ is the standard normal distribution.

5.1 Optimal solutions of models 1–3

Table 2 shows the solutions of models 1–3, and the proofs are shown in Appendix A.

5.2 Coordination conditions

We now examine the conditions under which the reciprocity contract can coordinate the LSSC. A reciprocity contract which can coordinate the LSSC must satisfy the following two conditions. First, the LSI's optimal total purchasing quantity under the reciprocity contract must coincide with that of the centralised system. Moreover, the LSI's and FLSP's profits under the reciprocity contract are not worse off compared to those of the decentralised setting (Alaei and Setak, 2015).

Proposition 1: The LSI and FLSP use the reciprocity contract with parameters (w_0, φ, η) ; if the wholesale price in the first stage satisfies:

$$w_0 = \hat{w}_0 = \frac{(1-\varphi)p + g - \rho\gamma - [(1-\varphi)(p-v) + g]G(Q_2^{c*})}{1-\eta} - kt^{r*}$$

and the two exogenous reciprocity factors φ and η satisfy:

$$E(\Pi_I^{d*}) - N \leq A(1-\varphi) - B(1-\eta) \leq -E(\Pi_F^{d*}) + A - cQ_2^{c*}$$

The reciprocity contract can coordinate the LSSC, where $A = pQ_2^{c*} - (p-v)\int_0^{Q_2^{c*}} G(X)dX$, $B = \hat{w}_I^{r*}Q_2^{c*} + kt^{r*}Q_1^{r*}$ and $N = g\left(Q_2^{c*} - \int_0^{Q_2^{c*}} G(X)dX - \mu_2\right) - \rho\gamma Q_2^{c*}$.

The proof for Proposition 1 is shown in Appendix B.

Proposition 1 shows that the proposed reciprocity contract can coordinate the LSSC and provides the parameter range. If the reciprocity factors φ and η satisfy the lower bound, i.e., $A(1-\varphi) - B(1-\eta) = E(\Pi_I^{d*}) - N$, then $\Delta\Pi_I = E(\Pi_I^{r*}) - E(\Pi_I^{d*}) = 0$. Thus, the FLSP receives all the extra profit gained by reciprocity. Similarly, if φ and η satisfy the upper bound, i.e., $A(1-\varphi) - B(1-\eta) = -E(\Pi_F^{d*}) + A - cQ_2^{c*}$, the LSI receives all the additional profit.

5.3 Effects of reciprocity on supply chain procurement decisions

We now show the effects of reciprocity on the LSI's optimal purchasing quantities decisions and the wholesale price in the reciprocity contract.

Proposition 2: When reciprocity contract can coordinate the LSSC, we obtain the following:

- 1 if $k < M_2^r$ and $T_2(1-\eta)k^2t^{r*} > \phi^2(0)$ are both satisfied, we have $\frac{\partial w_0}{\partial \phi} < 0$, i.e., the wholesale price w_0 in the first stage decreases with the LSI's reciprocity factor ϕ
- 2 if $k < M_2^r$ we have $\frac{\partial w_t}{\partial \phi} < 0$, i.e., the wholesale price in the second stage decreases with LSI's reciprocity factor ϕ .

The proof of Proposition 2 and the expression of M_2^r are shown in Appendix C.

Proposition 2 shows that when the reciprocity contract can coordinate the LSSC, the wholesale price in the first stage decreases with the LSI's reciprocity factor when the appropriate conditions satisfied. This is because, through the reciprocity contract, the LSI shares some of the profits with the FLSP, so the FLSP will be willing to sell the logistics service capabilities to the LSI at a lower wholesale price. Proposition 2 shows that LSI's reciprocal behaviour can bring benefits by reducing the wholesale price. This is also very common in real life; for example, after YTO Express and its FLSP establish a reciprocal long-term cooperative relationship, the wholesale price for YTO Express will be much lower than the market average price. Proposition 2 studies the influence of the LSI's reciprocity factor. In Proposition 3, we will analyse the impact of the FLSP's reciprocity factor on supply chain decision making.

Proposition 3: If $k < M_2^r$, we obtain the following:

- 1 the LSI's optimal purchasing quantity in the first stage increases with the FLSP's reciprocity factor η
- 2 if $\mu_2 - Q_1^{r*} - (1-\eta)\frac{\partial Q_1^{r*}}{\partial \eta} > 0$ is also satisfied, the LSI's optimal total purchasing quantity increases with the FLSP's reciprocity factor η
- 3 the LSI's optimal total purchasing time point t decreases with the FLSP's reciprocity factor η .

The proof for Proposition 3 is shown in Appendix D.

The first and second parts of Proposition 3 analyse the influence of the FLSP's reciprocity factor on the optimal purchasing quantities. It can be seen that under certain conditions, the LSI's first-stage order quantity and total order quantity will increase with the FLSP's reciprocity factor. This result explains that, with the increase in the reciprocity factor of the FLSP, although the reduction of the wholesale price will lose some of the FLSP's profit, because the LSI's order quantity is also increased at this time, this part of the increased profit can make up for the decrease due to the reduction in wholesale price. Therefore, the FLSP will reduce the wholesale price when its reciprocity factor increases.

The third part of Proposition 3 shows the reciprocal behaviour of FLSP can promote LSI determine the total purchasing quantity earlier. This conclusion tells us that the reciprocal behaviour of the FLSP increases the ability of the LSI to cope with the risk of uncertain demand. The LSI will then determine the total purchasing quantity in advance to ensure a lower wholesale price.

Through the analysis of Propositions 2 and 3, we find that the benefits of reciprocal behaviour to supply chain members are multifaceted. They can benefit from the direct profit sharing of the other party and enjoy the lower wholesale price or higher purchasing quantity of the other party to better promote the win-win situation of the supply chain members.

5.4 Interaction between the reciprocal behaviour of the LSI and FLSP

In the above analysis, the LSI's reciprocity factor φ and the FLSP's reciprocity factor η are assumed to be exogenous parameters. However, because of their significant impact on both parties' profits, the two parties sometimes set reciprocity factors based on profit maximisation, where the reciprocity factors become decision variables. Therefore, in this section, we further explore the relationship between the reciprocal behaviours of the two parties when the reciprocity factors are the decision variables, and advance Proposition 4.

Proposition 4: When the reciprocity factors are decision variables, the reciprocal behaviour of the LSI and the FLSP is mutually reinforcing.

The proof for Proposition 4 is shown in Appendix E.

From the above analysis, the reciprocal behaviour can bring benefits to both parties. For the FLSP, increasing reciprocity can increase LSI's purchasing quantity and achieve higher profits. For the LSI, improving its reciprocal behaviour can lower the wholesale price of the FLSP. Therefore, for both sides of the supply chain, strengthening cooperation and setting appropriate reciprocity factors can achieve a win-win situation and improve the overall supply chain performance. The conclusion of Proposition 4 further illustrates this point of view. When reciprocity factors are decision variables, the reciprocal behaviour of both parties can promote each other to further deepen cooperation and improve overall performance.

6 Case study

6.1 Methodology of the case study

In this section, we will use the case study method to verify the conclusions of this paper. From the perspective of research purposes, case studies can be divided into three types: exploratory case studies, descriptive case studies and explanatory case studies; from the perspective of case quantity, there are single case studies and multiple case studies (Yin, 2009). This section uses a single case for a descriptive case study, primarily for the following two reasons. On the one hand, the focus of this paper is on exploring the impact of reciprocal behaviour on purchasing decisions through game theory modelling. The modelling part and the theoretical analysis conclusions are the core content of this paper, and the case study is applied only to enhance the credibility of the modelling results. Therefore, we have chosen a single case for verification. On the other hand, through descriptive case studies, we can fully present the context in the case to ensure that the conclusions of this paper can indeed be applied in practice. Exploratory case studies and explanatory case studies are intended to explore new theoretical frameworks or causal relationships, which are not applicable to the context of this paper.

In the case selection, combined with the research theme of this paper, we have followed three principles: first, an LSI company, which should have a certain scale and reflect the operation status of most LSIs. Second, companies have carried out reciprocal cooperation with their logistics service providers. Last, companies are also faced with demand updates and the relevant data are available. Based on the above three principles, we decided to select Tianjin SND Logistics Company as a case study.

We use real data from Tianjin SND Logistics Company to verify our results.

- 1 *Acquisition of data.* Our data come from the interview data of the company's managers and refer to the social announcement data released by the company. To confirm the authenticity of the data, in addition to qualitative interviews, we also confirmed these data with the manager of the relevant department to ensure that all data were obtained in a rigorous, objective manner. For some data that cannot be measured directly, such as reciprocity factors, we have carefully discussed the situation with the interviewed managers to ensure that the data can be obtained and meet the needs of model calculation.
- 2 *Data processing.* In terms of data processing, based on the data obtained from the interview, we performed data cleaning and sorting, eliminating outliers and invalid values, so that all remaining data are valid. For example, we fit the demand data, and the fitting results show that the data do meet the normal distribution required for the model calculation.

6.2 *Case description*

6.2.1 *Demand updating in Tianjin SND Logistics Company*

Tianjin SND Logistics Company, founded in June 2007, is a third-party logistics enterprise providing domestic highway transportation as well as warehousing and logistics consulting services. SND owns more than 30 vehicles and integrates more than 2,000 social vehicles. Therefore, the company is able to dispatch a large number of vehicles, and the transportation service capacity is among the best in Tianjin. It currently has more than 30 branches covering major Chinese cities and has become one of the top ten logistics enterprises in Tianjin. By integrating more than 210 FLSPs, SND has successfully established widespread business relations with more than 20 multinational manufacturers, such as P&G, Siemens, and Delphi, and can supply customised services.

To illustrate the demand updating process in SND, we take its cooperation with P&G as an example. During festive occasions, P&G often does promotions and its demand for logistics service visibly increases. To provide better service to P&G, SND starts to forecast market demand one month before the sales season (such as May) and continuously observes and collects market signals during that month and updates market demand. Table 3 shows SND's monthly turnover from P&G's logistics business in 2015, where February to April are slack months and May to June is peak season. In May, SND's monthly turnover increased by 25% over April, which means that SND faced a demand surge in May. Thus, SND will suffer a great loss if it cannot satisfy the demand surge. Tianjin HONGWU Logistics Limited Company and Tianjin CQY Transportation Limited Company are SND's FLSPs. Table 3 also shows HONGWU's and CQY's monthly turnover and how much their turnover accounts for SND's monthly turnover.

Table 3 Monthly turnover of SND and its FLSP in slack and peak seasons

Month	<i>SND's monthly turnover from P&G's logistics business (thousands CNY)</i>	<i>Monthly turnover of Tianjin HONGWU Logistics Limited Company (CNY)</i>	<i>% of total logistics business turnover</i>	<i>Monthly turnover of Tianjin CQY Transportation Limited Company (CNY)</i>	<i>% of total logistics business turnover</i>
Feb	42,700	21,350	0.50%	250,666	5.87%
Mar	44,700	23,000	0.51%	347,704	7.78%
Apr	44,200	23,710	0.54%	434,412	9.83%
May	59,000	26,690	0.45%	505,169	8.56%
June	62,700	28,780	0.46%	572,730	9.13%

6.2.2 Reciprocal cooperation

SND cooperates with its FLSPs in many reciprocal ways. SND often provides a flexible work arrangement and settles accounts payable promptly to help its FLSPs. At the same time, the long-term cooperating FLSPs will take the initiative to set lower wholesale prices in order to obtain high profit margin lanes, and the higher the reciprocity degrees, the lower the wholesale prices will be. In return, SND also gives more profitable orders to FLSPs with a high reciprocity degree. However, the temporary FLSPs tend to set higher wholesale prices, as they lack the reciprocal cooperation with the SND's logistics company.

Reciprocal cooperation not only brings SND a stable service capacity reservation – SND can integrate more than 2,200 vehicles all the year round – but brings stable demand to the FLSPs. Over 80% of the long-term cooperating FLSPs have been working with SND for five years and over 30% of them have been working with SND for more than ten years. In the cooperation with the FLSPs, SND determines that both sides can earn higher profits in a growing logistics service market with high market demand and can save costs when market demand is low (such as the financial crisis in 2008–2009).

6.3 Case analysis

In this section, we collect data from the Tianjin SND logistics company and one of its FLSPs and validate the results of this paper. In Sub-section 6.3.1, we show the collected data. In Sub-section 6.3.2, we validated Proposition 1 of this paper, that is, reciprocity contract can coordinate the supply chain. In Sub-section 6.3.3, we validated the effect of the reciprocity factors on the relevant decision variables.

6.3.1 Data collection

To understand the effects of reciprocal behaviour, we conduct a numerical experiment on SND's transportation business from Tianjin to Taicang City, Jiangsu Province, in China. The numerical experiment data come from the transportation service from 2013 to 2016.

SND purchases transportation capacity from RPST (one of its FLSPs) at $w_0 = 275$ RMB/ton in the first stage and sells an integrated service to customers at $p = 370$ RMB/ton. If SND purchases more capacity from RPST in the second stage, the wholesale price increasing speed is $k = 1.1$. Surplus capacity is resold at $v = 45$ RMB/ton,

and the stock-out cost is $g = 53$ RMB/ton. The guarantee service level is $\gamma = 0.95$, and the logistics service level guarantee cost factor is $\rho = 5$ RMB/ton. The mean market demand in the first stage is $\mu_0 = 4,920$, in the second stage $\mu_2 = 5,950$, and the standard deviation of market demand in the first stage is $\sigma_0 = 500$. RPST allows SND to change its purchasing quantity at least a day before demand realisation; thus, $T_1 = 59$ and $T_2 = 60$. RPST has a unit operating cost of $c = 230$ and its reciprocity factor is $\eta = 0.84$. SND's reciprocity factor is $\varphi = 0.64$. To obtain the reciprocity factors, we let the operation managers of both SND and RPST rate the degree of each other's reciprocity on a scale from zero to nine and divide the degrees by nine to obtain the factors.

6.3.2 Supply chain coordination through reciprocity contract

Using the collected data, we find that a reciprocity contract can coordinate the LSSC. The optimal purchase quantities of the LSI, and the LSI's and FLSP's total profit, are shown in Table 4.

Table 4 Optimal solutions in three models

	Q^*	Q_2^*	LSI's total profit	RPST's total profit
Model 1	4,766	5,794	443,858	236,411
Model 2	4,918	5,950	–	–
Model 3	5,332	6,226	468,617	281,910

Table 4 shows that when SND and RPST cooperate reciprocally, SND's total purchase quantities can be even higher than those under a centralised setting. Further, both SND and RPST can benefit from reciprocal cooperation, as they earn a higher profit than that under a decentralised setting.

6.3.3 Effects of reciprocity on supply chain procurement decisions

In this section, we examine the effect of reciprocity on SND's purchase quantity and RPST's wholesale price. Figure 2 shows that SND's purchase quantity in the first stage increases with RPST's reciprocity factor η . η should be in an appropriate range, lest η is too large for RPST to afford or so small that SND does not want to purchase capacity from RPST. Figure 3 shows that SND's total purchase quantity also increases with η . When $0.6 < \eta < 0.78$, SND does not purchase more capacity in the second stage; thus its total purchase quantity equals that in the first stage (see Figure 3). Hence, when setting reciprocity factors, RPST should choose $0.5 < \eta < 0.6$ or $0.78 < \eta < 0.84$ to receive larger orders.

Figure 4 shows that when SND increases its reciprocity factor φ , it can purchase capacity from RPST with a low wholesale price in the second stage.

Figure 2 Variation tendency of Q_1^{r*} with η (see online version for colours)

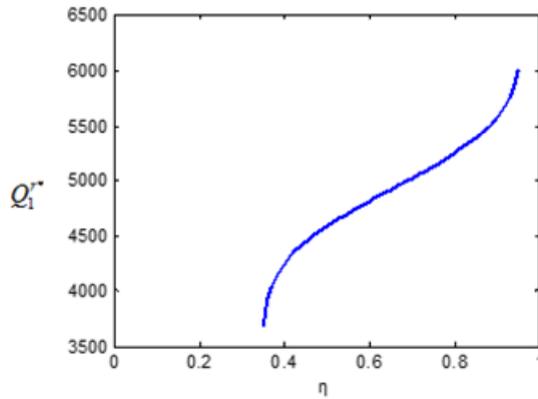


Figure 3 Variation tendency of Q_2^{r*} with η (see online version for colours)

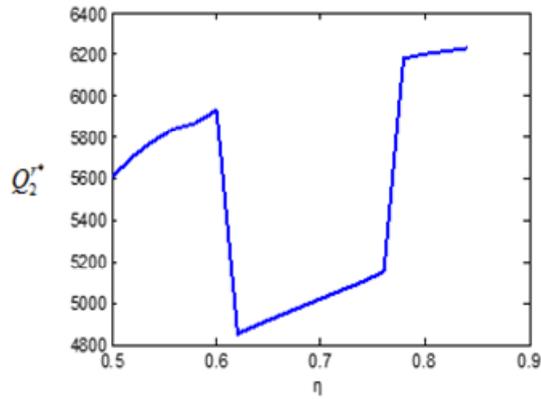
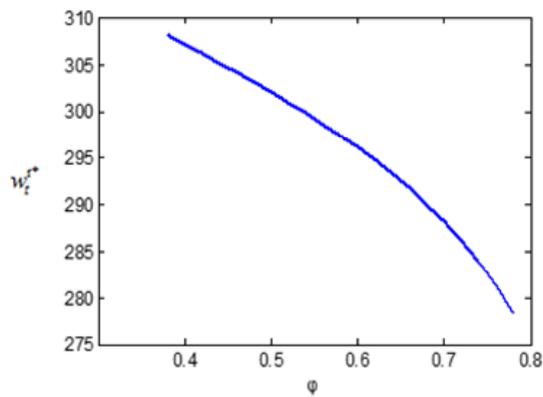


Figure 4 Variation tendency of w_1^{r*} with φ (see online version for colours)



7 Conclusions

7.1 *Main conclusions*

Considering the reciprocal cooperation between LSI and FLSP, this paper studies the two-stage procurement strategy in a LSSC. This paper focuses on the influence of reciprocal behaviour on the decision-making of supply chain members. The main conclusions obtained in this paper are as follows: first, the reciprocity contract can coordinate the supply chain under the premise that the reciprocal parameters meet a certain range. Second, the reciprocal behaviour of the LSI can lower the wholesale price in both stages, and the reciprocal behaviour of the FLSP can bring forward the purchasing time point in the second stage and increase the purchasing quantities of LSI. Third, the benefits of reciprocal behaviour to both sides of the supply chain are multifaceted. They can get a portion of the profits shared by the other party and enjoy lower wholesale prices or higher purchasing quantities at the same time. Lastly, the reciprocal behaviour of both parties can promote each party: one side can improve its reciprocity factor, while the other side can also increase its reciprocity factor in return.

7.2 *Management insights*

By studying the reciprocal cooperation problem under demand updating, we offer managers of the LSSC members some insights into making service capacity procurement decisions.

First, for the LSIs, they could establish a mutually beneficial relationship through reciprocity contracts to purchase logistics service capabilities at a lower wholesale price. LSIs should coordinate FLSPs regarding the reciprocity factor in the initial stage of cooperation to avoid potential profit conflicts between both sides. Second, for the FLSPs, it is necessary for them to actively cooperate with the LSIs to obtain more purchasing quantities from the LSIs by reducing the wholesale price and thus gain an advantage in the industry competition. Lastly, for the entire LSSC, reciprocal cooperation can bring about an overall improvement in performance, and relevant companies should actively cooperate upstream and downstream. In addition, because reciprocal cooperation is mutually reinforcing, some small companies can achieve faster profit growth through reciprocal cooperation.

7.3 *Limitations and future directions*

There are still some deficiencies in our work. For example, this paper studies an LSSC comprising one LSI and one FLSP. In practice, however, an LSI may have to integrate different kinds of FLSPs (such as transportation service providers and warehousing service providers) to satisfy customer demand. Thus, future work can study reciprocal cooperation problems in LSSC using different kinds of FLSPs. Moreover, this paper considers only one form of reciprocity, while in practice there are many other reciprocity forms, such as backup supply guaranteed by an FLSP. Other reciprocity forms can also be studied in the future.

Acknowledgements

This research is supported by the National Natural Science Foundation of China (Grant No. 71672121, 71372156). This research is also funded by Tianjin Science and Technology Program (18ZLGCX00090). The reviewers' comments are also highly appreciated.

References

- Alaai, S. and Setak, M. (2015) 'Multi objective coordination of a supply chain with routing and service level consideration', *International Journal of Production Economics*, Vol. 167, pp.271–281, <https://doi.org/10.1016/j.ijpe.2015.06.002>.
- Chen, M.S. and Chuang, C.C. (2000) 'An extended newsboy problem with shortage-level constraints', *International Journal of Production Economics*, Vol. 67, No. 3, pp.269–277.
- Chen, Y. and Wang, X.L. (2014) 'Service supply chain coordination mechanism research based on compensation-revenue sharing contract Mode', *International Conference on Management Science & Engineering (21st)*, pp.301–307.
- Choi, T.M., Li, D. and Yan, H. (2004) 'Optimal single ordering policy with multiple delivery modes and Bayesian information updates', *Computers & Operations Research*, Vol. 31, No. 12, pp.1965–1984.
- Choi, T.M., Li, D. and Yan, H. (2006) 'Quick response policy with Bayesian information updates', *European Journal of Operational Research*, Vol. 170, No. 3, pp.788–808.
- Donohue, L.K. (2000) 'Efficient supply contracts for fashion goods with forecast updating and two production modes', *Management Science*, Vol. 46, No. 11, pp.1397–1411.
- Du, S., Nie, T., Chu, C. et al. (2014) 'Reciprocal supply chain with intention', *European Journal of Operational Research*, Vol. 239, No. 2, pp.389–402.
- Electronic Commerce Research Center (ECRC) (2018) *The Hurt of Express Delivery: the Contradiction between YTO Express and Providers has Intensified*, in Chinese, Electronic Commerce Research Center [online] <http://www.100ec.cn/detail--6456624.html> (accessed 30 Sept 2019).
- Fehr, E. and Gächter, S. (2000) 'Fairness and retaliation: the economics of reciprocity', *Journal of Economic Perspectives*, Vol. 14, No. 3, pp.159–181.
- Fisher, M. and Raman, A. (1996) 'Reducing the cost of demand uncertainty through accurate response to early sales', *Operations Research*, Vol. 44, No. 1, pp.87–99.
- Given, L.M. (2008) *The Sage Encyclopedia of Qualitative Research Methods*, pp.892–894, Sage Publications, Thousand Oaks, CA.
- Gurnani, H. and Tang, C.S. (1999) 'Note: optimal ordering decisions with uncertain cost and demand forecast updating', *Management Science*, Vol. 45, No. 10, pp.1456–1462.
- Iyer, V.A. and Bergen, E.M. (1997) 'Quick response in manufacturer-retailer channels', *Management Science*, Vol. 43, No. 4, pp.559–570.
- Kogan, K. and Herbon, A. (2008) 'Production under periodic demand update prior to a single selling season: a decomposition approach', *European Journal of Operational Research*, Vol. 184, No. 1, pp.133–146.
- Lee, J.S., Lee, C.Y. and Lee, K.S. (2012) 'Forecasting demand for a newly introduced product using reservation price data and Bayesian updating', *Technological Forecasting & Social Change*, Vol. 79, No. 7, pp.1280–1291.
- Liu, W., Wang, D., Tang, O. et al. (2018) 'The impacts of logistics service integrator's overconfidence behaviour on supply chain decision under demand surge', *European J. Industrial Engineering*, Vol. 12, No.4, pp.558–597.

- Liu, W.H., Liu, X.Y. and Li, X. (2015a) 'The two-stage batch ordering strategy of logistics service capacity with demand update', *Transportation Research Part E: Logistics and Transportation Review*, Vol. 83, pp.65–89, <https://doi.org/10.1016/j.tre.2015.08.009>.
- Liu, W., Xie, D., Liu, Y. et al. (2015b) 'Service capability procurement decision in logistics service supply chain: a research under demand updating and quality guarantee', *International Journal of Production Research*, Vol. 53, No. 2, pp.488–510.
- Luo, X.M. and Zheng, Q.Q. (2013) 'Reciprocity in corporate social responsibility and channel performance: do birds of a feather flock together?', *Journal of Business Ethics*, Vol. 118, No. 1, pp.203–213.
- Ma, L.J., Zhao, Y.X., Xue, W.L. et al. (2012) 'Loss-averse newsvendor model with two ordering opportunities and market information updating', *International Journal of Production Economics*, Vol. 140, No. 2, pp.912–921.
- Maloni, M.J. and Benton, W.C. (1997) 'Supply chain partnerships: opportunities for operations research', *European Journal of Operational Research*, Vol. 101, No. 3, pp.419–429.
- Nie, W. and Kellogg, D.L. (1999) 'How professors of operations management view service operations?', *Production and Operations Management*, Vol. 8, No. 3, pp.339–355.
- Özen, U., Sošić, G. and Slikker, M. (2012) 'A collaborative decentralized distribution system with demand forecast updates', *European Journal of Operational Research*, Vol. 216, No. 3, pp.573–583.
- Qin, J.J. (2011) 'Contracts analysis based on information updating and loss aversion', *2011 Fourth International Conference on Intelligent Computation Technology and Automation*, Vol. 1, pp.1034–1037.
- Sethi, S.P., Yan, H., Zhang, H. et al. (2007) 'A supply chain with a service requirement for each market signal', *Production and Operations Management*, Vol. 16, No. 3, pp.322–342.
- Simatupang, T.M. and Sridharan, R. (2005) 'An integrative framework for supply chain collaboration', *International Journal of Logistics Management*, Vol. 16, No. 2, pp.257–274.
- Sina News (2017) 'Express delivery companies prepare for the November 11, YTO Express spend 30 million to add new equipment', in Chinese, *Sina News* [online] <http://news.sina.com.cn/o/2017-10-23/doc-ifymyxw4396888.shtml>.
- Sluis, S. and Giovanni, P.D. (2016) 'The selection of contracts in supply chains: an empirical analysis', *Journal of Operations Management*, Vol. 41, pp.1–11, <https://doi.org/10.1016/j.jom.2015.10.002>.
- So, K.C. and Zheng, X. (2003) 'Impact of supplier's lead time and forecast demand updating on retailer's order quantity variability in a two-level supply chain', *International Journal of Production Economics*, Vol. 86, No. 2, pp.169–179.
- Sohu (2017) 'YTO Express was most miserable after the November 11, what does YTO Express want to do?', in Chinese, *Sohu News* [online] http://www.sohu.com/a/205475013_100066877 (accessed 20 August 2018).
- Xia, L., Guo, T., Qin, J. et al. (2018) 'Carbon emission reduction and pricing policies of a supply chain considering reciprocal preferences in cap-and-trade system', *Annals of Operations Research*, Vol. 268, Nos. 1–2, pp.149–175.
- Yan, X. and Wang, Y. (2014) 'A newsvendor model with capital constraint and demand forecast update', *International Journal of Production Research*, Vol. 52, No. 17, pp.5021–5040.
- Yang, D.Q., Choi, T.M., Xiao, T.J. et al. (2011) 'Coordinating a two-supplier and one-retailer supply chain with forecast updating', *Automatica*, Vol. 47, No. 7, pp.1317–1329.
- Yin, R.K. (2009) *Case Study Research: Design and Methods*, 4th ed., Vol. 5, Sage Publications, Thousand Oaks, CA.
- Youth News (2015) 'Cainiao network's big data helps prepare for November 11, YTO Express is expected to send 200 million packages', in Chinese, *The Youth News* [online] http://news.youth.cn/jsxw/201510/t20151024_7238145.htm (accessed 2 April 2019).
- Zeng, A.Z. and Xia, Y. (2015) 'Building a mutually beneficial partnership to ensure backup supply', *Omega*, Vol. 52, pp.77–91, <https://doi.org/10.1016/j.omega.2014.10.008>.

- Zhang, J., Shou, B. and Chen, J. (2013) 'Postponed product differentiation with demand information update', *International Journal of Production Economics*, Vol. 141, No. 2, pp.529–540.
- Zhang, Y. and Xiao, H.W. (2011) 'Couriers' pressure upon thousands of packages on November 11', in Chinese, *Zhejiang News* [online] <http://zjnews.zjol.com.cn/05zjnews/system/2011/11/15/017997639.shtml> (accessed 23 September 2018).
- Zheng, M.M., Wu, K. and Shu, Y. (2016) 'Newsvendor problems with demand forecast updating and supply constraints', *Computers & Operations Research*, Vol. 67, pp.193–206, <https://doi.org/10.1016/j.cor.2015.10.007>.
- Zhou, Y.W. and Wang, S.D. (2012) 'Supply chain coordination for newsvendor-type products with two ordering opportunities and demand information update', *Journal of the Operational Research Society*, Vol. 63, No. 12, pp.1655–1678.
- Zhu, Q.H., Feng, Y.T. and Choi, S.B. (2016) 'The role of customer relational governance in environmental and economic performance improvement through green supply chain management', *Journal of Cleaner Production*, Vol. 155, No. 2, pp.46–53.

Appendix A

We take model 1 as an example of the model solution process and show the optimal purchased quantities and optimal purchasing time points under decentralised, centralised, and reciprocal cooperation settings. The LSI makes procurement decisions according to actual observed market signals collected continuously in the ordering interval, instead of the predicted demand update information. Thus, we first solve the problem in the first stage then calculate the optimal decision variables in the second stage.

Solution of model 1 in the first stage

LSI's expected profit in the first stage is:

$$E[\Pi_{l1}^d(Q_1^d)] = -(p + g - v) \int_0^{Q_1^d} F(X) dX + (p + g - w_0 - \rho\gamma) Q_1^d - g\mu_1 \quad (A1)$$

Take the first derivative of Q_1^d with respect to $E[\Pi_{l1}^d(Q_1^d)]$ and we have:

$$\frac{\partial E[\Pi_{l1}^d(Q_1^d)]}{\partial Q_1^d} = -(p + g - v)F(Q_1^d) + (p + g - w_0 - \rho\gamma)$$

As $\frac{\partial^2 E[\Pi_{l1}^d(Q_1^d)]}{\partial^2 Q_1^d} = -(p + g - v)f(Q_1^d) < 0$, the expected profit of the LSI in the first

stage, i.e., $E[\Pi_{l1}^d(Q_1^d)]$ is a concave function of Q_1^d . Solving $\frac{\partial E[\Pi_{l1}^d(Q_1^d)]}{\partial Q_1^d} = 0$, we get

the LSI's optimal purchased quantity in the first stage:

$$Q_1^{d*} = F^{-1}\left(\frac{p + g - w_0 - \rho\gamma}{p + g - v}\right)$$

As $0 \leq F(Q_1^{d*}) \leq 1$, thus $0 \leq \frac{p+g-w_0-\rho\gamma}{p+g-v} \leq 1$ needs to be satisfied. From

Assumption 4, we have $p > w_0 + \rho\gamma$, so there exists an optimal solution Q_1^{d*} .

Solution of model 1 in the second stage

In this stage, the LSI decides the optimal purchasing time point first and then decides the total purchasing quantity. According to the backward induction, we first solve the total purchasing quantity Q_2^d .

Step 1: solution of the optimal total purchasing quantity Q_2^{d}*

As for the optimal total purchasing quantity Q_2^{d*} , there are two cases.

Case 1 $Q_1^{d*} = Q_2^{d*}$.

If the LSI decides not to purchase more service capacity in the second stage, the LSI's total purchased quantity is equal to that in the first stage, i.e., $Q_1^{d*} = Q_2^{d*}$. Thus the LSI's total profit should be its profit at T_1 , when the mean of market demand is μ_2 and standard deviation of market demand is $\sigma_{T_1}^2$. The LSI's expected total profit is:

$$E[\Pi_T^d(T_1, Q_1^{d*})] = (p+g-w_0-\rho\gamma)Q_1^{d*} - (p+g-v) \int_0^{Q_1^{d*}} G(X) dX - g\mu_2$$

where $G(X) \sim N(\mu_2, \sigma_{T_1}^2)$.

The FLSP's expected total profit is:

$$\Pi_F^d(Q_1^{d*}) = (w_0 - c)Q_1^{d*}.$$

Case 2 $Q_1^{d*} < Q_2^{d*}$.

If the LSI decides to purchase more service capacity in the second stage, that is $Q_1^{d*} < Q_2^{d*}$, the total expected profit of the LSI is:

$$\begin{aligned} E[\Pi_T^d(t^d, Q_2^d)] &= (p+g-w_t^d-\rho\gamma)Q_2^d \\ &- (p+g-v) \int_0^{Q_2^d} G(X) dX - g\mu_2 + (w_t^d - w_0)Q_1^{d*} \end{aligned} \quad (\text{A2})$$

We get $Q_2^{d*} = G^{-1}\left(\frac{p+g-w_t^d-\rho\gamma}{p+g-v}\right)$. As $0 \leq G(Q_2^{d*}) \leq 1$, thus $0 \leq \frac{p+g-w_t^d-\rho\gamma}{p+g-v} \leq 1$

needs to be satisfied. We have $p > w_t^d + \rho\gamma \geq v$.

In the following, we solve the conditions that the LSI need purchase more service capacity in the second stage.

From $X \sim N(\mu_1, \sigma_0^2)$, we know $\frac{X - \mu_1}{\sigma_0} \sim N(0, 1)$. Thus, $\Phi\left(\frac{Q_1^{d*} - \mu_1}{\sigma_0}\right) = F(Q_1^{d*}) = \frac{p + g - w_0 - \rho\gamma}{p + g - v}$ and $Q_1^{d*} = \mu_1 + \Phi^{-1}\left(\frac{p + g - w_0 - \rho\gamma}{p + g - v}\right)\sigma_0$. Similarly, Q_2^{d*} can transform into $Q_2^{d*} = \mu_2 + \Phi^{-1}\left(\frac{p + g - w_i^d - \rho\gamma}{p + g - v}\right)\sigma_i^d$. Solving $Q_1^{d*} < Q_2^{d*}$, we have $\mu_1 + \Phi^{-1}\left(\frac{p + g - w_0 - \rho\gamma}{p + g - v}\right)\sigma_0 < \mu_2 + \Phi^{-1}\left(\frac{p + g - w_i^d - \rho\gamma}{p + g - v}\right)\sigma_i^d$. Let:

$$M_1^d = \mu_1 + \sigma_0 \left(\Phi^{-1}\left(\frac{p + g - w_0 - \rho\gamma}{p + g - v}\right) - \Phi^{-1}\left(\frac{p + g - w_i^d - \rho\gamma}{p + g - v}\right) \frac{T_2 - t^d}{T_2} \right)$$

Then when $\mu_2 > M_1^d$, we have $Q_1^{d*} < Q_2^{d*}$, that is, the LSI purchases more service capacity in the second stage.

Step 2: solution of the optimal purchasing time point t^{d}*

We now determine the LSI's optimal purchasing time point t^{d*} in the second stage in the case where $Q_1^{d*} < Q_2^{d*}$. We know that $Q_2^{d*} = \mu_2 + \Phi^{-1}\left(\frac{p + g - w_i^d - \rho\gamma}{p + g - v}\right)\sigma_i^d$. Let

$$z^d(t^d) = \Phi^{-1}\left(\frac{p + g - w_i^d - \rho\gamma}{p + g - v}\right), \text{ then } Q_2^{d*} = \mu_2 + z^d(t^d)\sigma_i^d.$$

Taking the second derivative of t^d with respect to $E[\Pi_I^d(t^d, Q_2^d)]$, we have $\frac{\partial^2 E[\Pi_I^d]}{\partial^2 t^d} = (1 - \eta)k \frac{\sigma_0}{T_2} z'(t^d) \left[\frac{2z(t^d)}{z'(t^d)} - (T_2 - t) \right]$. When $\frac{\partial^2 E[\Pi_I^d]}{\partial^2 t^d} \leq 0$, the $E[\Pi_I^d(t^d, Q_2^d)]$ is a concave function of t^d . Solving the $\frac{\partial^2 E[\Pi_I^d]}{\partial^2 t^d} \leq 0$, we know that the parameters should satisfy $w_0 > M_3^d, k < M_2^d$, where:

$$M_2^d = \min \left(\frac{p + g - w_0 - \rho\gamma - (p + g - v)\Phi(-1)}{T_1}, -\frac{2(p + g - v)}{T_2} \Phi^{-1}\left(\frac{p + g - w_0 - \rho\gamma}{p + g - v}\right) \phi\left(\Phi^{-1}\left(\frac{p + g - w_0 - \rho\gamma}{p + g - v}\right)\right) \right)$$

$$M_3^d = \frac{p + g + v}{2} - \rho\gamma$$

Based on the above parameters conditions, there is an optimal purchasing time point $t^{d*} \in (0, T_1]$ satisfying $\frac{(p + g - v)\sigma_0}{T_2} \phi(z^d(t^{d*})) - kz^d(t^{d*}) \frac{T_2 - t^{d*}}{T_2} \sigma_0 - \mu_2 k + kQ_1^{d*} = 0$ that maximises the LSI's expected profit in the second stage.

Appendix B

From Section 6.1, a reciprocity contract to coordinate the LSSC must satisfy two conditions. To satisfy the first condition of $Q_2^* = Q_2^{c*}$, we get

$$Q_2^{c*} = G^{-1} \left(\frac{(1-\varphi)p + g - (1-\eta)w_l^{r*} - \rho\gamma}{(1-\varphi)(p-v) + g} \right).$$

$$\text{We get } \hat{w}_0 = \frac{(1-\varphi)p + g - \rho\gamma - [(1-\varphi)(p-v) + g]G(Q_2^{c*})}{1-\eta} - kt^{r*}.$$

So, the wholesale price in the second stage is:

$$\hat{w}_l^{r*} = \frac{(1-\varphi)p + g - \rho\gamma - [(1-\varphi)(p-v) + g]G(Q_2^{c*})}{1-\eta}$$

Let $\Delta\Pi_I = E(\Pi_I^{r*}) - E(\Pi_I^{d*})$, $\Delta\Pi_F = E(\Pi_F^{r*}) - E(\Pi_F^{d*})$ be the extra profit gained by the LSI and FLSP under reciprocal cooperation, respectively. To satisfy the second condition, we need $\Delta\Pi_I = E(\Pi_I^{r*}) - E(\Pi_I^{d*}) \geq 0$ and $\Delta\Pi_F = E(\Pi_F^{r*}) - E(\Pi_F^{d*}) \geq 0$.

Taking $Q_2^{r*} = Q_2^{c*}$, \hat{w}_0 and \hat{w}_l^{r*} into the above inequalities, and letting $A = pQ_2^{c*} - (p-v) \int_0^{Q_2^{c*}} G(X)dX$, $B = \hat{w}_l^{r*}Q_2^{c*} - kt^{r*}Q_2^{c*}$, $N = g \left(Q_2^{c*} - \int_0^{Q_2^{c*}} G(X)dX - \mu_2 \right) - \rho\gamma Q_2^{c*}$.

$$\text{Thus } E(\Pi_I^{r*}) = A(1-\varphi) - B(1-\eta) + N, E(\Pi_F^{r*}) = A\varphi + B(1-\eta) - cQ_2^{c*}.$$

As $\Delta\Pi_I = E(\Pi_I^{r*}) - E(\Pi_I^{d*}) \geq 0$, $A(1-\varphi) - B(1-\eta) \geq E(\Pi_I^{d*}) - N$; similarly, as $\Delta\Pi_F = E(\Pi_F^{r*}) - E(\Pi_F^{d*}) \geq 0$, $A(1-\varphi) - B(1-\eta) \leq -E(\Pi_F^{d*}) - cQ_2^{c*} + A$.

Accordingly, φ and η should satisfy the following inequality:

$$E(\Pi_I^{d*}) - N \leq A(1-\varphi) - B(1-\eta) \leq -E(\Pi_F^{d*}) + A - cQ_2^{c*}$$

If the LSI agrees on the initial purchased quantity fixed in the first stage, $Q_1^{r*} = Q_1^{c*}$, so:

$$\tilde{w}_0 = \frac{(1-\varphi)p + g - \rho\gamma - [(1-\varphi)(p-v) + g]F(Q_1^{c*})}{1-\eta}$$

Similarly, taking $Q_1^{r*} = Q_1^{c*}$ and \tilde{w}_0 into the second condition and letting

$$\tilde{A} = pQ_1^{c*} - (p-v) \int_0^{Q_1^{c*}} G(X)dX, \tilde{B} = \tilde{w}_0Q_1^{c*}, \tilde{N} = g \left(Q_1^{c*} - \int_0^{Q_1^{c*}} G(X)dX - \mu_2 \right) - \rho\gamma Q_1^{c*},$$

we get $E(\Pi_I^{r*}) = \tilde{A}(1-\varphi) - \tilde{B}(1-\eta) + \tilde{N}$, $E(\Pi_F^{r*}) = \tilde{A}\varphi + \tilde{B}(1-\eta) - cQ_1^{c*}$.

Thus, φ and η satisfy $E(\Pi_I^{d*}) - \tilde{N} \leq \tilde{A}(1-\varphi) - \tilde{B}(1-\eta) \leq -E(\Pi_F^{d*}) + \tilde{A} - cQ_1^{c*}$.

Appendix C

1 The effects of the LSI's reciprocity factor on the wholesale price in the first stage.

When the reciprocity contract can coordinate the LSSC,

$$\hat{w}_0 = \frac{(1-\varphi)p + g - \rho\gamma - [(1-\varphi)(p-v) + g]G(Q_2^{c*})}{1-\eta} - kt^{r*}$$

Taking the first derivative of φ with respect to \hat{w}_0 , gives:

$$\frac{\partial \hat{w}_0}{\partial \varphi} = \frac{-1}{1-\eta} [p - (p-v)G(Q_2^{c*})] - k \frac{\partial t^{r*}}{\partial \varphi}$$

Solving $\frac{\partial t^{r*}}{\partial \varphi}$, and from Table 2, the optimal purchasing time point t^{r*} in the second stage is:

$$\frac{[(1-\varphi)(p-v) + g]\sigma_0}{T_2} \phi(z^r(t^{r*})) - kz^r(t^{r*}) \frac{T_2 - t^{r*}}{T_2} \sigma_0 - \mu_2(1-\eta)k + (1-\eta)kQ_1^{r*} = 0$$

Taking the first derivative of φ , we get:

$$\begin{aligned} & \left[\frac{\eta k \sigma_0}{T_2} z^r(t^{r*}) - k \sigma_0 (z^r(t^{r*}))' \frac{T_2 - t^{r*}}{T_2} \right] \frac{\partial t^{r*}}{\partial \varphi} \\ & = \frac{(p-v)\sigma_0}{T_2} \phi(z^r(t^{r*})) - (1-\eta)k \frac{\partial Q_1^{r*}}{\partial \varphi} \end{aligned} \quad (C1)$$

When $w_0 = \hat{w}_0$, Take the first derivative of φ with respect to Q_1^{r*} we have:

$$-(p-v)F(Q_1^{r*}) + f(Q_1^{r*}) \frac{\partial Q_1^{r*}}{\partial \varphi} [(1-\varphi)(p-v) + g] = -p - (1-\eta) \frac{\partial \hat{w}_0}{\partial \varphi}$$

Then,

$$f(Q_1^{r*}) \frac{\partial Q_1^{r*}}{\partial \varphi} [(1-\varphi)(p-v) + g] = -(p-v)(G(Q_2^{c*}) - F(Q_1^{r*})) + (1-\eta)k \frac{\partial t^{r*}}{\partial \varphi}$$

$$\text{So } \frac{\partial Q_1^{r*}}{\partial \varphi} = \frac{-(p-v)(G(Q_2^{c*}) - F(Q_1^{r*})) + (1-\eta)k \frac{\partial t^{r*}}{\partial \varphi}}{f(Q_1^{r*})[(1-\varphi)(p-v) + g]} \text{ and take it into equation (C1)}$$

$$\begin{aligned} & \left[\frac{\eta k \sigma_0}{T_2} z^r(t^{r*}) - k \sigma_0 (z^r(t^{r*}))' \frac{T_2 - t^{r*}}{T_2} + \frac{(1-\eta)^2 k^2}{f(Q_1^{r*})[(1-\varphi)(p-v) + g]} \right] \frac{\partial t^{r*}}{\partial \varphi} \\ & = -\frac{(p-v)\sigma_0}{T_2} \phi(z^r(t^{r*})) + (1-\eta)k \frac{(p-v)(G(Q_2^{c*}) - F(Q_1^{r*}))}{f(Q_1^{r*})[(1-\varphi)(p-v) + g]} \end{aligned} \quad (C2)$$

Next, consider:

$$\eta z^r(t^{r*}) - (z^r(t^{r*}))'(T_2 - t^{r*}) \tag{C3}$$

Let $H(t^{r*}) = \eta \frac{z^r(t^{r*})}{(z^r(t^{r*}))'} - (T_2 - t^{r*})$. From Appendix A in Liu et al (2015a), when:

$$1 - (z^r(t^{r*}))'^2 > 0, H(t^{r*}) \geq H(0) = \eta \frac{z^r(0)}{(z^r(0))'} - T_2 \tag{C4}$$

From Appendix A, $Q_2^r = \mu_2 + \Phi^{-1} \left(\frac{(1-\varphi)p + g - (1-\eta)w_t^r - \rho\gamma}{(1-\varphi)(p-\nu) + g} \right) \sigma_t^r$.

Let $\Phi(z^r) = \frac{(1-\varphi)p + g - (1-\eta)\hat{w}_t^r - \rho\gamma}{(1-\varphi)(p-\nu) + g}$. Taking the first derivative of r ,

$$\text{we have } (z^r(t^r))' = \frac{-(1-\eta)k}{[(1-\varphi)(p-\nu) + g]\phi(z^r)} < 0.$$

Thus, $\eta z^r(t^{r*}) - (z^r(t^{r*}))'(T_2 - t^{r*}) = (z^r(t^{r*}))'H(t^{r*}) < (z^r(t^{r*}))'H(0)$.

When $H(0) > 0$, $\eta z^r(t^{r*}) - (z^r(t^{r*}))'(T_2 - t^{r*}) > 0$. The coefficient of $\frac{\partial t^{r*}}{\partial \varphi}$ in equation (C2) is negative.

To get $1 - (z^r(t^{r*}))'^2 > 0$, $k < M_2^r$ should be satisfied, with:

$$M_2^r = \min \left[\begin{aligned} & \frac{(1-\varphi)p + g - (1-\eta)w_0 - \rho\gamma - [(1-\varphi)(p-\nu) + g]\Phi(-1)}{T_1}, \\ & -\frac{2[(1-\varphi)(p-\nu) + g]}{(1-\eta)T_2} \Phi^{-1} \left(\frac{(1-\varphi)p + g - (1-\eta)w_0 - \rho\gamma}{(1-\varphi)(p-\nu) + g} \right) \\ & \phi \left(\Phi^{-1} \left(\frac{(1-\varphi)p + g - (1-\eta)w_0 - \rho\gamma}{(1-\varphi)(p-\nu) + g} \right) \right) \end{aligned} \right]$$

As $G(Q_2^{c*}) - F(Q_1^{c*}) < G(Q_2^{c*}) - G(Q_2^{r*}) = 0$, equation (C2) can be changed to:

$$\begin{aligned} & \frac{(p-\nu)\sigma_0}{T_2} \phi(z^r(t^{r*})) + (1-\eta)k \frac{(p-\nu)(G(Q_2^{c*}) - F(Q_1^{c*}))}{f(Q_1^{c*})(\varphi p + g - \varphi\nu)} \\ & < \frac{(p-\nu)\sigma_0}{T_2} \phi(0) - (1-\eta)k \frac{\sigma_0(p-\nu)kt^{r*}}{\phi(0)} \end{aligned}$$

If $T_2(1-\eta)k^2t^{r*} > \phi^2(0)$, then $\frac{(p-\nu)\sigma_0}{T_2} \phi(0) - (1-\eta)k \frac{\sigma_0(p-\nu)kt^{r*}}{\phi(0)} < 0$, so $\frac{\partial t^{r*}}{\partial \varphi} < 0$.

So, $\frac{\partial w_0}{\partial \varphi} = \frac{1}{1-\eta} [p - (p-\nu)G(Q_1^{c*})] - k \frac{\partial t^{r*}}{\partial \varphi} < 0$.

Thus, if the parameters satisfy the conditions $k < M_2^r$ and $T_2(1-\eta)k^2t^{r*} > \phi^2(0)$, then

$$\frac{\partial w_0}{\partial \varphi} = \frac{1}{1-\eta} [p - (p-\nu)G(Q_1^{r*})] - k \frac{\partial t^{r*}}{\partial \varphi} < 0.$$

- 2 The effects of the LSI's reciprocity factor on the wholesale price in the second stage.

If the LSI purchases more capacity in the second stage, the wholesale price in the second stage becomes $w_i^{r*} = w_0 + kt^{r*}$. Taking the first derivative of φ w.r.t w_i^{r*}

yields $\frac{\partial w_i^{r*}}{\partial \varphi} = k \frac{\partial t^{r*}}{\partial \varphi}$. The optimal purchasing time point t^{r*} in the second stage

should satisfy:

$$\frac{[(1-\varphi)(p-\nu)+g]\sigma_0}{T_2} \phi(z^r(t^{r*})) - kz^r(t^{r*}) \frac{T_2-t^{r*}}{T_2} \sigma_0 - \mu_2(1-\eta)k + (1-\eta)kQ_1^{r*} = 0$$

Taking the first derivative of φ , we get:

$$\left[\frac{\eta k \sigma_0}{T_2} z^r(t^{r*}) - k \sigma_0 (z^r(t^{r*}))' \frac{T_2-t^{r*}}{T_2} \right] \frac{\partial t^{r*}}{\partial \varphi} = \frac{(p-\nu)\sigma_0}{T_2} \phi(z^r(t^{r*})) - (1-\eta)k \frac{\partial Q_1^{r*}}{\partial \varphi}$$

where $\frac{\partial Q_1^{r*}}{\partial \varphi} < 0$, so $\frac{\partial t^{r*}}{\partial \varphi} < 0$. Thus, $\frac{\partial w_i^{r*}}{\partial \varphi} = k \frac{\partial t^{r*}}{\partial \varphi} < 0$.

Appendix D

Taking the first derivative of η w.r.t Q_1^{r*} we get:

$$\frac{\partial Q_1^{r*}}{\partial \eta} = \frac{1}{f \left(\frac{(1-\varphi)p + g - (1-\eta)w_0 - \rho\gamma}{(1-\varphi)(p-\nu) + g} \right)} \frac{w_0}{(1-\varphi)(p-\nu) + g} > 0$$

If the LSI purchases more capacity in the second stage,

$$\frac{\partial Q_2^{r*}}{\partial \eta} = \frac{1}{g \left(\frac{(1-\varphi)p + g - (1-\eta)w_i^{r*} - \rho\gamma}{(1-\varphi)(p-\nu) + g} \right)} \frac{-1}{(1-\varphi)(p-\nu) + g} \left(-w_i^{r*} + k(1-\eta) \frac{\partial t^{r*}}{\partial \eta} \right)$$

Consider $\frac{\partial t^{r*}}{\partial \eta}$. The optimal purchasing time point t^{r*} in the second stage should satisfy:

$$\frac{[(1-\varphi)(p-\nu)+g]\sigma_0}{T_2} \phi(z^r(t^{r*})) - kz^r(t^{r*}) \frac{T_2-t^{r*}}{T_2} \sigma_0 - \mu_2(1-\eta)k + (1-\eta)kQ_1^{r*} = 0$$

Taking the first derivative of η ,

$$\left[\frac{\eta k \sigma_0}{T_2} z^r(t^{r*}) - k \sigma_0 (z^r(t^{r*}))' \frac{T_2 - t^{r*}}{T_2} \right] \frac{\partial t^{r*}}{\partial \eta} = -\mu_2 k + k Q_1^* - (1 - \eta) k \frac{\partial Q_1^*}{\partial \eta}$$

From Appendix C, $\frac{\eta k \sigma_0}{T_2} z^r(t^{r*}) - k \sigma_0 (z^r(t^{r*}))' \frac{T_2 - t^{r*}}{T_2} < 0$.

If $\mu_2 - Q_1^* - (1 - \eta) \frac{\partial Q_1^*}{\partial \eta} > 0$, then $\frac{\partial t^{r*}}{\partial \eta} < 0$.

$$\text{So } \frac{\partial Q_2^{mb*}}{\partial \eta} = \frac{1}{g \left(\frac{\varphi p + g - \eta w_i^{mb*} - \rho \gamma}{\varphi p + g - \varphi v} \right)} \frac{-1}{\varphi p + g - \varphi v} \left(-w_i^{mb*} + k \eta \frac{\partial t^{mb*}}{\partial \eta} \right) > 0.$$

Appendix E

Both the LSI and FLSP will not take reciprocal action unless their utilities are met.

First, we explore the relationship between the reciprocity factors of the LSI and FLSP. Under a reciprocal contract, the LSI's utility function is:

$$\begin{aligned} \Delta U &= E[\Pi_f^r] - E[\Pi_f^r] \\ &= -(2\varphi - 1) \left[ps(Q_2^r) + v \int_0^{Q_2^r} G(X) dX \right] - g \left(-Q_2^r + \int_0^{Q_2^r} G(X) dX + \mu_2 \right) \\ &\quad - 2(1 - \eta) \left[w_0 Q_1^r + w_i^r (Q_2^r - Q_1^r) \right] - (\rho \gamma - c) Q_2^r \end{aligned}$$

Taking the first derivative of Q_2^r with respect to ΔU and setting the derivative to zero gives:

$$-(2\varphi - 1) \left[p - pG(Q_2^r) + vG(Q_2^r) \right] - g \left(-1 + G(Q_2^r) \right) - 2(1 - \eta) w_i^r - \rho \gamma + c = 0$$

Taking the first derivative of η with respect to φ :

$$\frac{\partial \varphi}{\partial \eta} = \frac{w_i^r}{p - pG(Q_2^r) + vG(Q_2^r)}$$

where $0 < G(Q_2^r) < 1$, so $\frac{\partial \varphi}{\partial \eta} > 0$. The reciprocity factor of the FLSP increases with that of the LSI. Thus, reciprocal behaviour has mutual promotion effects.