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Supply Chain Information Sharing of Third-Level Coal Enterprises with Evaluation of Decision-Making Bias

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Abstract

Information sharing can reduce bullwhip effect on the supply chain of coal enterprises. This paper explores supply chain information sharing of three-level coal enterprises when there are decision-making biases; establishes supply chain model of third-level coal enterprises composed by coal-producing enterprises, coking coal-producing enterprises, and coal-demand enterprises; and analyzes the influential factors of information sharing value for coal enterprises with three types of conditions.

Keywords: *supply chain, information sharing, coal, decision bias*

1. Introduction

China is the host of an abundance of coal resources, which is considered as contrary distribution with the prosperous degree of regional economy, more in northern and western areas, and less in southern and eastern areas. Coal is produced in the northwestern regions, while its consumption is centered in mid-eastern regions. The difference in distribution between supply and demand results in an obvious bullwhip effect on the coal supply chain. When coal production is insufficient to meet consumption demand, coal prices will soar and inventory shortage will occur in various regions. When this happens, various distributors seek to garner benefits from coal trade, and coal-producing enterprises also earn a lot. However, coal-demand enterprises must buy coal at a high price, which leads to compressed profit margins, or even losses.

When coal supply exceeds its demand, coal manufacturer have to choose price competition if they cannot become more efficient in their output. A lack of efficiency may result in continued deterioration of oversupply, thus promoting a vicious price competition that will eventually bring about serious loss of coal-producing enterprises. Tiny changes in end demand may become huge fluctuations when the demand is transmitted into upstream enterprises, which greatly affects profits of all parties on the supply chain of coal enterprises. Therefore, reducing demand variability is a significant factor in the stability and long-term development of the supply chain of coal enterprises. Theoretical research shows that information sharing can reduce the bullwhip effect on the supply chain of coal enterprises, and can levy great practical significance in realizing the practice of information sharing for the supply chain of coal enterprises.

2. Literature Review

[1] laid the foundation for the research of supply chain information sharing. [2] explored the value of information sharing on two-stage supply chain. [3] found that when parameters of AR(1) were learned in the Lee model, information sharing benefits of producers were not obvious as the demand function model and parametric variation affected the value of information sharing. Previous explorations provided a prerequisite for follow-up research on information sharing value. At the same time, more scholars

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conducted research from different perspectives that focused on various kinds of information sharing values, which were dependent on motivation of information sharing, specific management strategies, competition degree of supply chain, and characteristics of product demand. [4] indicated the remarkable value of information sharing when the demand of two-stage supply chain is presented as the auto-regressive moving average (ARMA) model.

The ARMA process is more appropriate for products with long life cycles such as fuel, food, and mechanical instruments. [5] investigated the information sharing value of supply chain using Markov's decision modeling. [6] analyzed the influence of consumer information return on producers' wholesale price and order quantity of distributors without buy-back strategies, motivation of information sharing, and other relevant problems.[7] explored the supply chain of multi-channel producers and market requirement for producers and distributors. When offline and online products have sound substitutability, producers are willing to share their information; therefore, distributors will not experience profit loss due to information sharing. [8] pointed out the influence of investment cost and contract types on information sharing between two competitive supply chains, both composed of a producer and a distributor, with the only difference in investment cost of information sharing under high and low market requirements.

[9] explored various influences on the information sharing value between two competitive supply chains, such as diseconomies of scale, information accuracy, competition intensity, and competition type. In Bertrand model of competition, information sharing brings about greater fluctuation in the requirement of two supply chains. The number of distributors changes less but greater fluctuations are seen in competitors' supply chain demand. Research shows that enterprises in supply chain cannot make decisions regarding information sharing independently. Instead, they must consider competitors' reactions before making decisions. Although information sharing has the potential to bring benefits, losses may arise in the presence of the Cournot model of competition. Especially in a competitive environment with accurate information, the response of competitors will result in negative response. [10] analyzed supply chain information sharing in franchise operations under the condition that both parties owned private market requirement information.

Franchisers are always willing to share information, while distributors do the same when franchisers offer lower wholesale prices or set up gain sharing contracts with them. [11] believed that producers and distributors combine to form a supply chain. When both own part of the information, no information sharing is the sole factor to establish equilibrium. If there is no corresponding coordination mechanism, information sharing cannot add profit to a supply chain. [12] explained that substitutability of different products could reduce information sharing value for all enterprises in supply chain. It is shown that enterprises in supply chain, especially upstream firms, are faced with overestimation of the value of information sharing under the circumstances that substitutability demands correlations and has a partial information sharing effect.

[13] found that decision bias leads to information loss in the ordering process and generates value in downstream information sharing. Inspired by the research, this paper evaluated the influence of decision-making bias on multi-level coal enterprise supply chain. [14] explored given market requirements for distributors, but suppliers only learned about distribution of market requirements. Suppliers intend to bring out real condition of market requirements, while distributors may distort order quantity for the sake of their own interest. When entering into markets, suppliers will cooperate with distributors that can communicate well, particully when they have low effenciency in sales section.

At present, research of supply chain information sharing focuses mainly on the structure of two-level supply chain with less emphasis on three-level supply chain. Because the three-level supply chain model is relatively complicated, an analog simulation method is employed. [15] found that demand information sharing can considerably reduce the bullwhip effect by exploring the influence of inventory information and order information on the multi-level supply chain. [16] conducted research on information sharing in the three-level supply chain. It was shown that there are two conditions for information sharing. One is the absence of information-sharing, and the other is that each level on supply chain can share terminal demand information. There is no exploration on complicated partial information sharing.

[17] analyzed three-level supply chain systems and found that upstream cooperative partners provide incentive mechanism by revenue sharing, which urges downstream distributors share their information. They also indicated that the value in information sharing mainly lied in the reduction of inventory level and promotion of cooperation. [18] carried out a simulating research on the fact that demand information value was subject to the characteristics of supply chain and quality of demand information sharing. [19] discovered that the selection of a demand forecasting model would affect the information sharing value of supply chain. Meanwhile, information sharing value of supply chain was also affected by terminal demand model and production capacity. [20] indicated that specific organizational environments would affect the information sharing value based on the simulation of demand information sharing in multi-level supply chain.[21] investigated cost sharing in three-level supply chain and the supply chain coordination.[22] studied the bullwhip effect in a supply chain consisting of a manufacturer, a wholesaler and two retailers then quantified the impact of information sharing .

In conclusion, it was discovered that, based on theoretical derivation and simulation research, supply chain information sharing changes with the variation of characteristics, structure, demand, and sharing model. Currently, there is less research on information sharing in the coal enterprise supply chain. From the angle of mathematical induction, this paper explores the value of information sharing of coal enterprise supply chain under three conditions, including no information sharing, partial information sharing (part information here refers to the degree of information sharing), and complete information sharing with the evaluation of decision-making bias.

This paper is structured as follows. The first part establishes supply chain model of three-level coal enterprises. The second part builds supply chain information sharing model for three-level coal enterprises, and introduces information sharing models under three information sharing conditions. The third part evaluates supply chain information sharing value of coal enterprises, and explores inventory change and cost change among coal-demand enterprises, coking coal-producing enterprises, and coal-producing enterprises. In addition, a contrast analysis is conducted on the influence of parameters on the supply chain of coal enterprises. The fourth part verifies the deduction in the third part by numerical analysis, and elaborates the specific influence of parameters on the supply chain of coal enterprises. The final part provides conclusions, deficiencies, and research direction in the future.

3. Supply Chain Model of Three-Level Coal Enterprises

Supply chain of coal enterprises has various structural forms, such as long chain and short chain. This paper uses the long-chain structure. As coal needs to become coking coal by processing, the supply chain for coal enterprise is a three-level structure that is composed of coal-producing enterprises, coking-coal producing enterprises, and coal-demand enterprises. Coal-demand enterprises order a certain quantity of coal from coking coal-producing enterprises according to coal requirements. Coking coal-producing enterprises satisfy coal demand from downstream enterprises by inventory, with the shortage by ordering from upstream coal enterprises. Coal- producing enterprises are also dependent on storage to meet coal demand of coking coal-producing enterprises, with the remaining part by continued production. It is assumed that coal-producing enterprises have infinite production capacity.

4. Information Sharing Model of Three-Level Coal Enterprises

Supply chain of three-level coal enterprises are composed of coal-producing enterprises, coking coal-producing enterprises and coal-demand enterprises, which are indicated by m, c, and p respectively. The first condition is that there is no information sharing in the supply chain of three-level coal enterprises. Enterprises at different levels have to place orders from upstream enterprises, and then they can obtain new and past order information. The second condition is that when coking coal-producing enterprises order coal from coal-producing enterprises, they can obtain predictive coal demand information, in addition to order information of coal-demand enterprises. The third condition is that coal-demand enterprises transfer coal demand forecasting information to coking coal-producing enterprises and coal-producing enterprises. When formulating production plan, coal-producing enterprises can acquire coal demand forecasting information and decision-making bias information transmitted by coal-demand enterprises aside from order information of coking coal-producing enterprises.

In condition 1, there is no information sharing in supply chain of coal-producing enterprises. Coal demand enterprises are faced with coal demand D_t in period t. Thus, they need to order a certain quantity of coal y_t^p to meet regular production and inventory demand, with lead time I_p. Coal demand enterprises receive ordered coal in period $t+I_p+1$. After receiving orders from coal demand enterprises, coking coal-producing enterprises will satisfy requirement by inventory before ordering a certain quantity of coal y_t^c from coal-producing enterprises. Coal-producing enterprises meet demand by the current inventory, and the rest is satisfied by continued production, with lead time I_c. Coking coal-producing enterprises receive ordered coal in period $t+I_c+1$.

Figure 1. Coal Ordering Process Under Condition 1

In condition 2, partial information is shared. Coal requirement from coal demand enterprises is D_t in period t. In addition to the transmission of order information y_t^p between coal-demand enterprises and coking coal-producing enterprises, the latter can obtain forecasting information of coal demand from coal-demand enterprises when making decisions. The rest is similar to that in condition 1.

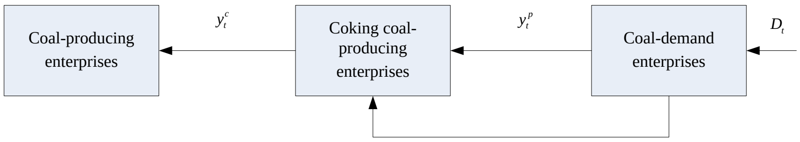

Figure 2. Coal Ordering Process Under Condition 2

In condition 3, coal-demand enterprises share order information, forecasting information, and decision bias with coal-producing enterprises and coking coal-producing enterprises. Coal-demand enterprises have coal requirement D_t in period t, with information y_t^p transmitted between coal-demand enterprises and coking coal-producing enterprises, and information y_t^c transmitted between coking coal-producing enterprises and coal-producing enterprises. Coking coal-producing enterprises and coal-producing enterprises can obtain coal demand forecasting information and decision bias when making decisions. The rest is similar to that in condition 2.

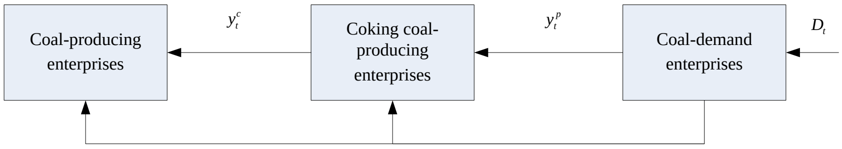

Figure 3. Coal Ordering Process Inder Condition 3

In this chapter, a three-level coal enterprise supply chain model is established by combining a coal-producing enterprise, a coking coal-producing enterprise, and a coal-demand enterprise. Assuming that coal demand can meet

$$D_t = \varphi_0 + \varphi_1 D_{t-1} + \varepsilon_t \quad (1)$$

where D_t is coal demand in period t, φ_0 is the average coal demand, φ_1 is the correlation between coal demand in period t and that in form period, ε_t is error term, which is generally independent identically distributed and normally distributed. It is generally assumed that σ is much less than φ_0, with mean value of 0 and standard deviation of σ^2. Therefore, negative demand is negligible in this paper.

At the beginning of period t ,coal-demand enterprises satisfy coal requirement D_t based on observations. At the end of period t ,coal-demand enterprises check their inventory level, and order a certain quantity of coal y_t^p from coking coal-producing enterprises. Coking coal- producing enterprises deliver goods to coal-demand enterprises after receiving orders from coal- demand enterprises at the end of period t. Coal-demand enterprises check their own inventory and order a certain quantity of coal y_t^c from coal-producing enterprises. Then, coal-producing enterprises deliver goods to coking coal-producing enterprises.

This paper assumes that both shortage cost and inventory cost are constant, p^p, p^c, p^m represent shortage cost of coal-demand enterprises, coking coal-producing enterprises, and coal- producing enterprises, h^p, h^c, h^m are inventory cost of the three kinds of enterprises, and s_t^p, s_t^c, s_t^m represent the ordering level of the three kinds of enterprises.

5. Supply Chain Information Sharing Value of Three-Level Coal Enterprises

5.1. The Best Inventory Level of Coal-Demand Enterprises

Ordering goods is the same for coal-demand enterprises under the three conditions. The best inventory level of coal-demand enterprises can be studied together as it is not affected by information sharing condition. Coal-demand enterprises are faced with coal requirement D_t in the period t, and order a certain quantity of coal y_t^p from coking coal-producing enterprises to their own production and inventory demand, with ordered coal in period $t+I_p+1$. To cut cost, the best ordering level is S_t^{p*}, to ensure the lowest overall inventory cost and shortage cost in period $t+I_p+1$. The ordered quantity is:

$$y_t^p = D_t + s_t^p - s_{t-1}^p + \xi_t^p \quad (2)$$

where ξ_t^p is decision deviation of coal-demand enterprises, with ξ_t^p as random variable. The overall coal demand in lead time I_p+1 is shown as follows.

$$\sum_{i=1}^{I_p+1} D_{t+i} = \frac{1}{1-\varphi_1}\left\{\varphi_0 \sum_{i=1}^{I_p+1}\left(1-\varphi_1^i\right)+\varphi_1\left(1-\varphi_1^{I_p+1}\right)D_t\right\}+\varepsilon_{l+1}$$
$$+\left(1+\varphi_1\right)\varepsilon_l+\cdots+\left(1+\varphi_1+\varphi_1^2+\cdots+\varphi_1^l\right)\varepsilon_{t+1} \tag{3}$$

when $m_t^p = E\left[\sum_{i=1}^{I_p+1} D_{t+i} \middle| D_t\right]$, $v_t^p = Var\left[\sum_{i=1}^{I_p+1} D_{t+i} \middle| D_t\right]$

m_t^p , v_t^p are conditional expectation and conditional variance respectively. It is deduced:

$$m_t^P = \frac{\varphi_0}{1-\varphi_1}\left\{\left(I_p+1\right)-\sum_{j=1}^{I_p+1}\varphi_1^j\right\}+\frac{\varphi_1\left(1-\varphi_1^{I_p+1}\right)}{1-\varphi_1}D_t \tag{4}$$

$$v_t^p = \frac{\sigma^2}{\left(1-\varphi_1^2\right)}\sum_{j=0}^{I_p}\left(1-\varphi_1^{j+1}\right)^2 \tag{5}$$

For coal-demand enterprises, the optimum inventory level in period t is:

$$s_t^{p*} = m_t^p + k_p\sqrt{v_t^p} \tag{6}$$

where $k_p = \varphi^{-1}\left[p_p \middle/ \left(p_p+h_p\right)\right]$, φ is standard normal distribution function.

5.2. The Optimum Inventory Level of Coking Coal-Demand Enterprises

When coking coal-demand enterprises receive orders y_t^p from coal-demand enterprises, they need to check out inventory to satisfy demand and order products from coal-producing enterprises to address any shortage. Coking coal-producing enterprises receive ordered coal in period $t+I_c+1$. In period t, order quantity of coal-demand enterprises is:

$$y_t^p = D_t + s_t^{p*} - s_{t-1}^{p*} + \xi_t^p$$
$$= D_t + \frac{\varphi_1\left(1-\varphi_1^{I_p+1}\right)}{1-\varphi_1}\left(D_t - D_{t-1}\right)+\xi_t^p \tag{7}$$

Based on (1) and (7), it is deduced:

$$y_{t+i}^p = \phi_0\frac{1-\phi_1^i}{1-\phi_1}+\phi_1^i y_t^p + \frac{1-\phi_1^{I_p+i}}{1-\phi_1}\varepsilon_{t+i}+\sum_{j=1}^{i-1}\phi_1^{I_p+j+1}\varepsilon_{t+i-j}-\phi_1^i\left(\frac{1-\phi_1^{I_p+1}}{1-\phi_1}\right)\varepsilon_t-\phi_1^i\xi_t^p+\xi_{t+i}^p \tag{8}$$

The overall coal requirement for enterprises in lead time I_c+1 is:

$$\sum_{j=1}^{I_c+1} y_{t+\mathrm{i}}^p = \frac{\phi_0}{1-\phi_1}\left[I_c+1-\frac{\phi_1\left(1-\phi_1^{I_c+1}\right)}{1-\phi_1}\right]+\frac{\phi_1\left(1-\phi_1^{I_c+1}\right)}{1-\phi_1}y_t^p$$
$$+\frac{1}{1-\phi_1}\sum_{i=1}^{I_c+1}\left(1-\phi_1^{I_c+i}\right)\varepsilon_{t+i}+\sum_{i=1}^{I_c+1}\sum_{j=1}^{i-1}\phi_1^{I_p+j+1}\varepsilon_{t+i-j}$$
$$-\frac{\phi_1\left(1-\phi_1^{I_c+1}\right)\left(1-\phi_1^{I_p+1}\right)}{\left(1-\phi_1\right)^2}\varepsilon_t-\frac{\phi_1\left(1-\phi_1^{I_c+1}\right)}{1-\phi_1}\xi_t^p+\sum_{i=1}^{I_c+1}\xi_{t+\mathrm{i}}^p \tag{9}$$

1. The first type

Without information sharing, coking coal-producing enterprises only learn about transportation quantity in lead time I_c+1. With a certain inventory level, y_t^p is known for coking coal-producing enterprises, with the remainder as a random variable. At that time, conditional expectation and variance are m_t^{c1} and v_t^{c1} respectively.

$$m_t^{c1}=\frac{\phi_0}{1-\phi_1}\left[I_c+1-\frac{\phi_1\left(1-\phi_1^{I_c+1}\right)}{1-\phi_1}\right]+\frac{\phi_1\left(1-\phi_1^{I_c+1}\right)}{1-\phi_1}y_t^p$$

$$v_t^{c1}=\left\{\begin{array}{l}\frac{1}{\left(1-\phi_1\right)^2}\left[\sum_{i=1}^{I_c+1}\left(1-\phi_1^{I_c+i}\right)\right]^2+\left(\sum_{i=1}^{I_c+1}\sum_{j=1}^{i-1}\phi_1^{I_p+j+1}\right)^2\\ +\left[\frac{\phi_1\left(1-\phi_1^{I_c+1}\right)\left(1-\phi_1^{I_p+1}\right)}{\left(1-\phi_1\right)^2}\right]^2\end{array}\right\}\sigma^2+\left\{\left[\frac{\phi_1\left(1-\phi_1^{I_c+1}\right)}{1-\phi_1}\right]^2+I_c+1\right\}D\left(\xi_t^p\right)$$

For coking coal-producing enterprises, the optimum inventory level s_t^{c1*} in period t is:

$$s_t^{c1*}=m_t^{c1}+k_c\sqrt{v_t^{c1}} \tag{10}$$

where $k_c=\varphi^{-1}\left[p_c/\left(p_c+h_c\right)\right]$, and ϕ is standard normal distribution function.

2. The Second Type

Under the condition of partial information sharing, when coal-demand enterprises share information with coking coal-producing enterprises, y_t^p is learned information for coking coal-producing enterprises with certain inventory level, in addition to transportation quantity of lead time I_c+1. Meanwhile, they also have predictive information of coal demand with conditional expectation and variance as m_t^{c2} and v_t^{c2} respectively.

$$m_t^{c2}=\frac{\phi_0}{1-\phi_1}\left[I_c+1-\frac{\phi_1\left(1-\phi_1^{I_c+1}\right)}{1-\phi_1}\right]+\frac{\phi_1\left(1-\phi_1^{I_c+1}\right)}{1-\phi_1}y_t^p$$
$$-\frac{\phi_1\left(1-\phi_1^{I_c+1}\right)\left(1-\phi_1^{I_p+1}\right)}{\left(1-\phi_1\right)^2}\varepsilon_t$$

$$v_t^{c2}=\left\{\frac{1}{\left(1-\phi_1\right)^2}\left[\sum_{i=1}^{I_c+1}\left(1-\phi_1^{I_c+i}\right)\right]^2+\left(\sum_{i=1}^{I_c+1}\sum_{j=1}^{i-1}\phi_1^{I_p+j+1}\right)^2\right\}\sigma^2+\left\{\left[\frac{\phi_1\left(1-\phi_1^{I_c+1}\right)}{1-\phi_1}\right]^2+I_c+1\right\}D\left(\xi_t^p\right)$$

For coking coal-producing enterprises, the optimum inventory level s_t^{c2*} in period t is:

$$s_t^{c2*} = m_t^{c2} + k_c \sqrt{v_t^{c2}} \tag{11}$$

where $k_c = \varphi^{-1}\left[p_c \big/ \left(p_c + h_c \right) \right]$, and ϕ are standard normal distribution functions.

3. The Third Type

With full information sharing, coal-demand enterprises and coking coal-producing enterprises learn about transportation quantity in lead time $I_c + 1$. With certain inventory level, y_t^p is learned information for coking coal-producing enterprises. Meanwhile, they also have predictive information of coal demand and decision deviation, with conditional expectation and variance as m_t^{c2} and v_t^{c2} respectively.

$$m_t^{c3} = \frac{\phi_0}{1-\phi_1}\left[I_c + 1 - \frac{\phi_1\left(1-\phi_1^{I_c+1}\right)}{1-\phi_1} \right] + \frac{\phi_1\left(1-\phi_1^{I_c+1}\right)}{1-\phi_1} y_t^p - \frac{\phi_1\left(1-\phi_1^{I_c+1}\right)\left(1-\phi_1^{I_p+1}\right)}{\left(1-\phi_1\right)^2}\varepsilon_t - \frac{\phi_1\left(1-\phi_1^{I_c+1}\right)}{1-\phi_1}\xi_t^p$$

$$v_t^{c3} = \left\{ \frac{1}{\left(1-\phi_1\right)^2}\left[\sum_{i=1}^{I_c+1}\left(1-\phi_1^{I_c+i}\right) \right]^2 + \left(\sum_{i=1}^{I_c+1}\sum_{j=1}^{i-1}\phi_1^{I_p+j+1} \right)^2 \right\}\sigma^2 + \left[\frac{\phi_1\left(1-\phi_1^{I_c+1}\right)}{1-\phi_1} \right]^2 D\left(\xi_t^p\right)$$

For coking coal-producing enterprises, the optimum inventory level s_t^{c3*} in period t is:

$$s_t^{c3*} = m_t^{c3} + k_c \sqrt{v_t^{c3}} \tag{12}$$

where $k_c = \varphi^{-1}\left[p_c \big/ \left(p_c + h_c \right) \right]$, and ϕ are standard normal distribution functions.

5.3. The Optimum Inventory Level of Coal-Producing Enterprises

With the confirmation of the optimum inventory level for coal-producing enterprises, coking coal-producing enterprises place orders y_t^c to coal producing enterprises. Firstly, coal-producing enterprises satisfy coal demand by inventory. If there is insufficient inventory, arrangements are made to continue to meet requirements, with lead time $t + I_m + 1$. y_t^c is considered as demand from coal-producing enterprises, thus it is deduced:

$$y_t^c = y_t^p + \left(s_t^{c*} - s_{t-1}^{c*} \right) + \xi_t^c \tag{13}$$

$$y_t^c = D_t + \frac{\varphi_1\left(1-\varphi_1^{I_p+1}\right)}{1-\varphi_1}\left(D_t - D_{t-1} \right) + \xi_t^p + m_t^c - m_{t-1}^c + \xi_t^c \tag{14}$$

1. The First Type

Without information sharing, coal-producing enterprises just learn about transportation quantity in lead time $I_m + 1$. With a certain inventory level, y_t^c is known for coal-producing enterprises, with the rest as random variable.

The demand in period $t+1$:

$$y_{t+1}^{c1} = \left(1+\varphi_1\right)\varphi_0 + \varphi_1 y_t^{c1} + \frac{1+\varphi_1-\varphi_1^{I_p+2}-\varphi_1^{I_c+2}}{1-\varphi_1}\varepsilon_{t+1} + \frac{\varphi_1}{1-\varphi_1}\left(\varphi_1^{I_p+2}+\varphi_1^{I_c+2}-2\right)\varepsilon_t - \varphi_1\xi_t^p - \varphi_1\xi_t^c + \xi_{t+1}^p + \xi_{t+1}^c \quad (15)$$

The demand in period $t+i$:

$$y_{t+i}^{c1} = \varphi_0\left(1+\phi_1\right)\frac{1-\phi_1^i}{1-\phi_1} + \varphi_1^i y_t^c + \frac{1+\varphi_1-\varphi_1^{I_p+2}-\varphi_1^{I_c+2}}{1-\varphi_1}\varepsilon_{t+i} - \sum_{j=1}^{i-1}\phi_1^j\varepsilon_{t+i-j} + \frac{\varphi_1^i\left(\varphi_1^{I_p+2}+\varphi_1^{I_c+2}-2\right)}{1-\varphi_1}\varepsilon_t - \phi_1^i\xi_t^p - \phi_1^i\xi_t^c + \xi_{t+\mathrm{i}}^p + \xi_{t+\mathrm{i}}^c \quad (16)$$

When $a = \frac{1+\varphi_1-\varphi_1^{I_p+2}-\varphi_1^{I_c+2}}{1-\varphi_1}$, $b = \frac{\varphi_1^{I_p+2}+\varphi_1^{I_c+2}-2}{1-\varphi_1}$

The overall demand in lead time:

$$\sum_{j=1}^{I_m+1} y_{t+i}^{c1} = \frac{\varphi_0\left(1+\phi_1\right)}{1\text{-}\phi_1}\left[I_m + 1\text{-}\frac{1\text{-}\phi_1^{I_m+1}}{1\text{-}\phi_1}\right] + \frac{\phi_1\left(1\text{-}\phi_1^{I_m+1}\right)}{1\text{-}\phi_1}y_t^{c1} + \mathrm{a}\sum_{i=1}^{I_m+1}\varepsilon_{t+i} - \sum_{i=1}^{I_m+1}\sum_{j=1}^{i-1}\phi_1^j\varepsilon_{t+i-j} + b\frac{\phi_1\left(1\text{-}\phi_1^{I_m+1}\right)}{1\text{-}\phi_1}\varepsilon_t - \frac{\phi_1\left(1\text{-}\phi_1^{I_m+1}\right)}{1\text{-}\phi_1}\xi_t^p - \frac{\phi_1\left(1\text{-}\phi_1^{I_m+1}\right)}{1\text{-}\phi_1}\xi_t^c + \sum_{i=1}^{I_m+1}\xi_{t+\mathrm{i}}^p + \sum_{i=1}^{I_m+1}\xi_{t+\mathrm{i}}^c \quad (17)$$

At that time, conditional expectation and variance are m_t^{m1} and v_t^{m1} respectively.

$$m_t^{m1} = \frac{\varphi_0\left(1+\phi_1\right)}{1\text{-}\phi_1}\left[I_m + 1\text{-}\frac{1\text{-}\phi_1^{I_m+1}}{1\text{-}\phi_1}\right] + \frac{\phi_1\left(1\text{-}\phi_1^{I_m+1}\right)}{1\text{-}\phi_1}y_t^c$$

$$v_t^{m1} = \sigma^2\left[a^2\left(I_m+1\right) + \frac{\phi_1\left(1\text{-}\phi_1^{I_m+1}\right)}{1\text{-}\phi_1} + b^2\frac{\phi_1^2\left(1\text{-}\phi_1^{I_m+1}\right)^2}{\left(1\text{-}\phi_1\right)^2}\right] + \left\{\left[\frac{\phi_1\left(1\text{-}\phi_1^{I_m+1}\right)}{1\text{-}\phi_1}\right]^2 + \left(I_m+1\right)\right\}D\left(\xi_t^p\right) + \left\{\left[\frac{\phi_1\left(1\text{-}\phi_1^{I_m+1}\right)}{1\text{-}\phi_1}\right]^2 + \left(I_m+1\right)\right\}D\left(\xi_t^c\right)$$

For coal-producing enterprises, the optimum inventory level $s_t^{\mathrm{m}1*}$ in period t is:

$$s_t^{m1*} = m_t^{m1} + k_m\sqrt{v_t^{m1}} \quad (18)$$

where $k_m = \varphi^{-1}\left[p_m \big/ \left(p_m + h_m\right)\right]$, and ϕ are standard normal distribution functions.

2. The Second Type

Under the condition of partial information sharing, when coal-producing enterprises share information, y_t^c is learned information for coal-producing enterprises with certain inventory level, in addition to transportation quantity of lead time I_m+1. Meanwhile, they also have predictive information of coal demand, with conditional expectation and variance as m_t^{c2} and v_t^{c2} respectively.

$$y_{t+1}^{c2} = (1+\varphi_1)\varphi_0 + \varphi_1 y_t^{c2} + \frac{1+\varphi_1-\varphi_1^{I_p+2}-\varphi_1^{I_c+2}}{1-\varphi_1}\varepsilon_{t+1} + \frac{\varphi_1}{1-\varphi_1}\left(\varphi_1^{I_p+2}+\varphi_1^{I_c+2}-2\right)\varepsilon_t - \varphi_1\xi_t^p - \varphi_1\xi_t^c + \xi_{t+1}^p + \xi_{t+1}^c - \frac{\phi_1\left(1-\phi_1^{I_c+1}\right)\left(1-\phi_1^{I_p+1}\right)}{(1-\phi_1)^2}(\varepsilon_t - \varepsilon_{t-1})$$

令 $c = \dfrac{\varphi_1\left(1-\varphi_1^{I_m+1}\right)\left(\varphi_1^{I_p+2}+\varphi_1^{I_c+2}-3+\varphi_1^{I_p+I_c+2}\right)}{(1-\varphi_1)^2}$

$$\sum_{j=1}^{I_m+1} y_{t+i}^{c2} = \frac{\varphi_0(1+\phi_1)}{1-\phi_1}\left[I_m+1-\frac{1-\phi_1^{I_m+1}}{1-\phi_1}\right] + \frac{\phi_1\left(1-\phi_1^{I_m+1}\right)}{1-\phi_1}y_t^{c2} + \mathrm{a}\sum_{i=1}^{I_m+1}\varepsilon_{t+i} - \sum_{i=1}^{I_m+1}\sum_{j=1}^{i-1}\phi_1^j\varepsilon_{t+i-j} + c\varepsilon_t - \frac{\phi_1\left(1-\phi_1^{I_m+1}\right)}{1-\phi_1}\xi_t^p - \frac{\phi_1\left(1-\phi_1^{I_m+1}\right)}{1-\phi_1}\xi_t^c + \sum_{i=1}^{I_m+1}\xi_{t+\mathrm{i}}^p + \sum_{i=1}^{I_m+1}\xi_{t+\mathrm{i}}^c \tag{19}$$

$$m_t^{m2} = \frac{\varphi_0(1+\phi_1)}{1-\phi_1}\left[I_m+1-\frac{1-\phi_1^{I_m+1}}{1-\phi_1}\right] + \frac{\phi_1\left(1-\phi_1^{I_m+1}\right)}{1-\phi_1}y_t^c + c\varepsilon_t$$

$$v_t^{m2} = \sigma^2\left[\left((I_m+1)a^2+\sum_{i=1}^{I_m+1}\sum_{j=1}^{i-1}\phi_1^j\right)\right] + \left\{\left[\frac{\phi_1\left(1-\phi_1^{I_m+1}\right)}{1-\phi_1}\right]^2 + (I_m+1)\right\}D(\xi^p) + \left\{\left[\frac{\phi_1\left(1-\phi_1^{I_m+1}\right)}{1-\phi_1}\right]^2 + (I_m+1)\right\}D(\xi^c)$$

For coal-producing enterprises, the optimum inventory level s_t^{m2*} in period t is:

$$s_t^{m2*} = m_t^{m2} + k_m\sqrt{v_t^{m2}} \tag{20}$$

where $k_m = \varphi^{-1}\left[p_m \big/ (p_m+h_m)\right]$, and ϕ are standard normal distribution functions.

3. The Third Type

With full information-sharing, coal-producing enterprises learn about transportation quantity in lead time I_m+1. With certain inventory level, y_t^c is learned information for coal-producing enterprises. Meanwhile, they also have predictive information and decision deviation, with conditional expectation and variance as m_t^{m3} and v_t^{m3} respectively.

$$\sum_{j=1}^{I_m+1} y_{t+i}^{c3} = \frac{\varphi_0\left(1+\phi_1\right)}{1\text{-}\phi_1}\left[I_m + 1\text{-}\frac{1\text{-}\phi_1^{I_m+1}}{1\text{-}\phi_1}\right] + \frac{\phi_1\left(1\text{-}\phi_1^{I_m+1}\right)}{1\text{-}\phi_1} y_t^c$$

$$+\text{a}\sum_{i=1}^{I_m+1}\varepsilon_{t+i} - \sum_{i=1}^{I_m+1}\sum_{j=1}^{i-1}\phi_1^j\varepsilon_{t+i-j} + c\varepsilon_t - \frac{\phi_1\left(1\text{-}\phi_1^{I_m+1}\right)\left(1\text{-}\phi_1^{I_c+1}\right)}{1\text{-}\phi_1}\xi_t^p \quad (21)$$

$$-\frac{\phi_1\left(1\text{-}\phi_1^{I_m+1}\right)}{1\text{-}\phi_1}\xi_t^c + \sum_{i=1}^{I_m+1}\xi_{t+\text{i}}^p - \frac{\phi_1\left(1\text{-}\phi_1^{I_c+1}\right)}{1\text{-}\phi_1}\xi_{t+}^p + \sum_{i=1}^{I_m+1}\xi_{t+\text{i}}^c$$

$$m_t^{m3} = \frac{\varphi_0\left(1+\phi_1\right)}{1\text{-}\phi_1}\left[I_m + 1\text{-}\frac{1\text{-}\phi_1^{I_m+1}}{1\text{-}\phi_1}\right] + \frac{\phi_1\left(1\text{-}\phi_1^{I_m+1}\right)}{1\text{-}\phi_1} y_t^c$$

$$v_t^{m3} = \sigma^2\left[\left(\left(I_m+1\right)a^2 + \sum_{i=1}^{I_m+1}\sum_{j=1}^{i-1}\phi_1^j\right)\right]$$

For coal-producing enterprises, the optimum inventory level $s_t^{\text{m3*}}$ in period t is:

$$s_t^{m3*} = m_t^{m3} + k_m\sqrt{v_t^{m3}} \quad (22)$$

where $k_m = \varphi^{-1}\left[p_m \big/ \left(p_m + h_m\right)\right]$, and ϕ is standard normal distribution function.

5.4. Value of Information Sharing

For coal enterprises, value of supply chain information sharing is measured from the angle of inventory level. Silver and Peterson (1985) put forward the average inventory level, which is shown as follows under the three conditions.

$$I_t = \left\{s_t - E\left(\sum_{i=1}^{L+1} Y_{t+i}\right) + E\left(Y_t\right)/2\right\} = \left\{s_t - m_t + E\left(Y_t\right)/2\right\} \quad (23)$$

$$I_t^{c_1} = S_t^{c_1} - m_t^{c_1} + E\left(Y_t\right)/2 = k_c\sqrt{v_t^{c_1}} + \frac{\varphi_0}{2\left(1-\varphi_1\right)} \quad (24)$$

$$I_t^{c_2} = S_t^{c_2} - m_t^{c_2} + E\left(Y_t\right)\big/2 = k_c\sqrt{v_t^{c_2}} + \frac{\varphi_0}{2\left(1-\varphi_1\right)} \quad (25)$$

$$I_t^{c_3} = S_t^{c_3} - m_t^{c_3} + E\left(Y_t\right)\big/2 = k_c\sqrt{v_t^{c3}} + \frac{\varphi_0}{2\left(1-\varphi_1\right)} \quad (26)$$

Deduction 1: for any $-1 < \varphi_1 < 1$, $I_t^{c_1} > I_t^{c_2} > I_t^{c_3}$

Deducing process:

$$v_t^{c_1} - v_t^{c_2} = \left[\frac{\phi_1\left(1-\phi_1^{I_c+1}\right)\left(1-\phi_1^{I_p+1}\right)}{\left(1-\phi_1\right)^2}\right]^2\sigma^2$$

$$v_t^{c_1} - v_t^{c3} = \left[\frac{\phi_1 \left(1-\phi_1^{I_c+1}\right)\left(1-\phi_1^{I_p+1}\right)}{\left(1-\phi_1\right)^2} \right]^2 \sigma^2 + \left(I_c+1\right) D\left(\xi_t^p\right)$$

$$v_t^{c2} - v_t^{c3} = \left(I_c+1\right) D\left(\xi_t^p\right)$$

It is shown from the above formula that $I_t^{c_1} - I_t^{c_2} > 0$, $I_t^{c_1} - I_t^{c_3} > 0$, $I_t^{c_2} - I_t^{c_3} > 0$, thus deduction 1 is proved.

The deduction above indicates that when compared with no information sharing, partial information sharing can reduce average inventory level, the lowering level of average inventory level is relevant to ϕ_1 and σ^2. With the rise of ϕ_1 and σ^2, average inventory level goes up. This means that when coal demand is closely correlated with the requirement of earlier stage, partial information has obvious benefit. In the comparison of no information sharing and full information sharing, average inventory level of coal enterprises is related with ϕ_1, σ^2, I_c, and $D\left(\xi_t^p\right)$.

With the increase of ϕ_1, average inventory level of coking coal-producing enterprises goes down, and increases with the increase of I_c. With the rise of $D\left(\xi_t^p\right)$, average inventory level of coking coal-producing enterprises drops greater. Compared with partial information sharing and full information sharing, average inventory level of coking coal-producing enterprises is related with I_c and $D\left(\xi_t^p\right)$. With longer I_c, average inventory level of coking coal-producing enterprises goes down greatly. As $D\left(\xi_t^p\right)$ increases, the decreasing range is larger for the average inventory level of coking coal-producing enterprises.

Under the three information sharing conditions, the average inventory level of coal-producing enterprises is as follows.

$$I_t^{m_1} = S_t^{m_1} - m_t^{m_1} + E\left(Y_t\right)/2 = k_m \sqrt{v_t^{m_1}} + \frac{\varphi_0}{2\left(1-\varphi_1\right)} \tag{27}$$

$$I_t^{m_2} = S_t^{m_2} - m_t^{m_2} + E\left(Y_t\right)/2 = k_m \sqrt{v_t^{m_2}} + \frac{\varphi_0}{2\left(1-\varphi_1\right)} \tag{28}$$

$$I_t^{m_3} = S_t^{m_3} - m_t^{m3} + E\left(Y_t\right)/2 = k_m \sqrt{v_t^{m3}} + \frac{\varphi_0}{2\left(1-\varphi_1\right)} \tag{29}$$

Deduction 2: for any $-1 < \varphi_1 < 1$, $I_t^{m_1} > I_t^{m_2} > I_t^{m_3}$

Deducing process:

$$v_t^{m_1} - v_t^{m_2} = \left[\frac{\phi_1\left(1\text{-}\phi_1^{I_m+1}\right)}{1\text{-}\phi_1} + b^2 \frac{\phi_1^2\left(1\text{-}\phi_1^{I_m+1}\right)^2}{\left(1\text{-}\phi_1\right)^2} - \sum_{i=1}^{I_m+1}\sum_{j=1}^{i-1}\phi_1^j \right]\sigma^2$$

$$v_t^{m_1} - v_t^{m_3} = \sigma^2 \left[\frac{\phi_1\left(1\text{-}\phi_1^{I_m+1}\right)}{1\text{-}\phi_1} + b^2 \frac{\phi_1^2\left(1\text{-}\phi_1^{I_m+1}\right)^2}{\left(1\text{-}\phi_1\right)^2} - \sum_{i=1}^{I_m+1}\sum_{j=1}^{i-1}\phi_1^j \right] + \left\{ \left[\frac{\phi_1\left(1\text{-}\phi_1^{I_m+1}\right)}{1\text{-}\phi_1} \right]^2 + \left(I_m+1\right) \right\} D\left(\xi_t^p\right)$$
$$+ \left\{ \left[\frac{\phi_1\left(1\text{-}\phi_1^{I_m+1}\right)}{1\text{-}\phi_1} \right]^2 + \left(I_m+1\right) \right\} D\left(\xi_t^c\right)$$

$$v_t^{m_2}-v_t^{m_3}=\left\{\left[\frac{\phi_1\left(1\text{-}\phi_1^{I_m+1}\right)}{1\text{-}\phi_1}\right]^2+\left(I_m+1\right)\right\}D\left(\xi_t^p\right)+\left\{\left[\frac{\phi_1\left(1\text{-}\phi_1^{I_m+1}\right)}{1\text{-}\phi_1}\right]^2+\left(I_m+1\right)\right\}D\left(\xi_t^c\right)$$

Based on the analysis above, $I_t^{c_1}-I_t^{c_2}>0$, $I_t^{c_1}-I_t^{c3}>0$, $I_t^{c_2}-I_t^{c_3}>0$.

It is shown from the deduction that partial information sharing can reduce average inventory level, when compared with no information sharing. The lowering degree of average inventory level is relevant to ϕ_1 and σ^2. The average inventory level rises with the increase of ϕ_1 and σ^2, which means that partial information sharing can bring great benefit when coal demand is closely related with requirement of earlier stage. By comparing no information sharing and full information sharing, it is indicated that the reduced average inventory level of coal-producing enterprises is relevant to ϕ_1, σ^2, I_m, $D\left(\xi_t^p\right)$ and $D\left(\xi_t^c\right)$. With the increase of ϕ_1, the average inventory level of coal-producing enterprises falls more. The average inventory level of coal-producing enterprises goes up with the rise of lead time I_m.With rising $D\left(\xi_t^p\right)$ and $D\left(\xi_t^c\right)$, the average inventory level of coal-producing enterprises has bigger decline. By comparing partial information sharing and full information sharing, it is shown that the decreasing degree of the average inventory level has correlation with ϕ_1, σ^2, I_m and $D\left(\xi_t^p\right)$. With longer I_m, the average inventory level of coal-producing enterprises drops off more sharply.

Deduction 3: when $\phi_1=0$, $I_t^{c_1}-I_t^{c_2}=0$, $I_t^{c_1}-I_t^{c3}>0$ $I_t^{c_2}-I_t^{c3}>0$

When coal demand is not correlated with requirement of earlier stage, there is no difference under partial information sharing and no information sharing. Compared with partial information sharing, full information sharing can reduce average inventory level.

6. Numerical Analysis

This chapter verifies the conclusion above and analyzes the influence of ϕ_1, ξ_t^c, ξ_t^p on supply chain information sharing of coal enterprises. Assuming that I_p=2, I_m=3, I_c=2, σ^2=1, $D\left(\xi^c\right)$=20, $D\left(\xi^p\right)$=20, the influence of inventory cost change in coking coal-producing enterprises is analyzed under various information sharing conditions.

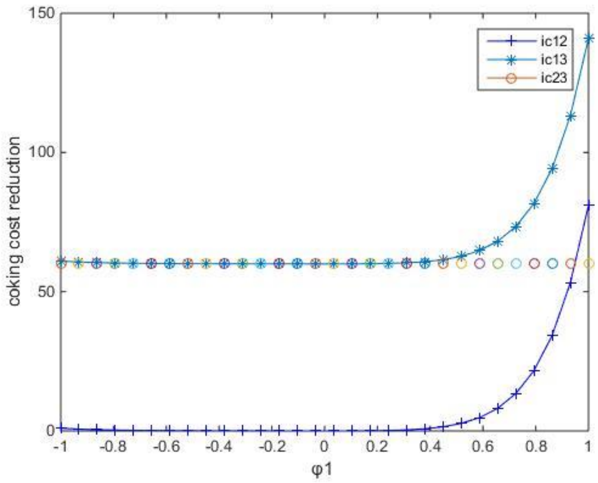

Figure 1. The Influence of ϕ_1 Change on Inventory Cost of Coking Coal-Producing Enterprises

Figure 1, illustrates that when correlation degree of coal demand is higher, full information sharing is the best choice. Partial information sharing can also bring benefits to coking coal-producing enterprises. Under the condition of partial information sharing and full information sharing, cost change of coking coal-producing enterprises is not correlated with ϕ_1. It means that under the condition of partial information sharing and full information sharing, benefit comparison is relevant to decision deviation and lead time. When lead time is longer, the cost of coking coal enterprises is higher. At that time, the benefit of full information sharing is more obvious, variance of decision deviation is greater, and coking coal enterprises save more cost, which can more embody the value of full information sharing.

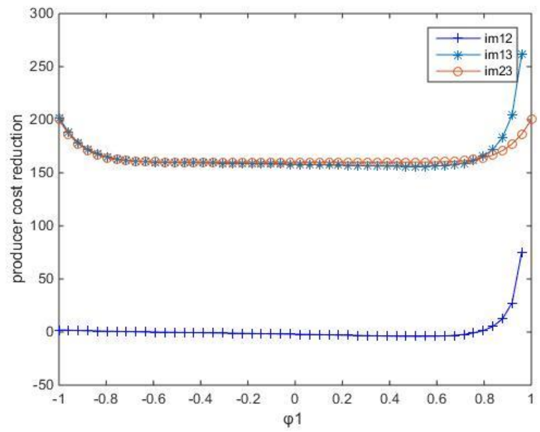

Figure 2. The Influence of ϕ_1 Change on Inventory Cost of Coal-Producing Enterprises

Figure 2, illustrates the influence of ϕ_1 change on inventory cost of coal-producing enterprises. Under the condition of no information sharing and partial information sharing, it can be seen that coal-producing enterprise can save more cost with the increase of ϕ_1, thus obtaining more profit. When the value of ϕ_1 is close to 1, no matter under partial information sharing or full information sharing, coal-producing enterprises can save more cost, that is, greater information sharing value.

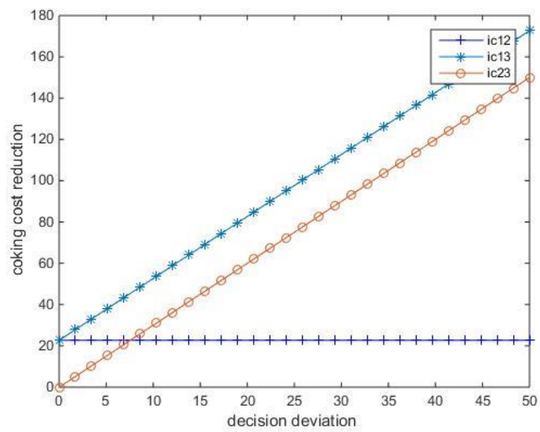

Figure 3. The Influence of Decision Deviation Change on Inventory Cost of Coking Coal-Producing Enterprise

Figure 3, illustrates that under the condition of no information sharing and partial information sharing, there is no difference in the influence of fluctuating decision bias on the cost of coking coal-producing enterprises. In comparison with full information sharing and no information sharing, it can be seen that the value of information sharing is significant, as sharing of decision bias can considerably reduce cost of coking coal-producing enterprises. The same thing is also observed in coking coal-producing enterprises when comparing partial information sharing and full information sharing.

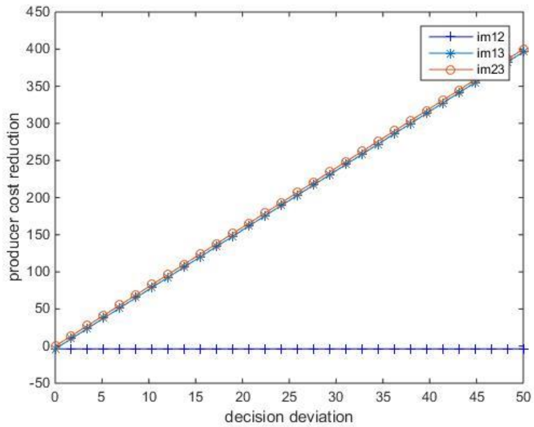

Figure 4. The Influence of Decision Deviation Change on Inventory Cost of Coal-Producing Enterprises

Figure 4, shows the influence of decision deviation change on coal-producing enterprise inventory cost. It can be seen that under the condition of no information sharing and partial information sharing, there is no difference in the influence of fluctuating decision bias on the cost of coal-producing enterprise. Compared with full information sharing and no information sharing, it is shown that information sharing is of great value, as sharing of decision bias can considerably reduce cost of coal-producing enterprises. The same effect is also observed in coal-producing enterprises when comparing partial information sharing and full information sharing.

7. Conclusion

This paper introduces the structural model for the three-level coal enterprise supply chain, and establishes the supply chain information sharing model of three-level coal enterprise. It also analyzes influence of decision bias, correlation degree of coal demand, lead time, and demand variability on multi-level coal enterprise supply chain. In addition, inventory level changes of coal-demand enterprises, coking coal-producing enterprises, and coal-producing enterprises are explored in the analysis on supply chain information sharing value, under the three conditions of no information sharing, partial information sharing, and full information sharing. It was discovered that information sharing has value for coking coal-producing enterprises and coal-producing enterprises, with evaluation of decision bias. A concrete analysis is made on the influence of decision, deviation change on inventory, and cost of coking coal-producing enterprises and coal-producing enterprises.

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