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Research on the Co-opetition Relationship of a Closed-loop Supply Chain Based on Private Information Leakage

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Abstract. To study the impacts of private information leakage on co-opetition relationships in a data-driven closed-loop supply chain in the Big Data era, firstly, we analyzed the importance of a Data Company in a supply chain in the new background. Then, we analyzed and built a new structure of the closed-loop supply chain with one central enterprise, one retailer, one Data Company, one third-party logistics and some scattered remanufacturers. Next, we considered private information leakage, and three new competition models of the closed-loop supply chain were constructed. Then, the optimal profit, optimal price, and competitive advantages of different competitors in the three new models were analyzed and compared. Findings: in the Big Data environment, the acquisition cost of private information, the logistics cost and the wholesale price affect the co-opetition relationship of the data-driven closed-loop supply chain. The acquisition cost decides who will win the competition. Finally, conclusions were verified by a numerical model.

Keywords: big data, cost improvement, supply chain coordination, supply chain management

1 Introduction

With the exhaustion of natural resources and energy sources as well as the crisis in environment, recycling products get more and more attention. To save resources and protect the environment, many countries have enforced environment legislation to producers, and these organizations request that producers should be responsible for the production of the entire product life cycle. Taking into account the economic benefits, more and more companies aware of the value of the recycled products and concern about the recycling business.

Meanwhile, with the popularity of the Internet and the rapid development of the Internet of Things (IoT) and the Cloud, global data are increasing rapidly. According to the prediction of International Data Corporation (IDC), global data would reach 35ZB by 2020 [1]. Meanwhile, the development of Cloud and virtual storage would make the storage cost of Big Data reduce [2-3]. All of these are an opportunity for the application and development of Big Data. The era of Big Data has arrived. However, in this era, information leakage become also easier. The exclusive control of supply chain members on closed-loop supply chain information gradually weakens, and competitors can obtain private information through Big Data technologies, which will help them gain a competitive advantage. *These conditions may lead to a change of co-opetition relationships among supply chain members, thus, in this paper, the change rules will be analyzed and discussed.*

Although, many studies have done this work, most focused on qualitative research, such as concepts

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and characteristics. Researchers rarely used a mathematical model to analyze the co-opetition relationships. Therefore, in this paper, we explain that supply chain enters the data-driven era and a Data Company as a "power center" holds an important position in the supply chain first. Then, based on this condition (i.e., there is a "power center" in the data-driven closed-loop supply chain), we discuss the impacts of private intelligence leakage (PIL) on supply chain members' co-opetition relationships.

The main contributions of this study were that (1) a new data-driven closed-loop supply chain model was proposed, and then three competition supply chain models were put forward in the Big Data background. (2) In addition, we also discussed the impacts of PIL on the data-driven closed-loop supply chain co-opetition relationships from an information competition aspect.

Aims of this paper is to analyze the entrance conditions of the used product market and the relationships between profits of closed-loop supply chain members and the acquisition cost of private information. For the data-driven closed-loop supply chain members, the results will provide a theoretical guidance to gain victory in the competition process, meanwhile, it will also help governments supervise and guide the development of closed-loop supply chain enterprises.

2 Research Status of PIL in the Big Data Background

Competitive intelligence was divided into partner intelligence, technical intelligence and market intelligence [4], and technical intelligence and market intelligence were often categorized as private information, which could enhance the productivity and profit of a company [5].

In the Big Data background, data have been called the indispensable raw materials of information economy [6] and have penetrated into every industry [7]. However, the open storage of data meant that user behavior left a "data footprint", and that competitors could easily collect all types of public and legal data [8], which would help them to understand their competitors well.

To prevent PIL, scholars have studied anti-competitive intelligence systems [5, 9-10]. However, in the Big Data environment, open cyberspace makes Big Data acquisition easier. For example, in the current era (i.e., Big Data became enterprises' means to gain competitiveness and profit [11-12]), to obtain greater profits, a large number of intelligent devices can be used. If the generate data spreads into cyberspace, the risk of PIL would increase [13]. At the same time, employees brought their own mobile devices into factories, which will cause problems to enterprise in controlling their private information [14]. To reduce the cost spending on data runs and storage, enterprises store their large data in the Cloud, which increases the risk of PIL. Meanwhile, a Data Company sees data as a commodity [15-16]. However, currently, regulations about Big Data are not sound, and the information sold by a Data Company may include private information.

In the Big Data environment, PIL problems are also discussed in the area of supply chain management. But, most of them focus on the qualitative researches and the quantitative researches are few.

In qualitative researches, many studies analyzed the current situations of consumer PIL and the protection method of private information. Reasons of consumer information leakage main come from two aspects: (1) to get the benefits from organization or other persons, consumers will leak themselves information actively [17-18]. (2) Consumers leak themselves information passively. It main includes that the third-party consumer database platform or corporate disclosure consumer privacy information [19]. In addition, some researchers discussed the current problems of consumer private information protection, meanwhile, some constructive advices were put forward to enhace the private information protection [20-21]. Consumer private information is the market demand information and manufacturer's private information, and its leakage will bring negative effects to enterprise and supply chain.

In quantitative researches, Shi et al. studied the impacts of PIL on competition relationships based on a closed-loop supply chain [8]. Meanwhile, a data-driven mass customization supply chain was analyzed in this paper. Moreover, his cooperator proposed an anti-competitive intelligence system to prevent information leakage in the Big Data environment [5]. However, they did not consider the important position of a Data Company in a supply chain, and enterprises that have poor IT departments may not utilize Big Data effectively if they do not have Data Services Company. Afterward, Liu & Yi also discussed the effects of PIL on co-opetition based on an Data-driven supply chain [22], however, the co-opetition relationship they discussed is based on a retail market, moreover, they did not discuss the effects of PIL on co-opetition based on a data-driven closed-loop supply chain.

Therefore, in the next section, we will analyze the important of a data company in a data-driven closed-loop supply chain. Meanwhile, we will analyze the development of the closed-loop supply chain in the Big Data era.

3 The Importance of Data and a Data Corporation in the Supply Chain in the Big Data Background

The data-driven supply chain cannot lack "data"; therefore, a Data Company that acts as a "power", will play a particularly important role in the data-driven supply chain compared with the traditional supply chain.

Data Company is demanded because of Big Data's "4V" features. The "4V" characters (i.e., Volume, Variety, Velocity and Value) [23-24] of Big Data are widely quoted. These characteristics bring new challenges for obtaining information.

Firstly, large amounts of data are difficult for IT departments to use well. According to the IDC, by 2020, the amount of global digital information will be 44 times greater than that of today [25]. A traditional enterprise's IT organization does not have the ability to collect, store and process these data. Secondly, most of the data (such as commercial trading information, web page information, etc.) was unstructured [26]. Facing the rapid updating and unstructured data, the IT department of a traditional enterprise does not have enough handling capacity [15]. Finally, to mine the potential value of Big Data, professional IT companies needed to screen using professional Big Data technologies [5].

Data Quality and Privacy Protection need a Professional Data Company. The quality of data would affect the use of Big Data [27]; therefore, the data quality of the supply chain would affect supply chain members' usage of Big Data [28]. However, each link (e.g., data generation, acquisition and transmission) is likely to affect data quality. The authenticity of the data source is an important factor that influences data quality. People protecting their privacy would lead to the inauthenticity of the data source [15]. According to a survey from the United States in 2008, to protect private information and obtain personalized service, 72% of people provided enterprises with incomplete information. Bowid found that companies that protected users' privacy information were considered to be trustworthy [29]; therefore, the users were more willing to provide personal information. The professional Data Company has advantages in obtaining Big Data compared with the IT departments of traditional enterprises.

4 Development of the Closed-loop Supply Chain Model in a Big Data Environment

Data-driven ideology purports that a system's various desired functions (e.g., prediction, evaluation, scheduling, monitoring, and optimization.) can be achieved by using the system's online or offline data [29], thus that a closed-loop supply chain system's various desired functions (e.g., prediction, evaluation, scheduling, monitoring, and optimization) can be obtained by using the system's online or offline data. In the Big Data background, some practices proved that using Big Data could improve corporate management and operations [5]. In addition, using Big Data could reduce remanufacturing costs [30]. Therefore, in foreign countries, many enterprises, such as, Kroger, Overstock.com, and so on, have used Big Data [28]. In China, there were also some companies, such as No.1 Store, that had undertaken a data-driven ideology to manage their supply chain [31]. In addition, Waller et al. hypothesized that Big Data would affect the design and management of the supply chain [13], therefore, the ideology of the data-driven supply chain was proposed [30, 32]. In the Big Data background, the closed-loop supply chain also will enter the data-driven era.

With the improvement of living standards, consumers' heterogeneity demand is increasing, and an individualized demand market is forming. This would lead to the traditional closed-loop supply chain gradually becoming a mass customization supply chain [5]. Compared with the traditional supply chain which focuses on product flow and cash flow, a mass customized supply chain is a demand-pull supply chain and focuses more on information flow [33]. The characteristics of Big Data can meet the demand of mass customization on consumers' accurate and timely information, and the development of Big Data technology can offer effective means to extract heterogeneity preferences of consumers. This will shift the supply chain from product "push" mode to the consumer demand data "pull" mode.

Based on the aforementioned analyses, in this paper, we thought, in the Big Data environment, the traditional supply chain will become a data-driven mass customized supply chain. In the supply chain, a data services company should be included in the supply chain. Here, we call this an information services company (ISC). To provide effective personalized service and ensure the dynamic combination and flexibility of the production line, the central enterprise (CE) must allocate a number of tasks to scattered remanufacturers (SRM) [5, 34]. CE is responsible for dispatching materials, obtaining information, and completing the final product to deploy SRM. Third-party logistics (TPL) are responsible for transport merchandise. The development of the traditional supply chain composed of one remanufacturer and one retailer under the Big Data era is shown in Fig. 1.

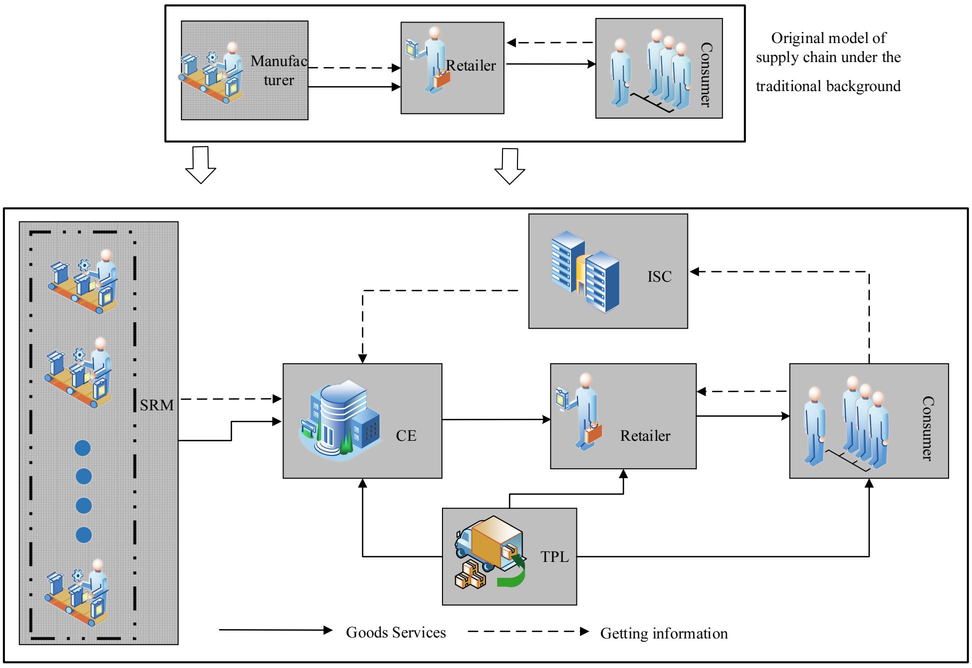


Fig. 1. The development of the closed-loop supply chain in a Big Data background (OM)

4.1 Redevelopment of OM Model in a Big Data Environment

In the Big Data background, enterprises' private information was seen as a competitive resource [35]. If members in the closed-loop supply chain obtain this information, they can enter the monopolized portion of the supply chain, and break the balance of the original supply chain. In the new environment, the PIL of the enterprise is likely to cause changes of the closed-loop supply chain structure. Models of the Third Party Logistics (TPL), CE, and ISC competing with original retailer (OR) are shown in Fig. 2, Fig. 3, and Fig. 4.

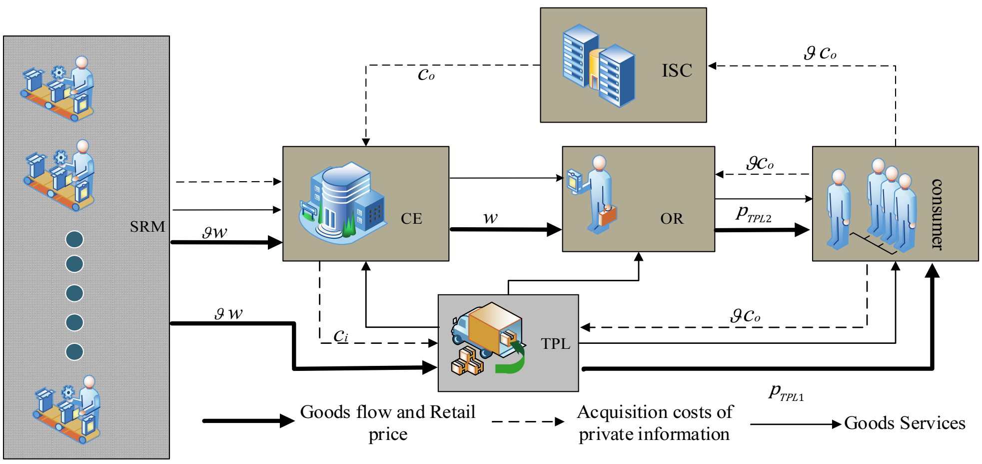


Fig. 2. Model of TPL participating in competition (TPL)

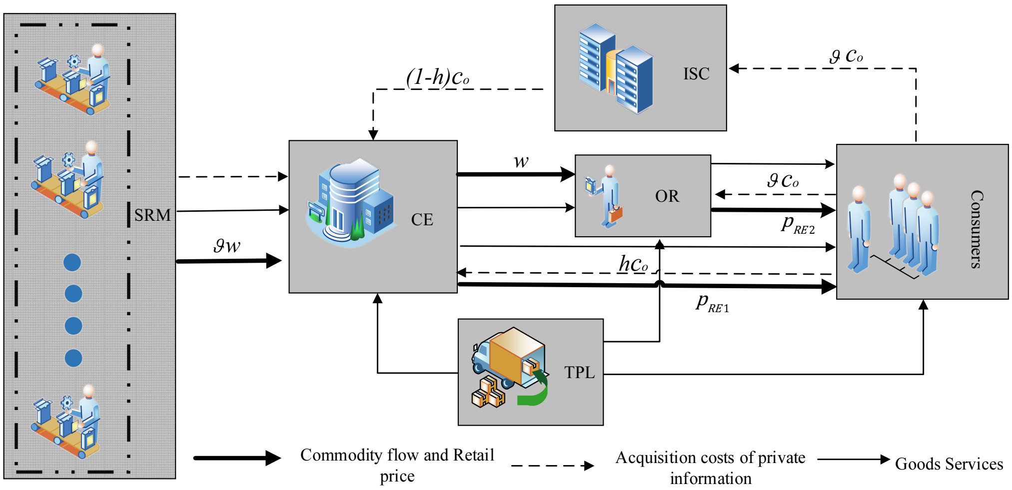


Fig. 3. Model of CE participating in competition (RE)

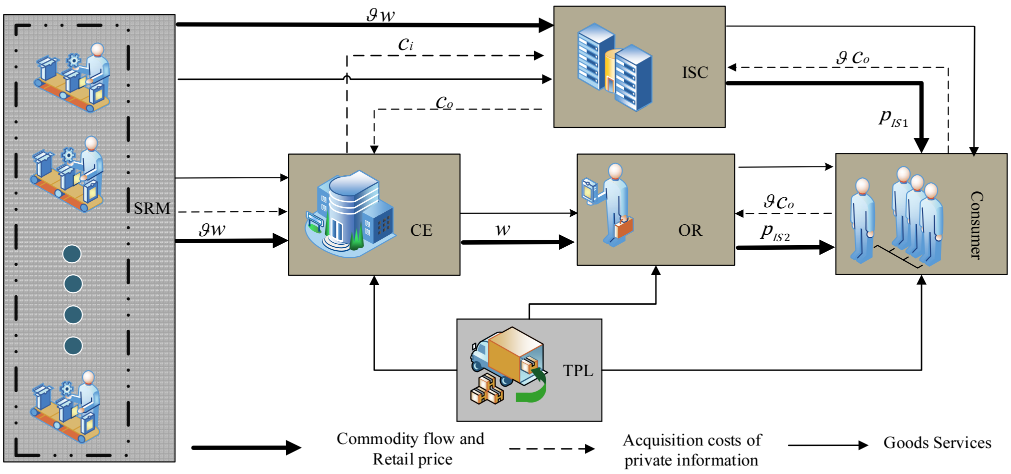


Fig. 4. Model of ISC participating in competition (IS)

4.2 Model Building

4.2.1 Variables and Parameters

ϑ is the industry cost improvement coefficient. by analyzing the internal Big Data and the external Big Data of an enterprise, we can get the related BDI, and then use it to obtain the enterprise's cost improvement. We assume that the optimization coefficient is ϑ and $\vartheta \in [0,1]$.

c_x is the acquisition cost. Here, x is equal to i or o. c_i represents the acquisition cost of CE internal information, and c_o represents the cost spent on obtaining consumer information.

w is the wholesale price of OR.

p_{i1} is the retail price of competitors under model i, and i is equal to TPL, RE or IS. The model of TPL participating in competition is called TPL model, and the model of CE participating in competition is called RE model, and the model of ISC participating in competition is called IS model.

p_{i2} is the retail price of the original competitors under model i.

k is the acquisition cost ratio that CE spends to obtain consumer information from consumers. Here, $k \in [0,1]$.

D_{i1} is the market demand of competitors under model i.

D_{i2} is the market demand of original competitors under model i.

π_{ij} is the revenue of j under model i, and j is equal to O or N. π_{iO} represents revenues of original competitors under model i, and π_{iN} stands for the revenues of competitors under model i.

$\Delta\pi_i$ is the revenue differences between competitors and original competitors under model i.

F_i is the retail price differences between competitors and original competitors under model i.

$\Delta\pi_r$ is the revenue differences among competitors, r is equal to 1, 2 or 3. $\Delta\pi_1$ represents the revenue difference between ISC and CE. $\Delta\pi_2$ stands for the revenue difference between ISC and TPL. $\Delta\pi_3$ expresses the revenue difference between CE and TPL.

Δp_r Retail price differences among competitors. ΔF_1 represents the retail price difference between ISC and CE. ΔF_2 stands for the retail price difference between ISC and SRMα. ΔF_3 expresses the retail price difference between CE and SRMα.

C is the logistics costs.

4.2.2 Demand Function and Model Assumptions

Demand function. To react to consumers' heterogeneity preferences, a standard Hotelling model was adopted. We assume that consumers are distributed in the 0-1 line uniformly and that the total market demand is "1" unit. In addition, one consumer purchases up to "1" unit of the product. We assume that the original competitor is 1, the competitor is 0, the unit transportation cost is *t*, and *t* reflects consumer preference. Demand functions of the original competitors and competitors are

$$\begin{cases} D_{i1}\left(p_{i1}, p_{i2}\right) = \dfrac{t + p_{i2} - p_{i1}}{2t} \\ D_{i2}\left(p_{i1}, p_{i2}\right) = \dfrac{t - p_{i2} + p_{i1}}{2t} \end{cases}.$$

Model assumptions.

(a) The closed-loop supply chain is composed of a plurality of SRM, one CE, one ISC, one retailer and end consumers.

(b) Using Big Data intelligence optimizes the remanufacturing production process; therefore, we assume that the optimizing coefficient of the remanufacturing production cost is ϑ consistently and that it is not affected by the handler. Therefore, under models of DM, RE, and IS, the wholesale price can be optimized and become ϑw. The acquisition cost that OR spends on consumer information is ϑc_o, as is ISC.

(c) There are two methods to obtain consumer information: one is from ISC and the other is from consumers. Because the two methods have advantages and disadvantages, we assume that a competitor obtains some information from ISC and other information from consumers, and the sum of the cost of obtaining consumer information is c_o, regardless of which methods are adopted. CE's private information is obtained from CE directly.

(d) The closed-loop supply chain members are totally rational and risk neutral. The competitors' goods are not obviously different on quality.

5 Effects of PIL on Co-opetition Relationship of Closed-loop Supply Chain

5.1 TPL Model

Take literatures [36] as an example, in the original model, logistics enterprises directly contact with remanufacturers and consumers, which give them an opportunity to obtain information of remanufacturers and consumers. In the Big Data era, TPL may be not satisfied with the transportation costs given by other participants. it will bypass CE and OR and obtain information of consumer and CE actively, and then sell products to consumers, as shown in Fig. 2. This leads to TPL as a latecomer participating in competition, which will form the TPL model. The profit functions of TPL and OR are

$$\max_{i=TPL} \pi_{iN} = [p_{i1} - \vartheta w - c_i - c_o - \vartheta C] D_{i1}(p_{i1}, p_{i2});$$
$$\max_{i=TPL} \pi_{iO} = (p_{i2} - \vartheta c_o - w - C) D_{i2}(p_{i1}, p_{i2}).$$

Conclusion 1 If ($\max_{i=TPL} \pi_{iN}, \max_{i=TPL} \pi_{iO}$) is a differentiable function with respect to p_{i1} and p_{i2} and (p^*_{TPL1}, p^*_{TPL2}) is the optimal prices of TPL and OR, respectively. $(\pi^*_{TPLN}, \pi^*_{TPLO})$ stands for the optimal revenues of TPL and OR, respectively. Therefore,

$$\begin{cases} p^*_{TPL1} = \dfrac{(2\vartheta+1)(w+C)+2(c_i+c_o)+\vartheta c_o+3t}{3} \\ p^*_{TPL2} = \dfrac{(\vartheta+2)(w+C)+c_i+c_o+2\vartheta c_o+3t}{3} \end{cases} \tag{1}$$

$$\begin{cases} \pi^*_{TPLN} = \dfrac{t\left[(1-\vartheta)(C+w-c_o)-c_i+3t\right]^2}{18} \\ \pi^*_{TPLO} = \dfrac{t[(1-\vartheta)(c_o-C-w)+c_i+3t]^2}{18} \end{cases} \tag{2}$$

Proof $\partial(\pi_{TPLN})/(\partial p_{TPL1}) = t(p_{TPL2} - 2p_{TPL1} + t + c_o + c_i + \vartheta w + \vartheta C)/2$, $\partial^2(\pi_{TPLN})/\partial(p_{TPL1})^2 = -t$, therefore, there is a p_{TPL1} that makes TPL's revenue maximize. $\partial(\pi_{TPLO})/(\partial p_{TPL2}) = t(-2p_{TPL2} + p_{TPL1} + t + \vartheta c_o + w + C)/2$, $\partial^2(\pi_{TPLO})/\partial(p_{TPL2})^2 = -t$, therefore, there is a p_{TPL2} that maximizes the benefit of OR. Through calculating we got formulas (1) and (2).

Conclusion 2 Under the TPL model, if $c_i > (1-\vartheta)(c_o - w - C)$ and $w < c_o - C$, TPL will acquire more benefits than OR, and TPL's retail price will also be lower than OR's retail price.

Proof As $\Delta\pi_{TPL} = \pi^*_{TPLN} - \pi^*_{TPLO} = \left[2t^2\left((w+C-c_o)(1-\vartheta)+c_i\right)/3\right] > 0$, $c_i > (1-\vartheta)(c_o - w - C)$. Because $c_i > 0$, $0 < 1-\vartheta < 1$, therefore, $w < c_o - C$. $F_{TPL} = p^*_{TPL1} - p^*_{TPL2} = \left((1-\vartheta)(c_o - w - C) + c_i\right)/3$, at this time, $p^*_{TPL1} < p^*_{TPL2}$. QED.

Conclusion 2 indicates that if TPL wants to enter the retail market and obtains more benefits than OR, the cost of TPL spending to obtain consumer information must be lower than the wholesale price. What's more, c_i must be more than $(1-\vartheta)(c_o - w - C)$. Otherwise, TPL will suffer serious losses because of the high entry condition. If TPL can meet the competitive conditions when it enters the market, OR will face the risk of being squeezed span.

5.2 RE Model

In the original model, CE may be dissatisfied with the delay of consumer information supplied by OR. To enhance their competitive advantage, CE will obtain initially consumer information, and sell products to consumers, as shown in Fig. 3. As a result, CE becomes a latecomer participating in this competition, which will form an RE model. Such as, Lenovo and Xiaomi, which have their own stores.

Profit functions of CE and OR are

$$\max_{i=RE} \pi_{iN} = \left[p_{i1} - \vartheta w - c_o(1-h) - hc_o - C\right] D_{i1}(p_{i1}, p_{i2});$$
$$\max_{i=RE} \pi_{iO} = (p_{i2} - \vartheta c_o - w - C) D_{i2}(p_{i1}, p_{i2}).$$

Conclusion 3 If ($\max_{i=RE} \pi_{iN}, \max_{i=RE} \pi_{iO}$) is a differentiable function with respect to p_{i1} and p_{i2}, and (p^*_{RE1}, p^*_{RE2}) is the optimal prices of CE and OR, respectively. Then (π^*_{REN}, π^*_{REO}) stands for the optimal revenues of CE and OR, respectively. Here,

$$\begin{cases} p_{RE1}^{*} = \dfrac{(1+2\vartheta)w+(2+\vartheta)c_o}{3}+t+C \\ p_{RE2}^{*} = \dfrac{(2+\vartheta)w+(1+2\vartheta)c_o}{3}+t+C \end{cases} \tag{3}$$

$$\begin{cases} \pi_{REN}^{*} = \dfrac{t[(1-\vartheta)(w-c_o)+3t]^2}{18} \\ \pi_{REO}^{*} = \dfrac{t[(1-\vartheta)(c_o-w)+3t]^2}{18} \end{cases} \tag{4}$$

Proof $\partial(\pi_{REN})/(\partial p_{RE1}) = t\left(p_{RE2}-2p_{RE1}+t+c_o+\vartheta w+C\right)/2$ and $\partial^2(\pi_{REN})/\partial(p_{RE1})^2 = -t$, therefore, p_{RE1} maximizes CE's revenue. $\partial(\pi_{REO})/(\partial p_{RE2}) = t\left(-2p_{RE2}+p_{RE1}+t+\vartheta c_o+w+C\right)/2$ and $\partial^2(\pi_{REO})/\partial(p_{RE2})^2 = -t$, therefore, p_{RE2} maximizes the benefit of OR. By calculating we got formulas (3) and (4).

Conclusion 4 Under the RE model, if the cost to obtain consumer information is higher than the wholesale price (i.e., $c_o < w$), RE participating in this competition will acquire more benefits than OR. CE owns a lower retail price than OR.

Proof $\Delta\pi_{RE} = \pi_{REN}^{*} - \pi_{REO}^{*} = 2t^2(w-c_o)(1-\vartheta)/3 > 0$, therefore, $c_o < w.$ $F_{RE} = p_{RE1}^{*} - p_{RE2}^{*} = (c_o-w)(1-\vartheta)/3$, at this moment, $p_{RE1}^{*} < p_{RE2}^{*}$. QED.

Conclusion 4 shows that if CE wants to access to the market, then its cost to obtain consumer information should be higher than the wholesale price; otherwise, CE will fail because of the high entry condition. If the mentioned conditions can be met, CE will have more advantages than OR. If OR does not take any measures, it will face the risk of being squeezed span and the direct selling model of RE will finally take shape.

5.3 IS Model

In the original model, ISC may be dissatisfied with the benefits of obtaining sale information. It may bypass CE and cooperate with SRM, and then sell products to consumers. As shown in Fig. 4, the IS model will form. A real world example of this model is that BaiDu invests in QiJia net [37] and enters the e-commerce industry.

Profit functions of ISC and OR are

$$\max_{i=IS} \pi_{iN} = \left(p_{i1} - \vartheta w - c_i - \vartheta c_o - C\right) D_{i1}\left(p_{i1}, p_{i2}\right);$$
$$\max_{i=IS} \pi_{iO} = \left(p_{i2} - \vartheta c_o - w -\right) D_{i2}\left(p_{i1}, p_{i2}\right).$$

Conclusion 5 If ($\max_{i=IS}\pi_{iN}, \max_{i=IS}\pi_{iO}$) is a differentiable function with respect to p_{i1} and p_{i2} , and (p_{IS1}^{*}, p_{IS2}^{*}) is the optimal prices of ISC and OR, respectively. $(\pi_{ISN}^{*}, \pi_{ISO}^{*})$ stands for the optimal revenues of ISC and OR, respectively.

$$\begin{cases} p_{IS1}^{*} = \dfrac{(1+2\vartheta)w+2c_i}{3}+\vartheta c_o+t+C \\ p_{IS2}^{*} = \dfrac{(2+\vartheta)w+c_i}{3}+\vartheta c_o+t+C \end{cases} \tag{5}$$

$$\begin{cases} \pi^*_{ISN} = \dfrac{t[(\vartheta-1)w+c_i-3t]^2}{18} \\ \pi^*_{ISO} = \dfrac{t((\vartheta-1)w+c_i+3t)^2}{18} \end{cases} \tag{6}$$

Proof $\partial(\pi_{ISN})/(\partial p_{IS1}) = t\left(p_{IS2}-2p_{IS1}+t+\vartheta c_o+c_i+\vartheta w+C\right)/2$ and $\partial^2(\pi_{ISN})/\partial(p_{IS1})^2=-t$, therefore, there is a p_{IS1} which can make ISC's revenue maximize. $\partial(\pi_{ISO})/(\partial p_{IS2})=t\left(-2p_{IS2}+p_{IS1}+t+\vartheta c_o+w+C\right)/2$ and $\partial^2(\pi_{ISO})/\partial(p_{IS2})^2=-t$, therefore, p_{IS2} maximize OR's benefit. Through calculating we get formulas (5) and (6).

Conclusion 6 Under the IS model, if $(1-\vartheta)$ times the wholesale price is more than the cost spending on obtaining CE internal information, ISC will acquire more benefits than OR. Moreover, ISC will have a lower retail price than OR.

Proof $\Delta\pi_{IS}=\pi^*_{ISN}-\pi^*_{ISO}=\left[2t^2\left(w(1-\vartheta)-c_i\right)/3\right]>0$ and $[c_i/(1-\vartheta)]<w$. $F_{IS}=p^*_{IS1}-p^*_{IS2}=\left(c_i-(1-\vartheta)w\right)/3$, therefore, $p^*_{IS1}<p^*_{IS2}$, QED.

Conclusion 6 demonstrates that if $(1-\vartheta)$ times the wholesale price is less than the cost to get CE internal information, ISC will keep the original partnership. On the contrary, ISC will enter the market to get more profits. If OR does not take any measures, it will face the risk of being squeezed span, ultimately, the closed-loop supply chain centering on ISC will form.

5.4 Comparison of the Three Competition Models

In this section, we provide a comparison analysis of the optimal prices and revenues among competitors. Assume that $\Delta p_r\ (r=1,2,3)$ represents the retail price differences among competitors, and $\Delta\pi_r\ (r=1,2,3)$ expresses the profit differences among competitors. $\Delta p_1=p^*_{IS1}-p^*_{RE1}=2[c_i-(1-\vartheta)c_o]/3$, and $\Delta\pi_1=\Delta\pi^*_{ISN}-\Delta\pi^*_{REN}=t[c_i-c_o(1-\vartheta)]\left[(c_o-2w)(1-\vartheta)+c_i-6t\right]/18t$. $\Delta p_2=p^*_{IS1}-p^*_{TPL1}=2(1-\vartheta)(C-c_o)/3$, and $\Delta\pi_2=\Delta\pi^*_{ISN}-\Delta\pi^*_{TPLN}=t(c_o-C)(1-\vartheta)\left[(2w-c_o+C)(1-\theta)-2c_i+6t\right]/18t$. $\Delta p_3=p^*_{RE1}-p^*_{TPL1}=2\left[C(1-\vartheta)-c_i\right]/3$, and $\Delta\pi_3=\Delta\pi^*_{REN}-\Delta\pi^*_{TPLN}=t\left[c_i-C(1-\vartheta)\right]\left[(2w-2c_o+C)(1-\vartheta)-c_i+6t\right]/18t$. When we combine of conclusions 2, 5 and 6, we got conclusion 7.

Conclusion 7 If $(1-\vartheta)C<c_i$ can be met, $p^*_{RE1}<p^*_{IS1}<p^*_{TPL1}$ and $\Delta\pi^*_{REN}>\Delta\pi^*_{ISN}>\Delta\pi^*_{TPLN}$. If $c_i>(1-\vartheta)c_o$, $p^*_{IS1}<p^*_{TPL1}<p^*_{RE1}$ and $\Delta\pi^*_{ISN}>\Delta\pi^*_{TPLN}>\Delta\pi^*_{REN}$. If $c_i=(1-\vartheta)\mathrm{C}$, $p^*_{TPL1}=p^*_{RE1}<p^*_{IS1}$ and $\Delta\pi^*_{ISN}<\Delta\pi^*_{REN}=\Delta\pi^*_{TPLN}$.

Conclusion 7 indicates that if $c_i=(1-\vartheta)\mathrm{C}$, competitors (i.e., TPL and CE) from model TPL and RE own the equal retail price and benefit. What's more, they have a lower retail price than competitor (i.e., ISC), and have a higher profit than ISC. With the continuous development, TPL and CE will replace OR, eventually the closed-loop supply chain system that is focused on TPL and CE will form.

When $c_i>(1-\vartheta)c_o$, competitor (i.e., ISC) from model IS owns a higher benefit and a lower retail price than other competitors (i.e., CE and TPL). Under this condition, if ISC enters this market, it will obtain more advantages compared with CE and TPL. Following the development, ISC will replace OR, and eventually a closed-loop supply chain system that is fcused on ISC will form.

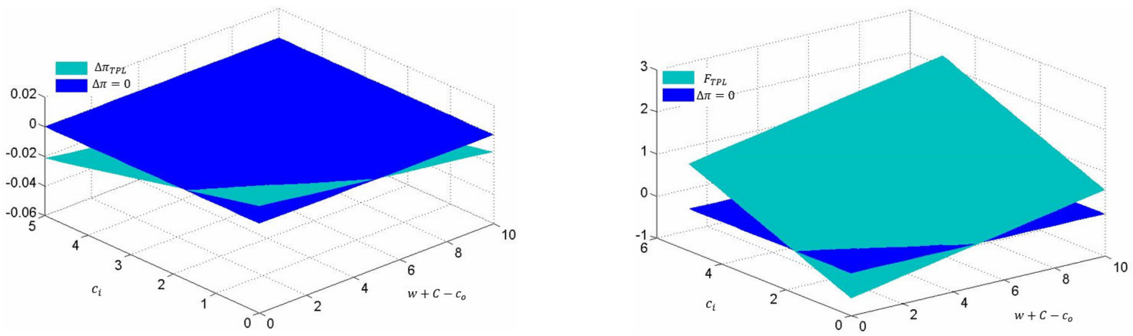
When $c_i<(1-\vartheta)C$, competitor (i.e., CE) from model RE owns a higher benefit and a lower retail price than other competitors (i.e., ISC and TPL). Thus, entering this market, it will have a higher competitiveness. Through the continuous development, a closed-loop supply chain system that centers on CE will take shape.

In summary, in the context of Big Data, scramble information may lead to the competition relationship change, which may cause a change of closed-loop supply chain structure, and this structure change is closely related to the acquisition costs of private information and logistics costs. This finding is important for government to implement supervision and guidance. For instance, the flattening trend of closed-loop supply chain can reduce the retail price, and which has a positive effect on stimulating market, but has a negative effect on creating jobs. Under this condition, government can prevent or slow down this flattening trend through controlling the acquisition cost of private intelligence or establishing a unified data "power center" to control the threshold to obtain private information, and implement a rational macro-control when facing different market conditions.

6 Numerical Analysis

To test the validity of the conclusions mentioned above and further investigate the effects of cost parameters' change on the closed-loop supply chain structure, a numerical simulation analysis method was used. Reference [38]. Let $\vartheta = 0.65, t = 0.1$.

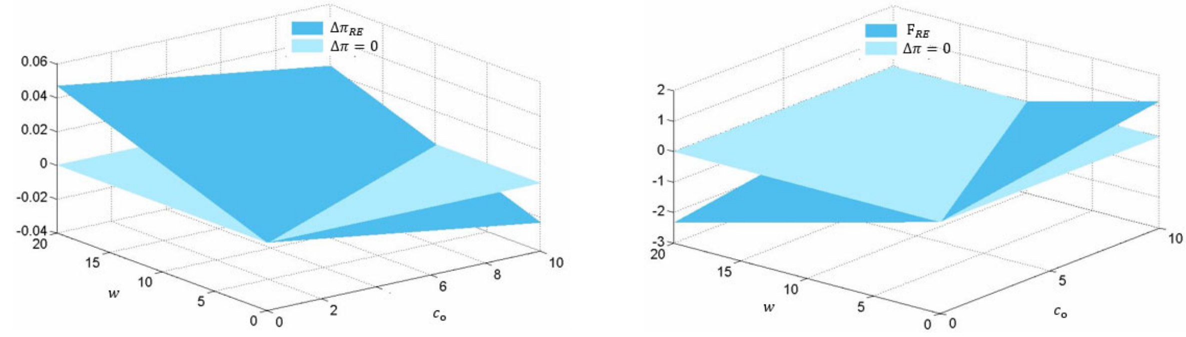
(1) In this section, effects of parameters (i.e., w, c_o, c_i, C) on the retail price differences and benefit differences between competitors and OR will be analyzed under the models of TPL, RE and IS. Under the TPL model, the change trends of $\Delta\pi_{TPL}$ and F_{TPL} are shown in Fig. 5. X-axis represents the acquisition cost of TPL internal information, and Y-axis indicates the difference between the wholesale price and the cost investing in obtaining consumer information, and Z-axis expresses the differences of decision variables (i.e., the optimal profits or retail prices). Based on Fig. 5, we get that if $(c_o - w - C)(1-\vartheta) < c_i$, TPL has a higher profit than OR, moreover, it has a lower retail price than OR. Here, TPL will own more advantages if it chooses to enter market. When $(c_o - w - C)(1-\vartheta) > c_i$, if TPL enters the market, it will face failure because of less advantages. When $(c_o - w - C)(1-\vartheta) = c_i$, the competitive strength of TPL and OR is equal. If the market is more mature, it is difficult for TPL to enter the market. If the market is immaturity, TPL may share the market together with OR. Conclusion 2 was proved.



(a) (b)

Fig. 5. Differences of profits and retail price under the TPL model

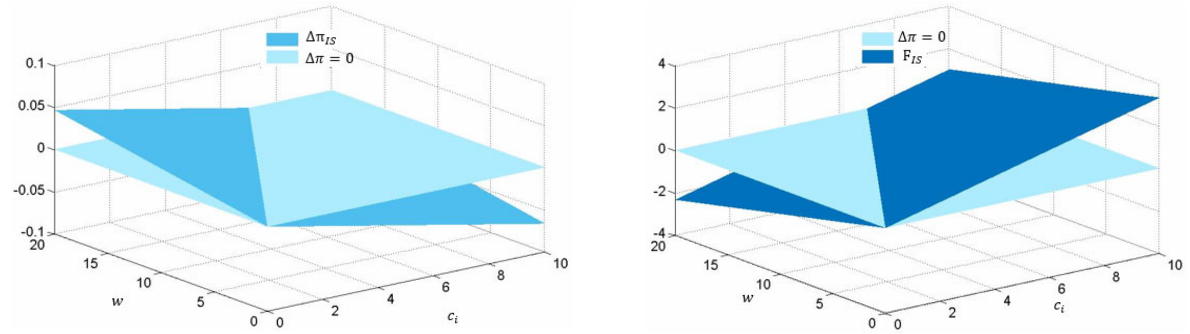
Under the RE model, the change trends of $\Delta\pi_{RE}$ and F_{RE} are shown in Fig. 6. X-axis represents the acquisition cost of consumer information, and Y-axis indicates the wholesale price, and Z-axis expresses the differences of decision variables (i.e., the optimal profits or retail prices). From Fig. 6, we can know that if $w > c_o$, CE has a higher benefit than OR, what's more, its retail price is lower than OR's retail price. At this time, CE will own more advantages if it chooses to enter the market. When $w < c_o$, CE will not have enough competitiveness, and entering the retail market will make CE face huge losses. When $w = c_o$, the competitive strength of CE and OR is equal. Conclusion 4 was confirmed.



(a) (b)

Fig. 6. Differences of profits or retail prices under the RE model

Under the IS model, the change trends of $\Delta\pi_{IS}$ and F_{IS} are shown in Fig. 7. X-axis represents the acquisition cost of CE internal information, and Y-axis indicates the wholesale price, and Z-axis expresses the differences of the profits or the retail prices. Fig. 7 demonstrates that when $w(1-\vartheta) > c_i$, ISC will have a higher revenue and a lower retail price compared with OR. Here, if ISC enters the market, it will have a higher competitiveness. When $w(1-\vartheta) < c_i$, it is not appropriate for ISC to enter the market. When $w(1-\vartheta) = c_i$, ISC and OR have an equal competitiveness, whether it is suitable for ISC to enter the market or not, which depends on the market maturity. Conclusion 6 was confirmed.



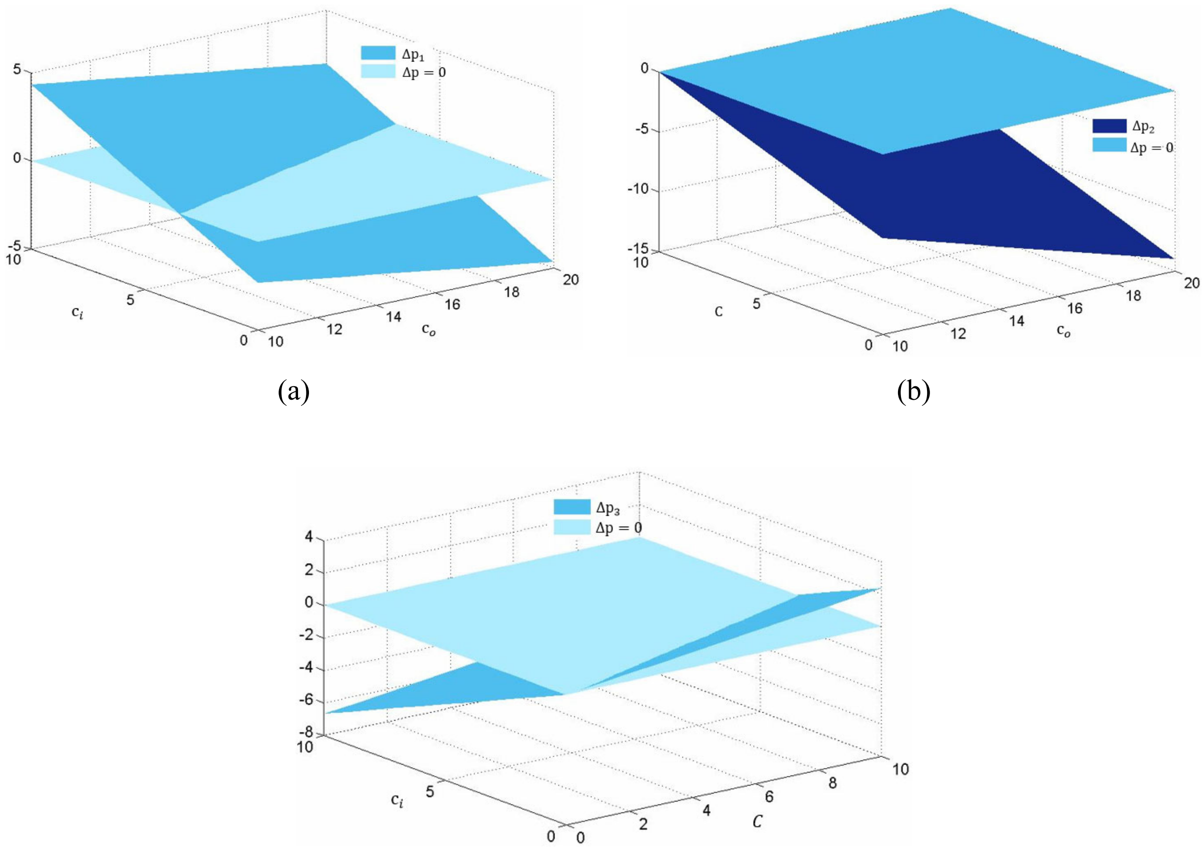
(a) (b)

Fig. 7. Differences of profits or retail prices under the IS model

(2) Under the models of TPL, RE and IS, effects of cost parameters (i.e., w, c_o, c_i, C) on the retail price differences and benefit differences among competitors will be analyzed in this section. The change trends of $\Delta p_r\ (r = 1,2,3)$ are shown in Fig. 8. X-axis represents the cost spending on getting consumer information, and Y-axis indicates the cost investing in getting CE internal information, and Z-axis expresses the differences of the retail price among competitors. Based on Fig. 8(a), we can get that if $c_i > (1-\vartheta)c_o$, CE will own a lower retail price than ISC. If $c_i < (1-\vartheta)c_o$, CE will have a higher retail price than ISC. If $c_i = (1-\vartheta)c_o$, the retail prices of ISC and CE are equal.

Based on Fig. 8(b) and conclusion 2, we can learn that ISC has a lower retail price than TPL. Namely, under the Big Data background, if TPL and ISC have participated in the retail market competition, ISC will have more competitive advantages.

From Fig. 8(c), we can know that if $c_i < (1-\vartheta)C$, TPL will have a lower retail price than CE. If $c_i > (1-\vartheta)C$, TPL will have a higher retail price than CE. If $c_i = (1-\vartheta)C$, the retail prices of TPL and CE are equal.



(a) (b)

(c)

Fig. 8. Retail price differences among competitors

Through analyzing, we can get that if $(1-\vartheta)C<c_i$, $p^*_{RE1}<p^*_{IS1}<p^*_{TPL1}$, and based on the expressions of $\Delta\pi^*_{REN}$, $\Delta\pi^*_{ISN}$ and $\Delta\pi^*_{TPLN}$, we can get $\Delta\pi^*_{REN}>\Delta\pi^*_{ISN}>\Delta\pi^*_{TPLN}$. Similarly, we can get that if $c_i>(1-\vartheta)c_o$, and $p^*_{IS1}<p^*_{TPL1}<p^*_{RE1}$, and $\Delta\pi^*_{ISN}>\Delta\pi^*_{TPLN}>\Delta\pi^*_{REN}$. If $c_i=(1-\vartheta)C$, and $p^*_{TPL1}=p^*_{RE1}<p^*_{IS1}$, and $\Delta\pi^*_{ISN}<\Delta\pi^*_{REN}=\Delta\pi^*_{TPLN}$. In summary, conclusion 7 was confirmed.

7 Conclusions and Significances

7.1 Conclusions

In the Big Data background, through analyzing the importance of a Data Company in a closed-loop supply chain, the original model of the closed-loop supply chain is constructed. Then, in the case of PIL, three competing models were built. Through analyzing we found:

(1) Under the TPL model, if $(1-\vartheta)$ times differences between the prices (i.e., wholesale price, Logistics Prices) and the cost spending to get consumer information are lower than the cost investing in getting CE internal information (i.e., $c_i>(1-\vartheta)(c_o-w-C)$), TPL will own a higher competitiveness than OR.

(2) Under the RE model, if the wholesale price is higher than the cost spending to obtain consumer information (i.e., $c_o<w$), CE will have a higher competitiveness than OR.

(3) Under the IS model, if $(1-\vartheta)$ times the wholesale price is higher than the acquisition costs of CE internal information (i.e., $c_i<(1-\vartheta)w$), ISC will get a higher competitiveness than OR.

These results suggest that the relationships among the wholesale price, the acquisition costs of consumer information and CE internal information determine that which competitors are suitable to enter the market. It also indicates that who enters the market can achieve more advantages.

(4) When $(1-\vartheta)$ times the logistics costs are lower than the costs investing in getting CE internal intelligence, TPL will have the strongest competitiveness in all competitors.

(5) When $(1-\vartheta)$ times the costs spending on getting consumer information are lower than the costs investing in getting CE internal intelligence, CE will have the strongest competitiveness in all competitors.

(6) When $(1-\vartheta)$ times the logistics costs and the costs investing in getting CE internal information are equal, CE and TPL will have equal competitiveness, and it is stronger than the competitiveness of ISC.

The findings mentioned indicate that the relationships between the cost spending on obtaining private information and the logistics costs determine that which competitors will obtain the strongest competitiveness in all competitors. It also expresses that who will achieve the ultimate victory.

7.2 Practical Significance

In the Big Data era, PIL may lead to changes of co-opetition relationships among closed-loop supply chain members, which may cause the changes of closed-loop supply chain structure, and these changes are closely related to the acquisition costs of consumer information and CE information. This finding is important for government to implement the supervision and guidance. Next, we will give some advices for government to guide the market.

(1) The life necessities market (e.g., edible oil market) is related to people's livelihood, and the price of life necessities needs to remain stable. If competitors achieve competitiveness by gaining private intelligence, then the closed-loop supply chain may become unstable. To against this, the government can maintain the stability of the closed-loop supply chain by establishing a unified data "power center" to control the acquisition threshold of private intelligence.

(2) A multi-level closed-loop supply chain can absorb more labor, and a new industry (e.g., Big Data Industry) may be able to increase the stages of the closed-loop supply chain and create more jobs. Therefore, in the Big Data environment, the government can maintain the multi-level nature of the closed-loop supply chain by controlling the acquisition cost of private information to balance competition.

7.3 Theoretical Significance

In a Big Data environment, PIL is becoming increasingly important, based on the characteristics of Big Data, a Data Company in the closed-loop supply chain is getting more and more important. This might lead to the change of the closed-loop supply chain structure, thus, we proposed the original model of a two-stage closed-loop supply chain in the Big Data environment, which made up for the lack of closed-loop supply chain structure in the Big Data era.

Based on the new data-driven closed-loop supply chain structure, PIL was considered, therefore, we analyzed and built three completion models to obtain the co-opetition relationships among CE, ISC, TPL and OR. We found that the acquisition cost of private information, the logistics cost and the wholesale price affected the co-opetition relationship of the closed-loop supply chain. Meanwhile, we obtained the conditions to obtain competitiveness under the new environment. Namely, the acquisition costs decides who will win the competition. These findings compensated for the study weaknesses of the closed-loop supply chain co-petition relationship in the Big Data environment.

8 Future Research

In this paper, we considered the effects of CE internal information leakge and consumer information leakage on the co-opetition relationships of data-driven closed-loop supply chain members. In the future, we can study methods and strategies to avoid the information leakge. Such as, we can research an anti-competitive intelligence system to protect the private information. In addition, we can study the mechanism of the closed-loop supply chain demand information leakage in the Big Data environment.

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Author Contributions

Pan Liu. and Shu Ping Yi conceived and designed the experiments, performed the experiments. Pan Liu analyzed the data and wrote the paper and Yue long offered some money from his fund to support this research.

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