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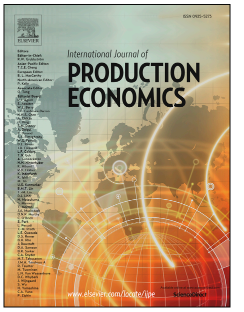

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The Impact of Different Contract Structures on IT Investment in Logistics Outsourcing

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The Impact of Different Contract Structures on IT Investment in Logistics Outsourcing

Abstract

The information technology (IT) capabilities of third-party logistics (3PL) providers are important for manufacturers because they enable manufacturers to optimize their operations. However, there exists an "IT gap," or discrepancy between manufacturers' expectations and their satisfaction with the IT capabilities of 3PL providers. Previous studies suggest that 3PL providers' IT investments are critical and necessary for developing superior IT capabilities, which, in turn, contribute to firm performance. To motivate 3PL providers to invest in developing their IT capabilities and, thus, reduce the "IT gap," we analyze a 3PL provider's IT investment, as well as its impact on supply chain profit, under four logistics outsourcing contract structures: a fixed-price contract, a contract contingent on the on-time delivery rate, a profit-sharing contract, and a revenue-sharing contract. We find that the 3PL provider's IT investment is higher under the contingent and profit-sharing contract structures than it is under the other two contract structures. The 3PL provider's IT investment under the contingent contract is no more than that of the profit-sharing contract. Additionally, we find that the contingent and profit-sharing contracts result in a higher profit within the supply chain than the other two contract structures do, and that the supply chain profits under contingent and profit-sharing contracts are dependent on the 3PL provider's IT investment. The results provide 3PL buyers and providers guidance in terms of using contract structures to motivate IT investment in logistics outsourcing.

Keywords: IT Investment, IT Capability, Logistics Outsourcing, 3PL, Contract Structure, Contract Design, Supply Chain, Supply Chain Profit, Game Theory

1 Introduction

The IT-based capabilities of third-party logistics (3PL) providers in areas such as transportation management (planning and scheduling), electronic data interchange (EDI), visibility in orders, shipments, inventory, real-time data collecting and sharing, utilizing big data, and analytics, among others, have become increasingly important for 3PL providers and buyers (Rai et al. 2012). 3PL providers can differentiate themselves by providing advanced IT-based capabilities (Sauvage 2003, Piplani 2004), and superior IT capabilities help them achieve competitive advantages in terms of cost, service variety, and service quality (Bhatt & Grover 2005, Lai et al. 2008). For example, UPS has invested approximately $1 billion annually in its On-Road Integrated Optimization and Navigation (ORION) system, and expects to utilize the system on 55,000 routes in the North American market by 2017. The ORION system will help enhance customer service to a new level and improve logistics efficiency—savings of one mile a day per driver can save up to $50 million annually (Krebs 2016). From the perspective of 3PL service buyers, the IT services provided by 3PL providers are critical to improving firm performance (Selviaridis & Spring 2007, Marasco 2008, Rai et al. 2012). When 3PL buyers face demand fluctuations, capacity constraints, and supply chain disruptions, they need real-time information from 3PL providers in order to manage shipping alternatives and to further optimize their supply chains.

However, the 2017 21st Annual Third-Party Logistics Study on the State of Logistics Outsourcing shows that the "IT gap," the difference between what shippers expect and what they are satisfied with in terms of 3PL providers' current IT capabilities, has established (Capgemini & Langley 2017). The Study has been tracking the IT gap over the past 15 years, and finds that although the gap is narrowing, it still has significant room for improvement. According to the 2017 study, 91% of shippers indicate that IT capabilities are necessary elements of 3PL expertise, while only 65% are satisfied with 3PL providers' current IT capabilities. Considering that big data and analytics have enormous potential to increase end-to-end visibility, drive supply chain optimization, and minimize disruptions, the above 2017 study suggests that 3PLs have not yet fully realized the importance of big data to shippers. Therefore, the state of logistics outsourcing suggests a need to improve 3PL providers' IT capabilities in order to narrow the IT gap.

To develop a 3PL provider's IT capabilities, it is critical and necessary that the provider invests in IT resources (Lai et al. 2008, Rai et al. 2012). From a resource-based view (RBV), a firm's IT capability is defined as the "ability to mobilize and deploy IT-based resources in combination or co-present with other resources and capabilities" (Bharadwaj 2000, p171). The level of a firm's investment in IT resources such as IT infrastructure and human IT skills is a critical factor in the development of its IT capability (Bharadwaj 2000). The combination of a firm's IT investment and other resources and capabilities determines its IT capability, which, in turn, creates competitive advantages and adds relational value for business partners (Bhatt & Grover 2005, Huang et al. 2006, Rai et al. 2012). In the context of the 3PL industry, a 3PL provider's investment in IT resources combines with the firm's managerial involvement in IT to determine its IT capability (Lai et al. 2008).

The literature on IT has examined a variety of antecedents and performance outcomes of 3PL providers' IT investments. With regard to the antecedents of such investments, 3PL providers that offer IT-based services to differentiate themselves from the competition (Sauvage 2003, Piplani 2004), have a stronger technology orientation (Lai et al. 2008), or trust buyers' commitment (Klein et al. 2007) tend to invest more in IT hardware, software, and other IT resources. Typically, 3PL buyers request that 3PL providers invest in specific IT services in order to pursue a long-term cooperative relationship (Langley 2007, Evangelista et al. 2012). Furthermore, buyers consider a 3PL providers' ability to provide IT-based services to be an important criterion when selecting providers (Vaidyanathan 2005; Min 2013, Evangelista et al. 2012, Qureshi et al. 2008). Their relationship-specific investment and IT commitment may also trigger 3PL providers' IT investments (Klein et al. 2007). In terms of the RBV, many studies have empirically examined the performance outcomes of 3PL providers' IT investments. The literature suggests that a 3PL provider's firm-specific investment in IT infrastructure and human IT resources has a positive impact on the firm's performance (Bharadwaj 2000, Huang et al. 2006, Aral & Weill 2007, Mithas et al. 2011, Evangelista et al. 2012), competitive advantages (Bhatt & Grover 2005, Lai et al. 2008), and relational value (Rai et al. 2012) by developing its IT capability. Logistics outsourcing contracts are important mechanisms in successfully managing and maintaining the relationship between 3PL providers and buyers (Selviaridis & Spring 2007, Marasco 2008). However, few studies have analyzed how different contract structures affect a 3PL provider's IT investment, or analytically examined the impact of a 3PL provider's IT investment on supply chain performance, under different contract structures.

Previous studies on 3PL contracts are based mostly on survey data or case studies, and the literature on analytical contract design is rather limited (Marasco 2008). Many studies have examined the formal provisions in 3PL contracts (Boyson et al. 1999, Olander & Norrman 2012) and the importance of 3PL contracts to managing and maintaining logistics outsourcing relationships (Andersson & Norrman 2004, Halldórsson & Skjϕtt-Larsen 2006, Hofenk et al. 2011, Huo et al. 2016, Selviaridis 2016). A few studies have examined logistics contract design empirically (Logan 2000, Forslund 2009, Selviaridis & Norrman 2015). Among the few studies on analytical 3PL contract design, Lim (2000) designed a contract to encourage 3PL providers to reveal their true logistics capability; Chen et al. (2001) and Nowicki et al. (2008) examined warehousing and inventory-related contracts; Alp (2003) and Aktas & Ulengin (2016) examined transportation contract design; and Wu and Dan (2009) and Wu et al. (2015) developed contracts that achieve channel and logistics activities coordination. A 3PL provider's IT investment is necessary in order to develop its IT capability, which, in turn, enables high-quality logistics services and adds value for logistics buyers (Bowersox & Daugherty 1995, Lewis & Talalayevsky 2000, Rai et al. 2012). However, few studies have analytically examined 3PL providers' IT investments in logistics contract design and the performance impact of such investments under different contract structures.

In order to fill these gaps in the literature, we use a game-theoretic approach to analytically examine a 3PL provider's IT investment under different contract structures, and to analyze how the 3PL provider's IT investment affects the profit of a supply chain under different contract structures. Specifically, we attempt to answer the following questions: How do alternative logistics contract structures affect a 3PL provider's IT investment? How does a 3PL provider's IT investment affect the supply chain profit under alternative logistics contract structures?

This study examines the logistics contract structures between a manufacturer and a 3PL provider by means of the following business model. The manufacturer relies on the data supplied by the 3PL provider to optimize operations and conduct data-driven decision-making. Therefore, the manufacturer signs a long-term cooperation contract with the 3PL provider, and requires that it deliver products from the manufacturer to a retailer, and that it provide the manufacturer with a series of logistics services at a contracted price. These logistics services include transportation and warehouse management; visibility in orders, shipments, and inventory; real-time data collecting and sharing; utilizing big data and analytics; among others. The 3PL provider would normally invest in IT in order to improve the quality of its logistics service and keep a long-term cooperative relationship with the manufacturer. We focus on IT investment to develop IT capability. Other factors that may affect IT capability are assumed to be relatively consistent among 3PL providers, and so are not examined here. Furthermore, the manufacturer's investment in marketing affects its demand from the retailer, and the selling price paid by the retailer to the manufacturer is contingent on the 3PL provider's delivery performance. We design and analyze four alternative contract structures for logistics outsourcing: a fixed-price contract, a contract contingent on the 3PL provider's on-time delivery rate, a profit-sharing contract, and a revenue-sharing contract.

We find that the 3PL provider's IT investment under the contingent contract is no more than that under the profit-sharing contract. However, IT investment is higher for both the contingent and the profit-sharing contract structures, in comparison with the revenue-sharing contract structure. In addition, we find that the contingent contract and the profit-sharing contract both bring a higher profit to the supply chain. In both cases, this profit is dependent on the 3PL provider's IT investment level. The supply chain profit under the fixed-price contract is the lowest of the four contract structures, because the 3PL provider has less of an incentive to invest in IT to improve its delivery performance. The study provides 3PL buyers and providers insights about the impact of contract structures on IT investment and performance.

The remainder of this paper is organized as follows. Section 2 reviews two streams of literature, namely, IT investments by 3PL providers, and 3PL contracts. Section 3 describes the model setup, and Section 4 analyzes the four contract structures for logistics outsourcing. Next, Section 5 analyzes the 3PL provider's IT investment and the supply chain profit under the four contract structures. Lastly, Section 6 concludes the paper, provides managerial implications, and discusses the direction of future work.

2 Literature Review

2.1 IT Investment by 3PL Providers

2.1.1 Antecedents of 3PL Providers' IT Investments

Many studies have examined the antecedents of 3PL providers' IT investments from the logistics service supplier and the buyer perspectives. First, 3PL providers have used IT as a key differentiator, in order to distinguish themselves from the competition (Sauvage 2003, Piplani 2004). Those 3PL firms with a stronger technology orientation invest more in hardware, software, and other IT resources (Lai et al. 2008). 3PL providers' trust in buyers' commitment motivates them to invest in customized IT solutions (Klein et al. 2007). From the 3PL service buyer's perspective, the capability of a 3PL provider in providing IT-based services is an important criterion when selecting 3PL providers (Vaidyanathan 2005; Min 2013, Evangelista et al. 2012, Qureshi et al. 2008). A high level of IT investment by 3PL providers is usually triggered by buyer-specific requests (Langley 2007, Evangelista et al. 2012). In addition, a 3PL buyer's relationship-specific investment is related the degree of IT customization by a 3PL provider (Klein et al. 2007).

2.1.2 The Impact of 3PL Providers' IT Investments on Firm Performance

Previous studies on the impact of IT investment on firm performance report inconclusive and mixed results (see Melville et al. (2004) for a comprehensive review of these studies). Using a meta-analysis, Kohli and Devaraj (2003) found that these mixed results are due to differences in studies' sample size, data source, industry context, and choice of dependent variables. Jeffers et al. (2008) summarized the empirical research that explained variant results in terms of three perspectives: a process-oriented view, a contingency approach, and a resource-based view. The process-oriented view examines the effects of IT on firm performance through intermediate business processes. The contingency approach considers other mediating variables, and organizational resources complementary to IT. The resource-based view states that IT-based resources together with other resources generate superior firm performance. Our study is closely related to a resource-based view of IT, because it focuses on motivating 3PL providers to invest in IT in order to improve their IT capability and, thus, narrow the "IT gap."

IT investment by a firm is necessary and important for the development of its IT capability and business performance. Bharadwaj (2000) classified firm-specific IT resources as IT infrastructure, human IT resources, and IT-enabled intangibles. Then, IT capability is defined as the ability to use IT-based resources, together with other resources and capabilities. The findings showed that firms with high IT capabilities tend to have superior performance. Bhatt and Grover (2005) classified IT capability into value, competitive, and dynamic capabilities, and argued that although the investments in quality IT infrastructure, which fall under value capability, may not directly contribute to differential advantage, they are competitive necessities, and lacking them may put firms at a competitive disadvantage. Huang et al. (2006) argued that a firm's IT investment could improve its IT infrastructure capability, which combines with IT-enabled intangible capabilities to achieve firm performance. Aral and Weill (2007) found that firms' IT investment allocations and their IT capabilities are related to differences in firm performance. Mithas et al. (2011) found that a firm's information management capability enables its ability to perform customer management, process management, and performance management, which, in turn, affect firm performance.

In the context of logistics outsourcing, Lai et al. (2008) found that a 3PL provider's IT investment is the antecedent of IT capability, which it creates in combination with managerial involvement, which, in turn, contributes to the firm's competitive advantage. Evangelista et al. (2012) found that the investment in IT applications is positively related to 3PL providers' performance. From a relational view, Rai et al. (2012) defined a 3PL provider's IT capability profiles as logistics automation, logistics coordination, logistics integration, and logistics synchronization. Their results showed that IT capability can affect relational value, measured as a share of wallet and loyalty.

To summarize, previous studies on 3PL providers' IT investment have investigated the antecedents and performance outcomes of such investment from different perspectives. IT investment by 3PL providers might not contribute directly to firm performance or competitive advantage, but it is necessary for the development of a firm's IT capability and business performance. In addition, most related studies are empirical studies based on survey data or firm and commercial databases (Kohli & Devaraj 2003, Jeffers et al. 2008). In logistics outsourcing, a 3PL contract offers economic and legal safeguards, and is usually used to govern and coordinate logistics activities (e.g., Selviaridis & Spring 2007, Marasco 2008, Selviaridis 2016). However, few studies have investigated the role of 3PL contracts in the antecedents and performance outcomes of 3PL providers' IT investment.

2.2 3PL Contracts

Previous studies have examined different aspects of 3PL contracts. Some have examined formal provisions in 3PL contracts. For instance, Boyson et al. (1999) studied necessary contract provisions, such as cost of services, performance metrics, and termination clauses. Olander and Norrman (2012) evaluated legal rules for a logistics contract between a 3PL provider and its customer. Many studies have empirically examined the role of contracts in logistics outsourcing governance. For example, Andersson and Norrman (2004) examined contract importance in the purchasing process of advanced logistics services. Halldrsson and Skjtt-Larsen (2006) examined contracts in terms of governing the dyadic relationships between 3PL buyers and providers. Hofenk et al. (2011) studied the effects of contractual and relational elements on the effectiveness of logistics outsourcing relationships. Recently, Huo et al. (2016) studied the relationships between relational norms, 3PL contracts, and 3PL providers' opportunism. Selviaridis (2016) examined multiple contract functions in the governance of logistics outsourcing.

The literature on logistics contract design is very limited (Marasco 2008, Wu et al. 2015). Some studies describe contract design and content, while others examine contract design using case studies or survey data. Logan (2000) illustrated how to use agency theory to design logistics outsourcing contracts that support an environment of trust and mutual satisfaction. Forslund (2009) used a case study approach to examine how contract design and content affect performance measurement processes. The results showed that logistics customer companies use different approaches in 3PL contract design, including fixed-price, fixed-price plus penalties, and fixed-price plus incentives and penalties contracts. Furthermore, these contracts all contribute to improved performance. Selviaridis and Norrman (2015) empirically examined the challenges of designing performance-based contracts (PBC) for advanced logistics services, and suggested related challenges in designing performance monitoring systems and appropriate incentives.

A few studies have examined contract design problems using analytical approaches. Lim

(2000) developed a game-theoretic model to study how a 3PL buyer designs a contract to encourage 3PL providers to reveal their true capability in logistics services. Chen et al. (2001) analyzed three forms of third-party warehousing contracts, with space commitments, from the user's perspective, and suggested cost-effective contract forms under certain demand patterns. Alp (2003) examined the transportation contract design between a manufacturer and a 3PL provider, and presented an approach to designing transportation contracts based on solving vehicle dispatching, inventory control, and contract value problems. Nowicki et al. (2008) studied spares provisioning performance-based logistics contracts, and developed a model to maximize the supplier's profit under this kind of contract. Wu and Dan (2009) found that a properly designed revenue-sharing contract could achieve channel coordination and a win–win outcome when a 3PL provider's logistics service levels do not influence customer demand. Wu et al. (2015) found that the power structure has an important effect on logistics contract design, and developed the revenue and service-cost sharing contract and the price-discount and inventory-risk sharing contract in order to coordinate logistics activities. Aktas and Ulengin (2016) proposed a penalty and reward contract to coordinate the transportation activities between a manufacturer and its logistics service provider, and found that the contract can improve both the individual firm's objective functions and the supply chain costs.

In summary, most studies on 3PL contracts are empirical works, and have examined formal provisions in 3PL contracts and the role of such contracts in logistics outsourcing governance. The literature on 3PL contract design is limited (Marasco 2008, Wu et al. 2015), with few studies having examined contract design problems using analytical approaches. Although 3PL providers' IT investment has significant implications in successful logistics outsourcing (Bowersox & Daugherty 1995, Lewis & Talalayevsky 2000, Rai et al. 2012), few studies have examined 3PL providers' IT investment problem in terms of 3PL contract design. To fill these gaps in the two streams of the literature, we analytically examine 3PL providers' IT investment, as well as how IT investment affects supply chain profit under different contract structures.

3 Model Setup

We analyze different contract structures for logistics outsourcing in a supply chain with one manufacturer and one 3PL provider. The manufacturer sells goods to a retailer, and contracts with the 3PL provider for all the logistics services between the manufacturer and the retailer. The manufacturer's demand function, D, is linearly affected by its investment in marketing, e_m, $e_m \in [0, \bar{e}]$. We assume the manufacturer's demand will increase with additional marketing investment, and that there is a baseline demand without any marketing investment. The manufacturer satisfies the demand based on cost function C. We assume the manufacturer has no limit in its production capability, so it can satisfy the demand of its retailer fully at any level. Without loss of generality, we assume that the manufacturer incurs a constant and identical production cost. However, we do not consider this cost because we focus on the manufacturer's marketing investment and logistics costs. In addition, in order to simplify the cost structure, we consider a quadratic cost function. Therefore, we can specify the manufacturer's demand and cost, as follows:

$$D(e_m) = \alpha + \beta e_m, \;\; C(e_m) = \gamma e_m^2,$$

where $\alpha \in R^+$, $\beta \in R^+$, and $\gamma \in R^+$.

The 3PL provider is an exclusive logistics service provider, which means that it only provides logistics services to this manufacturer. The revenue of the 3PL provider is related to its logistics volume. In this case, its logistics volume is equal to the demand in the manufacturer's distribution network. To improve its logistics service quality, the 3PL provider makes a specific IT investment, $I (I \in R^+)$, which includes transportation management systems, radio-frequency identification (RFID), warehouse management systems, EDI, big data and analytics, and so on.

According to the resource-based view of IT (Bharadwaj 2000, Lai et al. 2008), a 3PL provider's IT investment in quality IT infrastructure and human IT resources can develop superior IT capability together with its managerial involvement. This capability contributes to its own operational and financial performance and adds relational value for 3PL buyers (Bhatt & Grover 2005, Huang et al. 2006, Lai et al. 2008, Evangelista et al. 2012, Rai et al. 2012). In this case, we assume that other factors that affect IT capability are relatively consistent among 3PL providers, and so are not studied here. The IT capabilities enabled by the 3PL provider's IT investment improve its logistics automation, coordination, integration, and synchronization, which, in turn, enhance its logistics performance. On-time delivery rate is an important key performance indicator (KPI) regulated by a logistics contract (Gunasekaran et al. 2001, Krauth 2005, Forslund 2009). Thus, in order to provide an analytical assessment of the impact of IT investment of the 3PL provider, we use the on-time delivery rate as the KPI. Future analyses may include an aggregated factor of multiple KPIs in order to provide a broader measurement of the impact of IT.

The 3PL provider's on-time delivery rate, μ, which is the number of on-time deliveries divided by the total number of deliveries, is dependent on its specific IT investment. We assume that increasing the 3PL provider's IT investment will improve its on-time delivery performance at a decreasing rate, $\mu = \sqrt{I/a}$. The 3PL provider may have some existing IT investment to support logistics operations. However, without loss of generality, we assume this is zero. In order to simplify the 3PL provider's IT expenditure/cost structure, we specify its IT cost function, $I(\mu)$, as

$$I(\mu) = a\mu^2,$$

where $a \in R^+$ is the 3PL provider's IT investment parameter. The larger the value of a, the greater is the IT investment needed by the 3PL to achieve perfect delivery performance–100% on-time delivery. At a certain level of logistics technology, the 3PL provider's unit operation cost is constant. Thus, we assume the unit operation cost is zero, and then the total cost of the 3PL provider is $I(\mu)$. The 3PL provider's on-time delivery rate, μ, affects the price paid by the retailer to the manufacturer, which is denoted as p_m. Given the 3PL provider's on-time delivery rate, the effective selling price is μp_m.

We examine four conventional alternative contract structures for logistics outsourcing.

The contract offered to logistics service providers usually includes either a penalty or a gain–share scheme (Lim 2000). Previous studies have examined various contract structures, including fixed-price, fixed-price plus penalties, and fixed-price plus incentives and penalties contracts (Forslund 2009); performance-based contracts (PBC) (Nowicki et al. 2008, Selviaridis & Norrman 2015), revenue-sharing and service-cost-sharing contracts (Wu & Dan 2009, Wu et al. 2015); penalty and reward contracts (Aktas & Ulengin 2016); and profit-sharing contracts (Lim 2000, Giovanni 2016). We focus on the following four contract structures for logistics outsourcing: a fixed-price contract; a contingent contract, based on the 3PL provider's performance, and incorporating a penalty; a revenue-sharing contract; and a profit-sharing contract. These contract structures represent the types of contracts commonly used in logistics outsourcing.

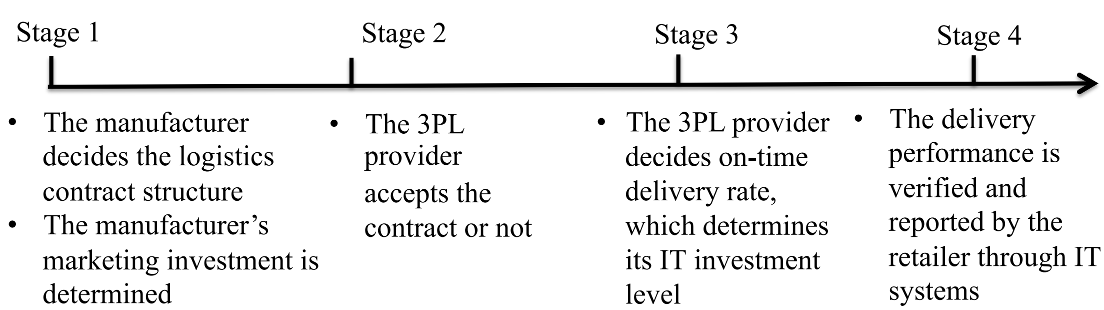
Under the fixed-price contract, the manufacturer pays the 3PL a fixed price for every unit of logistics service, p_f. Under the logistics contract contingent on the 3PL provider's on-time delivery rate, the manufacturer determines the logistics service price, p_l, and the penalty rate, b, $b \in R^+$. If the 3PL delivers on time, the manufacturer pays p_l per unit of delivery to the 3PL. If there is delivery delay, then the 3PL obtains a penalty price, $[1-b]p_l$. According to the 3PL provider's on-time delivery rate, the 3PL is paid p_l for one unit of delivery, with probability μ, and is paid $[1-b]p_l$, with probability $1-\mu$. Under the profit-sharing contract, the manufacturer shares a certain percentage of the profit with the 3PL, at rate ω. Under the revenue-sharing contract, the manufacturer pays a certain percent of its revenue to the 3PL, at rate ϕ. The manufacturer needs to decide on the profit-sharing rate and the revenue-sharing rate. Table 1 lists the variables and notation.

The events and the time line associated with logistics outsourcing contracts can be summarized as follows. In the first stage, the manufacturer sets up the logistics price scheme and determines the marketing investment. In the second stage, the 3PL provider decides whether to accept the logistics contract. In the third stage, the 3PL provider estimates its on-time delivery rate, which determines its IT investment. Lastly, the delivery is realized

Table 1. The Parameters and Notations

Parameter	Notation
D	The manufacturer's demand
C	The manufacturer's cost
e_m	The manufacturer's investment in marketing
α	The manufacturer's demand without marketing investment
β	The rate of change of the manufacture's demand with respect to its marketing investment
γ	The rate of change of the effect of the manufacturer's marketing investment on its cost with respect to its marketing investment
a	The 3PL provider's IT investment parameter, which is the IT investment needed by the 3PL provider to achieve 100% on-time delivery
I	The 3PL provider's IT investment
μ	The 3PL provider's on-time delivery rate
p_m	The negotiated selling price between the manufacturer and the retailer
b	The penalty rate applied for late delivery
p_l	The logistics service price per unit of delivery when the 3PL provider delivers on time under the contingent contract structure
p_f	The logistics service price per unit of delivery paid by the manufacturer to the 3PL provider under the fixed contract structure
ω	The profit sharing rate provided by the manufacturer to the 3PL provider under the profit sharing contract structure
ϕ	The revenue sharing rate provided by the manufacturer to the 3PL provider under the revenue sharing contract structure

Figure 1. The Time Line of the Model



and the delivery performance of the 3PL provider is verified and reported by the retailer through inter-organizational systems. The timing of the model is shown in Figure 1.

4 Four Alternative Contract Structures for Logistics Outsourcing

4.1 Fixed-Price Contract

Under the fixed price contract, the 3PL provider obtains a fixed payment per unit of logistics service, regardless of whether the 3PL provider delivers on time. However, if it chooses to deliver on time, incurring a certain level of IT investment cost, it will obtain less profit than when it does not deliver on time. By the rationality rule, the 3PL provider prefers not to invest in IT to increase its on-time delivery rate, in order to reduce costs. Therefore, when its on-time delivery rate is zero, $\hat{\mu} = 0$ and, thus, its logistics costs are zero, $I(\hat{\mu}) = 0$, and its profit is maximized.

The profit maximization for the manufacturer is given by

$$\max_{p_f, e_m} \Pi_m(p_f, e_m) = \mu p_m D(e_m) - C(e_m) - p_f D(e_m), \tag{1}$$

$$s.t \;\; p_f D(e_m) - I(\mu) \geq 0.$$

The individual rationality condition for the manufacturer is binding, for which we obtain

$$p_f D(e_m) - I(\mu) = 0. \tag{2}$$

Because $I(\hat{\mu}) = 0$ and $D(e_m) > 0$, we have $\hat{p}_f = 0$, from (2). Substituting $D(e_m) = \alpha + \beta e_m, C(e_m) = \gamma e_m^2$ into (1), the manufacturer's problem is simplified as follows:

$$\max_{e_m} \Pi_m(e_m) = \mu p_m[\alpha + \beta e_m] - \gamma e_m^2.$$

The necessary first-order condition for profit maximization is

$$\frac{\partial \Pi_m(e_m)}{\partial e_m} = \beta \mu p_m - 2\gamma e_m = 0.$$

Because $\hat{\mu} = 0$, we obtain $\hat{e}_m = 0$, which means that the manufacturer chooses not to invest in marketing.

Intuitively, under the fixed-price contract, the 3PL provider has no incentive to invest in special IT assets to improve on-time delivery rate, because even if it does not deliver on time, it still receives a fixed revenue. However, the on-time delivery rate is zero in this case, causing the selling price paid to the manufacturer by the retailer to be zero as well. This implies that the manufacturer has no revenue, even when there is demand from the retailer, in which case the manufacturer has no incentive to invest in marketing.

4.2 Contingent-Price Contract

Under the contingent contract, the time line of the model is the same as that under the fixed-price contract. However, in the first stage, the manufacturer needs to decide on a logistics price p_l and a penalty rate b.

Lemma 1 *Under the contingent contract for logistics outsourcing (p_l, b), the manufacturer's investment in marketing e_m and the 3PL provider's on-time delivery rate μ constitute a Nash equilibrium. Here, p_l, b, e_m, and μ are given by $p_l = \frac{4ap_m - p_m^2\tilde{D}}{4a}$, $b = \frac{4a}{4a - p_m\tilde{D}}$, $e_m = \frac{\alpha\beta p_m^2}{4a\gamma - \beta^2 p_m^2}$, and $\mu = \frac{p_m\tilde{D}}{2a}$, where $\tilde{D} = \alpha + \frac{\alpha\beta^2 p_m^2}{4a\gamma - \beta^2 p_m^2}$. The 3PL provider has an incentive to invest an amount of $\frac{(p_m\tilde{D})^2}{4a}$* in IT.

Proof: Using backward induction, we begin with the third stage. The profit maximization of the 3PL provider is

$$\max_{\mu} \Pi_l(\mu) = p_l\mu D(e_m) + [1 - b]p_l[1 - \mu]D(e_m) - I(\mu).$$

The first condition for profit maximization when choosing an on-time delivery rate is

$$\frac{\partial \Pi_l(\mu)}{\partial \mu} = p_l D(e_m) - [1 - b]p_l D(e_m) - 2a\mu = 0. \tag{3}$$

Solving (3), we obtain $\tilde{\mu}$. Substituting $\tilde{\mu}$ into $I(\mu) = a\mu^2$, we obtain $I(\tilde{\mu})$, where

$$\tilde{\mu} = \frac{bp_l D(e_m)}{2a}, \quad I(\tilde{\mu}) = \frac{(bp_l D(e_m))^2}{4a}. \tag{4}$$

In the second stage, the 3PL provider decides whether to accept the contract. If it accepts the contract, then

$$p_l\mu D(e_m) + [1-b]p_l[1-\mu]D(e_m) - I(\mu) \geq 0.$$

The individual rationality of the manufacturer is binding. Therefore, we have

$$p_l\mu D(e_m) + [1-b]p_l[1-\mu]D(e_m) - I(\mu) = 0. \tag{5}$$

Thus, the manufacturer's problem is simplified as

$$\begin{aligned}\max_{p_l,b,e_m} \Pi_m(p_l,b,e_m) &= \mu p_m D(e_m) - C(e_m) - I(\mu) \\ &= \mu p_m[\alpha+\beta e_m] - \gamma e_m^2 - a\mu^2.\end{aligned} \tag{6}$$

After substituting (4) into (6), the necessary first-order condition that maximizes the profit of the manufacturer is

$$\frac{\partial \Pi_m(p_l,b,e_m)}{\partial e_m} = \frac{bp_lp_m}{a}[\alpha+\beta e_m]\beta - 2\gamma e_m - \frac{b^2p_l^2}{2a}[\alpha+\beta e_m]\beta = 0, \tag{7}$$

$$\frac{\partial \Pi_m(p_l,b,e_m)}{\partial p_l} = \frac{bp_mD(e_m)^2}{2a} - \frac{b^2D(e_m)^2p_l}{2a} = 0, \tag{8}$$

$$\frac{\partial \Pi_m(p_l,b,e_m)}{\partial b} = \frac{p_lp_mD(e_m)^2}{2a} - \frac{bp_l^2D(e_m)^2}{2a} = 0. \tag{9}$$

From (8) and (9), we obtain $bp_l = p_m$. Substituting p_m for bp_l in (7), we obtain

$$\tilde{e}_m = \frac{\alpha\beta p_m^2}{4a\gamma - \beta^2p_m^2}.$$

Substituting (4) and $bp_l = p_m$ into (5), we obtain

$$\tilde{p}_l = \frac{4ap_m - p_m^2\tilde{D}}{4a}, \tilde{b} = \frac{4a}{4a - p_m\tilde{D}},$$

where $\tilde{D} = \alpha + \frac{\alpha\beta^2p_m^2}{4a\gamma-\beta^2p_m^2}$, and then obtain $\tilde{\mu} = \frac{p_m\tilde{D}}{2a}$ and $I(\tilde{\mu}) = \frac{(p_m\tilde{D})^2}{4a}$. □

Lemma 2 *Under the contingent contract structure, the 3PL provider's IT investment and on-time delivery rate increase with an increase in the unit logistics service price and penalty rate.*

Proof: In order to understand how the contingent contract affects the 3PL provider's delivery performance and IT investment, we take the first derivative of (4) with respect to b and p_l, respectively. The results are all positive in the following. This suggests that increases in the penalty rate b and the unit logistics service price p_l can make the 3PL provider increase its IT investment and improve the on-time delivery rate:

$$\frac{d\tilde{\mu}}{db} = \frac{p_l D(e_m)}{2a} > 0 \quad \text{and} \quad \frac{d\tilde{\mu}}{dp_l} = \frac{bD(e_m)}{2a} > 0$$

$$\frac{dI}{db} = \frac{bp_l^2 D(e_m)^2}{2a} > 0 \quad \text{and} \quad \frac{dI}{dp_l} = \frac{p_l b^2 D(e_m)^2}{2a} > 0.$$

□

In the model setup, the selling price paid by the retailer to the manufacturer is affected by the 3PL provider's logistics performance. Therefore, the manufacturer needs to control the logistics performance in order to maintain a level of revenue. The contingent price contract is a good choice for the manufacturer to restrain the 3PL provider's behavior. The logistics price obtained by the 3PL provider is dependent on its performance. If the 3PL provider delivers on time, the manufacturer can obtain a normal selling price p_m, in which case it pays the 3PL provider the normal logistics price p_l. When 3PL provider does not deliver on time, the manufacturer imposes a penalty. Thus, the manufacturer can use the contingent contract parameters to motivate the 3PL provider to invest more in IT and, thus, improve its on-time delivery performance, by increasing the unit logistics service price and penalty rate. In addition, the contingent price contract provides an important incentive for the 3PL provider to fulfill its liabilities and responsibilities.

4.3 Profit-Sharing Contract

Under the profit sharing contract, the manufacturer decides the profit sharing rate and the marketing investment in the first stage. The stages are the same as before.

Lemma 3 *Under the profit-sharing contract for logistics outsourcing, the manufacturer and the 3PL provider share the profit equally. The 3PL provider's on-time delivery rate is 100%, and the 3PL provider has the greatest incentive to invest in IT, at an amount of a.*

Proof: Solving backwards, the profit maximization of the 3PL provider is

$$\max_{\mu} \Pi_l(\mu) = \omega[\mu p_m D(e_m) - C(e_m)] - I(\mu) = \omega[\mu p_m D(e_m) - \gamma e_m^2] - a\mu^2.$$

The first-order condition for profit maximization when choosing the on-time delivery rate is

$$\frac{\partial \Pi_l(\mu)}{\partial \mu} = \omega p_m D(e_m) - 2a\mu = 0. \tag{10}$$

Solving (10), we obtain

$$\bar{\mu} = \frac{\omega p_m D(e_m)}{2a}, \;\; \textit{and then} \;\; I(\bar{\mu}) = \frac{(\omega p_m D(e_m))^2}{4a}.$$

In the second stage, the 3PL provider chooses whether to accept the contract. If agreeing to the contract,

$$\omega[\mu p_m D(e_m) - C(e_m)] - I(\mu) \geq 0.$$

The individual rationality of the manufacturer is binding. Therefore, we have

$$\omega[\mu p_m D(e_m) - C(e_m)] - I(\mu) = 0.$$

Then, the manufacturer's problem is simplified to

$$\begin{aligned} \max_{\omega, e_m} \Pi_m(\omega, e_m) &= [1-\omega][\mu p_m D(e_m) - C(e_m)] \\ &= \frac{[1-\omega]}{\omega} I(\mu) = \frac{[1-\omega][\omega p_m D(e_m)]^2}{4\omega a} \\ &= \frac{\omega[1-\omega]p_m^2}{4a}[\alpha + \beta e_m]^2. \end{aligned}$$

The necessary first-order condition to maximize the manufacturer's profit is

$$\frac{\partial \Pi_m(\omega, e_m)}{\partial \omega} = \frac{p_m^2 D(e_m)^2}{4a}[1 - 2\omega] = 0, \tag{11}$$

$$\frac{\partial \Pi_m(\omega, e_m)}{\partial e_m} = \frac{\omega[1-\omega]\beta p_m^2}{2a}[\alpha + \beta e_m] = 0. \tag{12}$$

From (11) we obtain $\bar{\omega} = 1/2$. Substituting $\bar{\omega} = 1/2$ into (12), we obtain

$$\frac{\partial \Pi_m(\omega, e_m)}{\partial e_m} = \frac{\beta p_m^2}{8a}[\alpha + \beta e_m] > 0, \tag{13}$$

where $\alpha > 0$ and $\beta > 0$. Therefore, we cannot obtain the interior solution for e_m from (13). However, there is a corner solution for e_m. When $\bar{\mu} = 1$, the manufacturer can obtain a maximum profit. Therefore, let

$$\bar{\mu} = \frac{\bar{\omega} p_m D(e_m)}{2a} = \frac{p_m[\alpha + \beta e_m]}{4a} = 1. \tag{14}$$

We obtain the optimal e_m from (14),

$$\bar{e}_m = \frac{4a - \alpha p_m}{\beta p_m}.$$

The profit-sharing rate ω, the manufacturer's marketing investment e_m, and the 3PL provider's on-time delivery rate μ constitute a Nash equilibrium, where ω, e_m, μ and $I(\mu)$ are given by $\omega = 1/2, e_m = \frac{4a-\alpha p_m}{\beta p_m}$, $\mu = 1$, and $I(\mu) = a$. $\square$

Under the profit-sharing contract, the manufacturer and the 3PL provider make up a profit community. They share the profit equally, which motivates the 3PL provider to invest in IT to improve its logistics service. However, this requires that the manufacturer and the 3PL provider share information at a high level, and the 3PL provider needs to know the profit of the manufacturer.

4.4 Revenue-Sharing Contract

Under the revenue-sharing contract, the manufacturer and the 3PL provider share revenue in the supply chain according to a revenue-sharing rate. The events and the time line are similar to those under the other contracts.

Lemma 4 *Under the revenue-sharing contract for logistics outsourcing, the revenue-sharing rate ϕ, the manufacturer's investment in marketing e_m, and the 3PL provider's on-time delivery rate μ constitute a Nash equilibrium, where ϕ, e_m, and μ are given by $\phi = 1/2, e_m =$*

$\frac{\alpha\beta p_m^2}{16a\gamma-\beta^2 p_m^2}$, *and* $\mu = \frac{p_m}{4a}(\alpha + \frac{\alpha\beta^2 p_m^2}{16a\gamma-\beta^2 p_m^2})$. *The IT investment by the 3PL provider under the revenue-sharing contract is no more than the amount of* a.

Proof: Again, we work backwards. The profit maximization of the 3PL provider is

$$\max_{\mu} \Pi_l(\mu) = \phi[\mu p_m D(e_m)] - I(\mu) = \phi\mu p_m D(e_m) - a\mu^2.$$

The first-order condition for profit maximization after choosing an on-time delivery rate is

$$\frac{\partial \Pi_l(\mu)}{\partial \mu} = \phi p_m D(e_m) - 2a\mu = 0. \tag{15}$$

Solving (15), we obtain

$$\check{\mu} = \frac{\phi p_m D(e_m)}{2a}, \ \ \textit{and then} \ \ I(\check{\mu}) = \frac{(\phi p_m D(e_m))^2}{4a}.$$

In the second stage, the 3PL provider chooses whether to accept the contract. If it does so,

$$\phi\mu p_m D(e_m) - I(\mu) \geq 0.$$

The individual rationality of the manufacturer is binding. Therefore, we have

$$\phi\mu p_m D(e_m) - I(\mu) = 0.$$

Then, the manufacturer's problem is simplified to

$$\begin{aligned}\max_{\phi, e_m} \Pi_m(\phi, e_m) &= [1-\phi]\mu p_m D(e_m) - C(e_m) \\ &= \frac{\phi[1-\phi]p_m^2}{4a}[\alpha + \beta e_m]^2 - \gamma e_m^2.\end{aligned}$$

The necessary first-order condition to maximize the manufacturer's profit is

$$\frac{\partial \Pi_m(\phi, e_m)}{\partial \phi} = \frac{p_m^2 D(e_m)^2}{4a}[1-2\phi] = 0, \tag{16}$$

$$\frac{\partial \Pi_m(\phi, e_m)}{\partial e_m} = \frac{\phi[1-\phi]\beta p_m^2}{2a}[\alpha + \beta e_m] - 2\gamma e_m = 0. \tag{17}$$

From (16), we obtain $\check{\phi} = 1/2$. Substituting $\check{\phi} = 1/2$ into (17), we obtain

$$\frac{\partial \Pi_m(\phi, e_m)}{\partial e_m} = \frac{\beta p_m^2}{8a}[\alpha + \beta e_m] - 2\gamma e_m = 0.$$

Then, we can obtain the optimal $\check{e}_m$,

$$\check{e}_m = \frac{\alpha\beta p_m^2}{16a\gamma - \beta^2 p_m^2}.$$

Substituting $\check{e}_m$ into $\check{\mu} = \frac{\phi p_m D(e_m)}{2a}$, we obtain

$$\check{\mu} = \frac{p_m}{4a}[\alpha + \frac{\alpha\beta^2 p_m^2}{16a\gamma - \beta^2 p_m^2}].$$

Because $\check{\mu} \le 1$, we have $I(\check{\mu}) \le a$. Therefore, the 3PL provider's optimal IT investment under the revenue-sharing contract is no more than the amount of a. □

Under the revenue-sharing contract, the optimal revenue-sharing rate is 1/2, which is the same as the optimal profit-sharing rate under the profit-sharing contract. The optimal on-time delivery rate under the revenue-sharing contract is no more than that under the profit-sharing contract. Thus, the 3PL provider's IT investment under the revenue-sharing contract is no more than that under profit-sharing contract. In addition, the 3PL provider does not need to know the marketing investment of the manufacturer.

5 Analysis of the 3PL Provider's IT Investment and Supply Chain Profit

5.1 The 3PL Provider's IT Investment Analysis

Proposition 1 *The 3PL provider's on-time delivery rate and related IT investment are higher under the contingent contract and profit-sharing contract structures than under the revenue-sharing contract structure, and, under the contingent contract, is no more than that under the profit-sharing contract.*

According to Lemmas 1, 3, and 4, the on-time delivery rate under the contingent, profit-sharing, and revenue-sharing contract structures are μ_c, μ_p, and μ_r, respectively, where

$$\mu_c = \frac{p_m}{2a}[\alpha + \frac{\alpha\beta^2 p_m^2}{4a\gamma - \beta^2 p_m^2}], \quad \mu_p = 1, \quad \mu_r = \frac{p_m}{4a}[\alpha + \frac{\alpha\beta^2 p_m^2}{16a\gamma - \beta^2 p_m^2}].$$

Because $2a < 4a$ and $4a\gamma - \beta^2 p_m^2 < 16a\gamma - \beta^2 p_m^2$, we obtain $\mu_c > \mu_r$. With $\mu_p = 1$, we have $\mu_p \ge \mu_c > \mu_r$. Because $I(\mu) = a\mu^2$, we obtain $I(\mu_p) \ge I(\mu_c) > I(\mu_r)$. □

Under the profit-sharing contract, the 3PL provider and the manufacturer form a profit community, and share the profit according to the revenue-sharing rate. In this case, the 3PL provider has the most incentive to invest in IT to improve its delivery performance and, thus, the on-time delivery rate is 100%. Under the contingent-price contract, the logistics price is contingent on its delivery performance. This type of performance-based contract structure motivates the 3PL provider to improve its on-time delivery rate by investing in IT. Here, its IT investment and on-time delivery rate are no more than those under the profit-sharing contract. Under the revenue-sharing contract, the 3PL provider's on-time delivery rate and IT investment are lowest. This might be because of the profit maximization and cost minimum objectives, which make it reduce its IT investment to achieve a certain level of profit.

5.2 The Supply Chain Profit Analysis

A supply chain consists of two or more individual organizations, linked by material, information, and financial flows (Stadtler 2015). Outsourcing logistics changes the structure of a supply chain (Lambert 2000), and the logistics service provider becomes one of the primary members of the supply chain (Lambert 2000, Mejza 2001). In our study, we focus on a simple two-tier supply chain, composed of a manufacturer and a 3PL provider. We analyze the profit of a short supply chain for the following reasons. First, we focus on how the contract structures between the 3PL provider and the manufacturer affect the 3PL provider's IT investment. Thus, we analyze the performance impact of the 3PL provider's IT investment on the logistics service buyer and the provider in the contract. Second, in the game-theoretic framework, the 3PL provider and the manufacturer are the decision-makers. Thus, it is reasonable to determine how their decision-making affects their total payoff. Third, although the retailer is part of the extended supply chain and the 3PL provider's delivery performance affects its sales, we do not set its cost structure owing to our research focus and scope. Therefore, we do not analyze its profit.

We compare the profit of the supply chain, composed of the profit earned by the manufacturer (Π_m) and the 3PL provider (Π_l), under the four contract structures for logistics outsourcing. Under the fixed-price contract, the supply chain profit SW_f is

$$\begin{aligned}SW_f = \Pi_m + \Pi_l &= \hat{\mu} p_m D(\hat{e}_m) - C(\hat{e}_m) - I(\hat{\mu}) \\ &= \hat{\mu} p_m[\alpha + \beta \hat{e}_m] - \gamma \hat{e}_m^2 - 0 \\ &= 0.\end{aligned}$$

Because $\hat{\mu} = 0$, $I(\hat{\mu}) = 0$, and $\hat{e}_m = 0$ under the fixed-price contract, the profit of the supply chain is zero.

According to the proof of Lemma 1, $\tilde{e}_m = \frac{\alpha\beta p_m^2}{4a\gamma - \beta^2 p_m^2}$, and $\tilde{\mu} = \frac{p_m D(\tilde{e}_m)}{2a}$. The total supply chain profit in the contingent contract SW_c is

$$\begin{aligned}SW_c = \Pi_m + \Pi_l &= \tilde{\mu} p_m D(\tilde{e}_m) - C(\tilde{e}_m) - I(\tilde{\mu}) \\ &= \frac{p_m^2}{2a} D(\tilde{e}_m)^2 - \gamma \tilde{e}_m^2 - \frac{p_m^2}{4a} D(\tilde{e}_m)^2 \\ &= \frac{p_m^2}{4a}[\alpha + \frac{\alpha\beta^2 p_m^2}{4a\gamma - \beta^2 p_m^2}]^2 - \gamma[\frac{\alpha\beta p_m^2}{4a\gamma - \beta^2 p_m^2}]^2 \\ &= \frac{\gamma\alpha^2 p_m^2}{4a\gamma - \beta^2 p_m^2}.\end{aligned}$$

According to the proof of Lemma 3, under the profit-sharing logistics contract, $\bar{\omega} = 1/2$, and the manufacturer's profit is maximized when $\bar{\mu} = 1$. Thus, the supply chain profit SW_p is

$$\begin{aligned}SW_p = \Pi_m + \Pi_l &= [1 - \bar{\omega}][\mu p_m D(\bar{e}_m) - C(\bar{e}_m)] \\ &= \frac{[1 - \bar{\omega}]}{\bar{\omega}} I(\bar{\mu}) = a\bar{\mu}^2 \\ &= a.\end{aligned}$$

We have $\breve{\mu} = \frac{\phi p_m D(e_m)}{2a}$, and $\breve{e}_m = \frac{\alpha\beta p_m^2}{16a\gamma - \beta^2 p_m^2}$, based on the proof of Lemma 4. Under the revenue-sharing logistics contract, the supply chain profit SW_r is

$$\begin{aligned} SW_r &= \Pi_m + \Pi_l = [1-\check{\phi}][\mu p_m D(\check{e}_m) - C(\check{e}_m)] \\ &= \frac{\check{\phi}[1-\check{\phi}]p_m^2}{4a}[\alpha + \beta\check{e}_m]^2 - \gamma\check{e}_m^2 \\ &= \frac{p_m^2}{16a}[\alpha + \beta\frac{\alpha\beta p_m^2}{16a\gamma - \beta^2 p_m^2}]^2 - \gamma[\frac{\alpha\beta p_m^2}{16a\gamma - \beta^2 p_m^2}]^2 \\ &= \frac{\gamma\alpha^2 p_m^2}{16a\gamma - \beta^2 p_m^2}. \end{aligned}$$

Proposition 2 *The supply chain profits under the contingent contract, profit-sharing contract, and revenue-sharing contract are higher than that under the fixed-price contract because they motivate the 3PL to invest in IT to improve its delivery performance.*

Proof: The supply chain profit under the fixed-price contract is zero, while

$$SW_c > 0, \ \ SW_p > 0, \ \ and\ SW_r > 0,$$

from Lemmas 1, 3, and 4. In addition, the 3PL has a certain level of incentive to invest in IT to improve the on-time delivery rate, from Proposition 1. However, the fixed contract structure cannot motivate the 3PL to invest in specific IT to improve delivery performance, which results in a poor supply chain profit.□

In our model setup, the 3PL provider's on-time delivery rate has an important effect on the retailer, so the retailer pays the manufacturer based on the delivery performance. Under the fixed-price contract, although the delivery performance is important for the manufacturer, the fixed-price scheme cannot motivate the 3PL to invest in IT initiatives in order to improve its logistics performance, resulting in a poor supply chain profit. However, under the other three contracts, the 3PL has to invest in IT to improve its performance in order to obtain a certain profit. Therefore, the supply chain profits under these three contracts are all higher than that under the fixed-price contract.

Proposition 3 *Both the contingent contract and profit-sharing contract earn a higher profit for the supply chain than that of the revenue-sharing contract. The supply chain profits under* *the contingent contract and profit-sharing contract are dependent on the 3PL provider's IT investment.*

Proof: We know that SW_c and SW_r have the same numerators, but the denominator of SW_c, $4a\gamma - \beta^2 p_m^2$, is less than the denominator of SW_r, $16a\gamma - \beta^2 p_m^2$. Therefore, $SW_c > SW_r$.

When comparing the supply chain profits under the contingent contract and the profit-sharing contract, we let $f(a)$ be a function defined as

$$f(a) = SW_p - SW_c = a - \frac{\gamma\alpha^2 p_m^2}{4a\gamma - \beta^2 p_m^2},$$

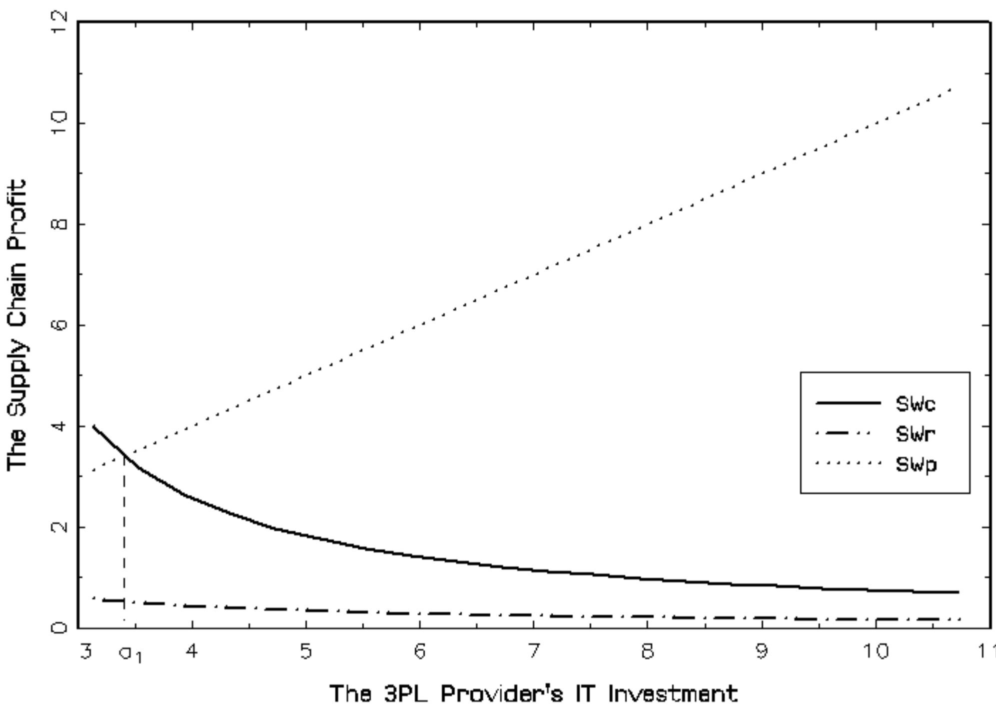
where $4a\gamma - \beta^2 p_m^2 > 0$. When $SW_p - SW_c = 0$, we have

$$\bar{f}(a) = 4\gamma a^2 - \beta^2 p_m^2 a - \gamma\alpha^2 p_m^2 = 0. \tag{18}$$

Solving (18), we obtain one solution for a satisfying $4a\gamma - \beta^2 p_m^2 > 0$, which is $a_1 = \frac{\beta^2 p_m^2 + \sqrt{\beta^4 p_m^4 + 16\gamma^2\alpha^2 p_m^2}}{8\gamma}$. Similarly, when $\bar{f}(a) > 0$, $SW_p > SW_c$, and we have $a > a_1$; when $\bar{f}(a) < 0$, $SW_p < SW_c$, we have $\frac{\beta^2 p_m^2}{4\gamma} < a < a_1$. Since $SW_c > SW_r$, when $4a\gamma - \beta^2 p_m^2 > 0$ is satisfied, we can conclude that when $a > a_1$, $SW_p > SW_c > SW_r$. When $\frac{\beta^2 p_m^2}{4\gamma} < a < a_1$, $SW_c > SW_p > SW_r$. This suggests that the supply chain profits under the profit-sharing contract and the contingent contract are dependent on the 3PL provider's IT investment. □

The supply chain profit under the contingent contract is higher than that under the revenue-sharing contract for two important reasons. First, because the 3PL is willing to invest more in IT, its on-time delivery rate is higher under the contingent contract than it is under the revenue contract. Therefore, the selling price paid to the manufacturer is higher, and the manufacturer obtains more revenue and more profit, holding its demand constant. Second, the manufacturer's marketing investment under the contingent contract is higher than that under the revenue-sharing contract, $\frac{\alpha\beta p_m^2}{4a\gamma - \beta^2 p_m^2} > \frac{\alpha\beta p_m^2}{16a\gamma - \beta^2 p_m^2}$. Thus, the manufacturer has higher demand for its products from retailers under the contingent contract, and can obtain greater revenue and profit, holding the on-time delivery rate constant. Therefore, the supply chain profit under the contingent contract is higher than that under the revenue-sharing contract.

Figure 2. The Supply Chain Profit and the 3PL Provider's IT Investment



In Figure 2, we show the effect of a 3PL provider's IT investment on the supply chain profit under the contingent, profit-sharing, and revenue-sharing logistics contracts. When the on-time delivery rate μ reaches the optimal level, the IT investment by the 3PL is determined by its IT investment parameter a, which also influences the supply chain profit. Among these three situations, the optimal on-time delivery rate and corresponding IT investment are lowest under the revenue-sharing contract, which makes the supply chain profit the lowest. Additionally, under the contingent contract and the revenue-sharing logistics contract, the first and second derivatives of the supply chain profit with respect to the IT investment parameter a are negative, as shown in the following. This implies that supply chain profit decreases at a decreasing rate with increases in a 3PL provider's IT investment under these two situations, as represented in Figure 2.

$$\frac{dSW_c}{da} = -\frac{4\gamma^2\alpha^2p_m^2}{[4a\gamma - \beta^2p_m^2]^2} < 0 \quad \text{and} \quad \frac{d^2SW_c}{da^2} = -\frac{8\gamma^2\alpha^2p_m^2}{[4a\gamma - \beta^2p_m^2]^2} < 0$$

$$\frac{dSW_r}{da} = -\frac{16\gamma^2\alpha^2p_m^2}{[16a\gamma - \beta^2p_m^2]^2} < 0 \quad \text{and} \quad \frac{d^2SW_r}{da^2} = -\frac{32\gamma^2\alpha^2p_m^2}{[16a\gamma - \beta^2p_m^2]^2} < 0.$$

The supply chain profit under the contingent contract and the profit-sharing contract are dependent on the level of the 3PL provider's IT investment. Under the profit-sharing logistics contract, the supply chain profit and the 3PL provider's IT investment have a linear relationship, in which the supply chain profit increases with increases in IT investment and $\frac{dSW_p}{da} = 1 > 0$. When $a > a_1$,the profit-sharing contract motivates the 3PL to invest more in IT and, thus, earns higher optimal on-time delivery rate, and also generates higher profit for the supply chain. When $\frac{\beta^2 p_m^2}{4\gamma} < a < a_1$, the supply chain profit under the contingent contract dominates the other. Therefore, there is no one logistics outsourcing contract structure that dominates at all levels of IT investment by the 3PL provider in terms of optimizing the supply chain profit. However, the contingent contract and profit-sharing contract can generate a higher profit for the supply chain than the revenue-sharing contract can.

6 Conclusion

A 3PL provider's investments in its IT infrastructure and human IT resources are critical and necessary for developing superior IT capabilities, which, in turn, contributes to its competitive advantage in the logistics industry. In this study, we analyze the 3PL provider's IT investment and the supply chain profit under four alternative contract structures for logistics outsourcing. We found that the 3PL provider's IT investment is higher under the contingent contract and profit-sharing contract structures than under the revenue-sharing and fixed-price contract structures, and its IT investment under the contingent contract is no more than that under the profit-sharing contract.

In addition, we found that both the contingent contract and profit-sharing contract generate a higher profit for the supply chain than the other two contract structures can. In addition, the supply chain profits under the contingent and profit-sharing contracts are dependent on the 3PL provider's IT investment. The supply chain profits under the contingent, profit-sharing, and revenue-sharing contracts are higher than that under the fixed-price contract because they motivate the 3PL provider to invest more in IT to improve its delivery performance.

6.1 Theoretical Contributions

This study has three important contributions. First, it adds to the literature on the antecedents of 3PL providers' IT investments. Previous studies have investigated the antecedents of IT investments by 3PL providers from the provider and user perspectives. 3PL firms that have a strong technology orientation, trust in the buyers' commitment to a logistics relationship, and intend differentiating themselves from the competition may invest more in IT. In addition, the IT investment of 3PL providers can be triggered by buyer-specific requests, their 3PL selection criteria, and their commitment to relationship-specific investment, and so on. From a different perspective, we focus on the logistics contract, which is an important mechanism for coordinating the relationship between 3PL providers and buyers, and examine the IT investment of a 3PL provider under the different contract structures. The findings suggest that the IT investment of the 3PL provider may be relatively higher under the contingent contract and profit-sharing contract, as compared with the other two contract structures.

Second, our study contributes to the resource-based view of the impact of IT investment on firm performance. Most related studies are empirical works, and suggest that IT investment is necessary for developing a firm's IT capability, in combination with its managerial involvement and other resources and capabilities, and that IT capability can contribute to firm performance. In contrast to previous studies, we analytically examine how the IT investment of a supply chain member affects supply chain performance. Specifically, with different levels of IT investment by a 3PL provider, the total profit of the supply chain can be optimized by applying different logistics contract structures. For example, when the 3PL provider's IT investment is at a relatively lower level, the optimal supply chain profit is achieved under the contingent contract structure. However, when the 3PL provider's IT investment is at a relatively higher level, the optimal supply chain profit is achieved under the profit-sharing contract. There is no one best contract structure that can support optimal supply chain profits at all levels of the 3PL provider's IT investment.

Thirdly, this study contributes to the limited body of literature on logistics contract design, using analytical approaches. A few studies have examined logistics contract design problems analytically, including the truth-telling problem in logistics outsourcing, warehousing contracts, transportation contracts, spares provisioning, channel coordination, and power structures. Our study uses a game-theoretic approach to examine the IT investment of a 3PL provider under four conventional contract structures for logistics outsourcing. The findings suggest that the 3PL provider's IT investment is relatively higher under the contingent contract and the profit-sharing contract structures than it is under the revenue-sharing contract and fixed-price contract structures. Furthermore, its IT investment under the contingent contract is no more than that under the profit-sharing contract.

6.2 Managerial Implications

Our study has several important managerial implications. First, 3PL buyer managers can use different logistics contract structures in different situations to motivate 3PL providers to invest in IT. 3PL buyer managers usually use logistics contracts to regulate 3PL providers' services and activities, service levels, performance measurement, allocation of roles and responsibilities, and so on. To encourage a 3PL provider to invest more in specific IT resources, 3PL buyer managers can use a contingent contract or a profit-sharing contract. The contingent contract is a type of performance-based contract and incorporates penalty clauses for service failures. When buyer managers prefer a performance-based contract, they can choose to use the contingent contract structure to stimulate 3PL providers' IT investment. If both parties would like to share strategic information with regard to logistics revenue and cost structure, 3PL buyer managers may apply a profit-sharing contract to motivate the 3PL provider's IT investments.

Second, the findings provide 3PL provider managers with a better understanding of the impact of the contract structures on IT investment and performance. 3PL provider managers have a greater incentive to invest in quality IT resources under the contingent contract and profit-sharing contract structures than they do under the other contract structures. They can take advantage of the cooperation with 3PL shippers under these types of contract structures to develop superior IT capabilities. By investing in quality IT infrastructure and IT-human resources, and strengthening their managerial involvement in IT, they can improve their IT capabilities. Consequently, the "IT gap" can be reduced. With superior IT capabilities, 3PL providers can achieve competitive advantages in terms of logistics costs, service variety, and quality, and add value for 3PL buyers. In addition, from a supply chain perspective, 3PL provider managers can adjust their IT investment according to the given contract structure in order to achieve optimal supply chain benefits.

6.3 Limitations and Further Research Directions

There are limitations in our work. We consider a relatively condensed model setup, and the model is stylized in order to isolate the mechanisms at work. The limitations and future opportunities are as follows. First, consider more realistic and complicated cost structures, especially when the demand of the manufacturer, which is equal to the delivery volume of the 3PL provider, has affects the unit cost of the 3PL provider. We will capture this point in future work by constructing a more realistic cost structure for the 3PL provider. Second, analyze different demand functions. We built a linear demand function, with a constant and the manufacturer's investment in marketing as variables. In general, demand is also affected by the manufacturer's selling price. This point will be considered in future work. Third, use the manufacturer's selling price as a decision variable, which we do not do here. However, except for the logistics decisions, the manufacturer can choose the selling price to optimize its profit. Using the manufacturer's selling price as a decision variable will make our model more realistic. Fourth, consider different timing lines. We consider four alternative contract structures for logistics outsourcing, all using the same time line. If the time line changes, there might be different conclusions. For example, outcomes may be quite different if the decision on investment by the manufacturer is made in the first stage of the current model setup, as opposed to between the second stage and the third stage, after the 3PL provider accepts the contract and before its investment. Fifth, improve the measurement of the impact of IT investment by using other KPIs, instead of on-time delivery rate only. This can be represented as multiple factors or as a single aggregated factor.

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Figure 1. The Time Line of the Model

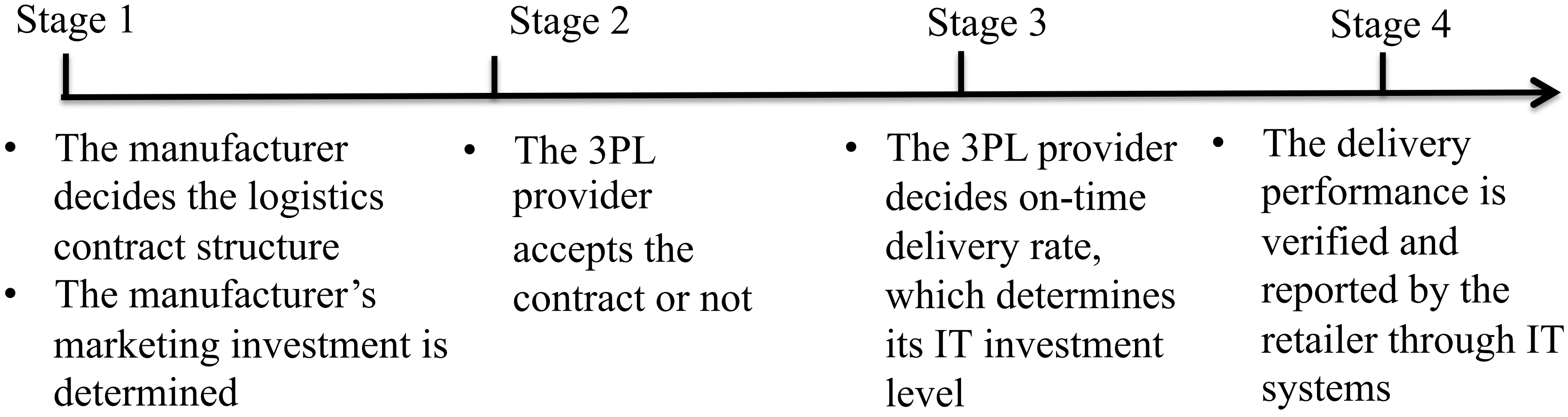

Figure 2. The Supply Chain Profit and the 3PL Provider's IT Investment