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Transaction Efficiency, Stability and Pricing in Supply Chain Network

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Abstract. The paper presents measurement method of transaction efficiency and stability in supply chain network for the problem of anti-interference ability in crisis events. Interferences mainly include two forms, transaction chain broken and node reduction. Transaction efficiency, stability and optimum pricing strategy are presented under each interference form. Results show that when crisis events occur, transaction efficiency will decline if the minimum quantity of suppliers and retailers remain stable. If transaction efficiency decreases sharply, it shows that stability of the original supply chain network is poor.

Keywords: Transaction efficiency, trading chain broken, Nodes decrease.

1. Introduction

With the development of information technology and economic globalization, supply chain faces the challenge of globalization, and are developed into supply chain network. Firms not only care about its own profit, but also the transaction efficiency, stability and profit possibility, especially when some big crisis events occurs (such as production accident, transportation interruption, natural disaster). Many researchers have studied supply chain networks issues; see, for example, Nagurney (2006), Klibi et al. (2010) and Santoso et al. (2005). Nagurney (2006) visualize the supply chain structure as a network with the appropriate topology consisting of nodes and links. Decision-makers are the nodes and transaction/transportation are links in the network. Based on this conception, Nagurney (2010) models supply chain network design problem with oligopolistic firms who are involved in the competitive production, storage, and distribution of a homogeneous product to multiple demand markets.

Klibi et al. (2010) discusses supply chain network design problem under uncertainty. Through an analysis of supply chains uncertainty sources and risk exposures, he reviews key random environmental factors and discusses the nature of major disruptive events threatening supply chain network. Santoso et al. (2005) proposes a stochastic programming model and solution algorithm for solving supply chain network design problems of a realistic scale. Supply chain network, however, is not designed but emerged. The emerged network may be efficiency or inefficiency, be stability or instability as crisis event occurs, these are the problems facing supply chain network.

Klibi et al. (2010) studies chain-stable networks. He assumes that agents' preferences satisfy the cross-side complementarity and same-side substitutability conditions which are proposed by Sun and Yang (2006), and defines a chain-stable network as a set of bilateral contracts such that no upstream–downstream sequence of agents can add a chain of contracts (and drop, if necessary, some other contracts) that would make them all better off. In fact, the essential of stable state in his study is equilibrium state, in which no firms has willingness to change transaction quantity, price or transaction object. According to Liapunov stability theory, stability is an ability of returning back to the original equilibrium state when system is influenced by outside factor. In the same way, stability of supply chain network should be the ability of maintaining supply of goods or service when there is disruption occurs in node or transaction chain.

In this paper, we develop a transaction efficiency model in supply chain networks. Such a model provides a method of measuring stability which is an important index in evaluating anti-interference of a supply chain network. This model captures both manufacturer's and retailer's willingness as well as the effect of their interactions. It provides the foundation for developing dynamic models for the study of supply chain network disruption.

The rest of this paper is organized as follows. Section 2 formally introduces the definition of transaction efficiency and stability of supply chain networks. Section 3 presents the pricing in original supply chain networks. Section 4 and section 5 studies the changing of transaction efficiency, stability and pricing after chain and node is disrupted. Section 6 illustrates some results derived in this article by numerical example. Section 7 concludes and gives extensions of the model.

2. Transaction Efficiency, Stability of Supply Chain Network

Suppose there are m manufactures and n retailers. The willingness (or possibility) of manufacturer i sells to retailer j is $0 \le a_{ij} \le 1$, and the willingness of retailer j buy from manufacturer i is $0 \le b_{ji} \le 1$. Their willingness satisfies the conditions $0 \le \sum_{i=1}^{m} a_{ij} \le 1$ and $0 \le \sum_{j=1}^{n} b_{ji} \le 1$ .Transaction efficiency between manufacturer i and retailer j is the possibility transaction between them can be realized: $ET_{ij} = a_{ij}b_{ji}$. Transaction efficiency of manufacturer i is the possibility manufacturer i could sell his product to retailers: $EM_i = \sum_{j=1}^{n} a_{ij}b_{ji}$. Transaction efficiency of retailer j is the possibility retailer j could buy from manufacturers: $ER_j = \sum_{i=1}^{m} a_{ij}b_{ji}$. Contribution rate of manufacturer i on retailer j is the proportion of transaction efficiency between manufacturer i and retailer j to retailer j 's transaction efficiency: $CM_{ij} = ET_{ij} / ER_j$. Contribution rate of retailer j on manufacturer i is the proportion of transaction efficiency between manufacturer i and retailer j to manufacturer i 's transaction efficiency: $CR_{ij} = ET_{ij} / EM_i$. Transaction efficiency of supply chain network is the mean transaction efficiency rate of all manufacturers or retailers. It can be expressed by: $E = \sum_{i=1}^{m}\sum_{j=1}^{n} ET_{ij} \Big/ min(m,n)$. Stability of supply chain network is the ability of anti-interference as crisis event occurs. Here, we use interrupt on the chain with maximal transaction efficiency to express interference on the supply chain network. The stability of supply chain network can be computed by: $S = \frac{mn}{mn-1}(1 - max(ET_{ij}) \Big/ \sum_{i=1}^{m}\sum_{j=1}^{n} a_{ij}b_{ji})$. When E is close to 1 , it means that transaction efficiency of the supply chain network is high; when E is close to 0 , it means the transaction efficiency is low.

Obviously, the larger the value of S is, the stronger the stability of supply chain network will be. Generally, if transaction efficiency of a chain is very high, stability of the supply chain network must be poor. Under such circumstances, when crisis event disrupts this core chain, it will have destructive force on this supply chain network. Therefore, once the core chain is break off, manufacturer and retailer even consumer will suffer great loss. External assistance by the Government probably is required to maintain normal operation.

3. Pricing in Initial Supply Chain Network

In a supply chain network with only one manufacturer and one retailer, assuming market demand is $D = \alpha - \beta p$, wholesale price ω and unit cost c , manufacturer's profit will be $(\omega - c)(\alpha - \beta p)$, retailer's profit will be $(p - \omega)(\alpha - \beta p)$. It's easy to get the optimal wholesale price of manufacturer is $\bar{\omega} = c/2 + \alpha/2\beta$, retailer's optimal retail price is $\bar{p} = \alpha/2\beta + \omega/2$. Here, we call them standard wholesale price and standard retail price respectively.

In the next paper, we will discuss a simple supply chain network. In this network, there are two manufacturers and two retailers that is manufacturer 1, manufacturer 2, retailer 1 and retailer 2. Assuming the consumer market of retailer 1 and retailer 2 are in different region, retail price each one region can be different, and consumer in one region will not buy product from other region. Assuming the total market demand still is $D = \alpha - \beta p$,the willingness (or possibility) manufacturer 1 sell to retailer 1 is a_{11} , the willingness to retailer 2 is a_{12} ;and the willingness manufacturer 2 sell to retailer 1 is a_{21} , to retailer 2 is a_{22} . Assuming the willingness retailer 1 buy from manufacturer 1 is b_{11} , from manufacturer 2 is b_{12} ; and the willingness retailer 2 buy from manufacturer 1 is b_{21} , from manufacturer 2 is b_{22} .

Transaction efficiency of supply chain network 2is:

$$E_1 = \sum_{i=1}^{m}\sum_{j=1}^{n} a_{ij}b_{ji} \Big/ min(m, n) = \frac{a_{11}b_{11} + a_{21}b_{12} + a_{12}b_{21} + a_{22}b_{22}}{2}. \tag{1}$$

Stability of supply chain network 2 is:

$$S_1 = \frac{mn}{mn-1}(1 - max(ET_{ij})\Big/ \sum_{i=1}^{m}\sum_{j=1}^{n} a_{ij}b_{ij}). \tag{2}$$

Let M_1, M_2, R_1, R_2 denote profit of manufacture 1, manufacturer 2, retailer 1 and retailer 2 respectively. Assuming that all the manufacturers and retailers are profit-maximizers, the optimization problems of them are given by

$$M_1 = max\{(\omega_1 - c)(\alpha - \beta p_1)a_{11}b_{11} + (\omega_1 - c)(\alpha - \beta p_2)a_{12}b_{21}\}, \tag{3}$$

$$M_2 = max\{(\omega_2 - c)(\alpha - \beta p_1)a_{21}b_{12} + (\omega_2 - c)(\alpha - \beta p_2)a_{22}b_{22}\}, \tag{4}$$

$$R_1 = max\{(p_1 - \omega_1)(\alpha - \beta p_1)a_{11}b_{11} + (p_1 - \omega_2)(\alpha - \beta p_1)a_{21}b_{12}\}, \tag{5}$$

$$R_2 = max\{(p_2 - \omega_1)(\alpha - \beta p_2)a_{12}b_{21} + (p_2 - \omega_2)(\alpha - \beta p_2)a_{22}b_{22}\}, \tag{6}$$

Differentiate Eq.5 with respect to p_1 , we get the optimal retailer price of retailer 1, which is

$$p_1^* = \frac{\alpha}{2\beta} + \frac{\omega_1}{2} + \frac{a_{21}b_{12}(\omega_2 - \omega_1)}{2a_{11}b_{11} + 2a_{21}b_{12}} = \frac{\alpha}{2\beta} + \frac{CM_{11}\omega_1}{2} + \frac{CM_{21}\omega_2}{2}, \tag{7}$$

Differentiate Eq.6 with respect to p_2 , we get

$$p_2^* = \frac{\alpha}{2\beta} + \frac{\omega_2}{2} + \frac{b_{21}a_{12}(\omega_1 - \omega_2)}{2b_{21}a_{12} + 2a_{22}b_{22}} = \frac{\alpha}{2\beta} + \frac{CM_{12}\omega_1}{2} + \frac{CM_{22}\omega_2}{2}, \tag{8}$$

where, CM_{21} is contribution rate of manufacturer 2 on retailer 1, CM_{11} is contribution rate of manufacturer 1 on retailer 2, CM_{12} is contribution rate of manufacturer 1 on retailer 2, and CM_{22} is contribution rate of manufacturer 2 on retailer 2.

Theorem 1. The influence degree of wholesale price on retail price is half of contribution rate of manufacture on retailer, that is $\frac{dp_1^*}{d\omega_1} = \frac{CM_{11}}{2}, \frac{dp_1^*}{d\omega_2} = \frac{CM_{21}}{2}, \frac{dp_2^*}{d\omega_1} = \frac{CM_{12}}{2}, \frac{dp_2^*}{d\omega_2} = \frac{CM_{22}}{2}$.

Increase of any manufacturer's wholesale price will lead to the descendent of retail price of retailers having transaction with it.

Substitute Eq.7 and Eq.8 into Eq. 3 and Eq. 4 respectively, we have

$$\omega_1{*} = \frac{c}{2} + \frac{\alpha}{2\beta} + \frac{a_{11}b_{11}a_{21}b_{12}(\alpha - \beta\omega_2)ER_2 + b_{21}ER_1a_{12}[b_{21}a_{12}\omega_2\beta + \alpha a_{22}b_{22}]}{2\beta a_{11}^2b_{11}^2ER_2 + 2\beta a_{12}^2b_{21}^2ER_1}, \tag{9}$$

$$\omega_2^* = \frac{c}{2} + \frac{\alpha}{2\beta} + \frac{a_{12}a_{22}b_{22}b_{21}(\alpha - \beta\omega_1)ER_1 + a_{21}b_{12}[a_{21}b_{12}\beta\omega_1 + \alpha a_{11}b_{11}]ER_2}{2\beta a_{21}^2b_{12}^2ER_2 + 2\beta a_{22}^2b_{22}^2ER_1}. \tag{10}$$

Theorem 2. Both wholesale prices of manufacturer 1 and manufacture 2 are great than standard wholesale price, that is $\omega_1^* > \bar{\omega}$, $\omega_2^* > \bar{\omega}$.

4. Stability and Pricing Under Chain Broken

When supply chain network is disrupted by crisis events, such as transportation interruption, transaction between manufacturer 2 and retailer 2 is break off, we call the supply chain network after transaction chain broken supply chain network 2(SCN2). In supply chain network 2, we have

$$a_{22} = 0, \quad b_{22} = 0. \tag{11}$$

Note that a_{12} , $a_{21}, a_{11}, b_{11}, b_{12}, b_{21}$ remain unchanged. This is mainly because crisis events like transportation interruption always comes quickly, firms have not enough time to adjust its transaction object and transaction willingness. Substitute Eq. 11 into Eq.1, we can get transaction efficiency of supply chain network 2 is $E_2 = 1/2\,(a_{11}b_{11} + a_{12}b_{21} + a_{21}b_{12})$

Theorem 3. When transaction chain is broken, transaction efficiency of supply chain network decreases.

Substitute Eq.11 into Eq. 9, we can get stability of supply chain network 2:

$$S_2 = \frac{mn}{mn-1}(1 - max(ET_{ij}) \Big/ \sum_{i=1}^{m}\sum_{j=1}^{n} a_{ij}b_{ij}).$$

Note that stability of supply chain network after chain broken may decrease or increase, that depends on the next maximal transaction efficiency.

Similarly, substitute Eq. 11 into 7 and 8 respectively, we can get retail price in supply chain network 2:

$$p_1^* = \frac{\alpha}{2\beta} + \frac{\omega_1}{2} + \frac{a_{21}b_{12}(\omega_2 - \omega_1)}{2a_{11}b_{11} + 2a_{21}b_{12}}, = \frac{\alpha}{2\beta} + \frac{CM_{11}\omega_1}{2} + \frac{CM_{21}\omega_2}{2}. \quad p_2^* = \frac{\alpha}{2\beta} + \frac{\omega_1}{2}$$

Theorem 4. Transaction chain broken between manufacturer 2 and retailer 2 doesn't change the influence ratio of each wholesale price on retailer 1's retail price that is $\frac{dp_1^*}{d\omega_1} = \frac{CM_{11}}{2}$, $\frac{dp_1^*}{d\omega_2} = \frac{CM_{21}}{2}$.

Theorem 5. Transaction chain broken between supplier 2 and retailer 2 makes wholesale price of manufacture 2 has no effect on retailer 2's retail price, while influence ratio of manufacturer 1's whole sale price on retailer 2's retail price reach the maximal level.

In fact, manufacture 1 is the only supply source of retailer 2, therefore, wholesale price of manufacture 1 has determining influence on retailer 2's retail price.

Substitute Eq.11 into 9 and 10, we get

$$\omega_1{*} = \frac{c}{2} + \frac{\alpha}{2\beta} + \frac{a_{11}b_{11}a_{21}b_{12}(\alpha - \beta\omega_2) + \omega_2\beta a_{12}b_{21}(a_{11}b_{11} + a_{21}b_{12})}{2\beta a_{11}^2 b_{11}^2 + 2\beta a_{12}b_{21}(a_{11}b_{11} + a_{21}b_{12})}, \quad \omega_2^* = \frac{c}{2} + \frac{\alpha}{2\beta} + \frac{\alpha a_{11}b_{11} + a_{21}b_{12}\beta\omega_1}{2\beta a_{21}b_{12}}.$$

5. Stability and Pricing Under Node Reduction:

When node denoting manufacturer 2 in initial supply chain network disappear, for example, as natural disaster occurs, manufacturer 2 has no production capability any more, we have $a_{21} = 0, a_{22} = 0, b_{22} = 0, b_{12} = 0$. Parameters a_{11} , a_{12} , b_{11} , b_{21} maintain unchanged like last section. We call this transaction network after manufacturer 2 disappear supply chain network 3(SCN3). According to definition 6 and definition 7, Transaction efficiency of supply chain network 3 is: $E_3 = a_{11}b_{11} + a_{12}b_{21}$.

Stability of supply chain network 3 is:

$$S_2 = \frac{mn}{mn-1}(1 - \frac{max(ET_{ij})}{\sum_{i=1}^{m}\sum_{j=1}^{n} a_{ij}b_{ij}}) = 2(1 - \frac{max(a_{11}b_{11}, a_{12}b_{12})}{a_{11}b_{11} + a_{12}b_{12}}).$$

Theorem 6. When a node in supply chain network disappear, transaction efficiency of this supply chain network will decline if the minimum quantity of manufacture and retailer does not change.

It should also be noted that node reduction does not necessarily change stability of new supply chain network. In supply chain network 3, profit of manufacture 1 is: $M_1 = max\{(\omega_1 - c)(\alpha - \beta p_1)\frac{a_{11}b_{11}}{E_3} + (\omega_1 - c)(\alpha - \beta p_2)a_{12}b_{21}\}$.

Profit of retailer is: $R_1 = max\{(p_1 - \omega_1)(\alpha - \beta p_1)a_{11}b_{11}\}$. $R_2 = max\{(p_2 - \omega_1)(\alpha - \beta p_2)a_{12}b_{21}\}$. Using the same computation method as last section, we can get optimal wholesale price and optimal retail price: $p_1^* = p_2^* = \frac{\alpha}{2\beta} + \frac{\omega_1}{2}$, $\omega_1^* = \frac{c}{2} + \frac{\alpha}{2\beta}$.

Obviously, in supply chain network 3, both retail price of retailer 1 and retailer 2 are standard retail price, and manufacture 1's wholesale price is standard wholesale price. This conclusion does not always hold as some node disappear. In most cases, node reduction only changes wholesale price and retail price, it doesn't mean wholesale price and retail price will always achieve its standard price.

6. Numerical Analysis

In our experiment, suppose parameters are $\alpha = 200$, $\beta = 10$, $a_{11} = 0.7$, $a_{12} = 0.3$, $a_{21} = 0.5$, $a_{22} = 0.5$, $b_{11} = 0.8$, $b_{12} = 0.2$, $b_{21} = 0.6$, $b_{22} = 0.4$, $c = 2$, $k = 5$ .It can be seen from table 1 that transaction efficiency of supply chain network decreases when transaction chain is broken or node disappears as crisis events occurs. Stability of supply chain network, however, has no definite trending up or down as transaction efficiency changes.

Table 1 also shows that wholesale price and retail price change when transaction chain between manufacturer 2 and retailer 1 is broken. In this numerical example, both wholesale price and retail price decline, and profit of manufacturer 2 decrease sharply, which is the intermediate victim in crisis events. It's worthwhile to note that although wholesale price of manufacturer 1 always decreases, its profit appears to be on the rise. Therefore, manufacturer 1 is the beneficiary as chain broken and node reduction, for whose competitor is frustrated in crisis events.

Table 1. Optimal solutions comparison under different interferences in supply chain network

case	E	S	ω_1^*	ω_2^*	p_1^*	p_2^*	M_1	M_2	R_1	R_2
SCN1	0.51	0.6013	14.2525	14.3689	17.1365	17.1536	258.2698	98.1115	54.4763	26.826
SCN2	0.43	0.4651	13.4282	14.0104	16.7655	16.7141	273.6169	45.8977	69.8632	18.715
SCN3	0.37	0.4865	11	0	15.5	15.5	298.54	0	112.12	35.73

7. Conclusion

This paper introduces transaction efficiency, stability and pricing in supply chain network. Transaction efficiency of supply chain network is the mean transaction efficiency rate of all manufacturers or retailers. While stability of supply chain network is the ability of anti-interference as crisis event occurs. We use interrupt on the chain with maximal transaction efficiency to express interference on the supply chain network. Interferences mainly include two forms, transaction chain broken and node reduction. We present transaction efficiency stability and optimal pricing in each kind of interferences. Results show that when transaction chain is broken, transaction efficiency of supply chain network decreases. Transaction efficiency of this supply chain network declines also as a node in supply chain network disappear, if the minimum quantity of manufacture and retailer does not change. We present pricing trend in each case, stability of new supply chain network, however, does not always go up or down. In our numerical example, all wholesale prices and retail prices decrease as disruption occurs.

Our analysis is just the first step in transaction efficiency, stability and pricing in supply chain network. There are abundant opportunities for research on extensions. For example, when structure of supply chain network changes, willingness of manufactures and retailers may change also, in this circumstance, the relationship between transaction efficiency, stability and pricing perhaps will show different characteristics, this is a problem need to be studied.

Another extension of the research in this paper is to investigate a case where production cost is a nonlinear function of transaction efficiency.

8. References

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