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Financing strategies for coal-electricity supply chain under yield uncertainty

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ABSTRACT

The financing strategies for a coal-electricity supply chain in which the coal company has capital constraint and faces yield uncertainty were studied. We propose an advance payment mechanism: in the coal company's initial production period, the electricity company provides advance payment to the coal company, and the coal company pays interest to the electricity company as the risk compensation. The optimal operation strategies for the coal company and the electricity company under the advance payment mechanism are derived and compared with those under the bank loan financing case. We find that, the expected profit functions of the coal company and the electricity company under the advance payment mechanism are the same with those under the case that the coal company has enough capital; under the advance payment mechanism, the profits of the coal company and the electricity company are higher than those under the bank financing case. We also discuss the compensation interest rate of the advance payment and the ordering and production quantities under the advance payment mechanism.

1. Introduction

Capital constraint is very common for a coal company, and it affects the strategies and profits of the coal-electricity supply chain. How to effectively finance the coal company with capital constraints and uncertain yield is an important research subject.

Supply chain finance is an effective financial mode for the capital constrained company. Most of the researches on supply chain finance focus mainly on capital constraint of the distributor. The existing literatures on financing strategy of capital constrained distributor can be classified into two categories. Papers in one category concentrate on the situation where the distributor applies for loans from financial institutions. Based on the classical newsvendor model, some researchers combine the asset-based financing and inventory decision and establish the leader-follower game of the bank and the distributor [1–4]. Papers in the other category focus on comprehensive decision in forms of trade credit from varies aspects. Related papers include trade credit and comprehensive decision of inventory [5–7]; trade credit and comprehensive decision of optimal ordering quantity [8]; optimal production quantity decision with trade credit [9]; trade credit considered as endogenous variable and motivation tool to study supply chain coordination [10–12]. There are also other literatures comparing exterior financing and trade credit. According to Ref. [13], complementary exists in these two financing methods when the distributor's internal capital stands at an extremely low level. Refs. [14–15] show that when the production cost is relatively low, trade credit financing can reduce double marginal effect more effectively than bank loan financing, otherwise the bank loan financing case performs better.

Recently, problems with two-level trade credits have gained more and more attentions from researchers. With the two-level deferred payment trade credits, the supplier offers the distributor trade credit, and then, the trade credit is offered by the distributor to customers. Some researchers consider the decision of wholesale price, economic ordering quantity, and optimal replenishment cycle with the two-level trade credit [16–18].

In terms of capital insufficiency faced by the supplier, Ref. [19] shows that supply disruption induced by the problem of the supplier financing is an important part of the producer's risk portfolio, and financing subsidy offered by producer can result in a healthy condition of capital for supplier. Ref. [20] considers the effectiveness of the supply chain under the circumstances of supplier's capital constraint in reservation, delegate, and mixed forms. Refs. [21–22] consider the optimal price discount and

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batch-ordering policy of perishable goods in supply chains with advance payments. Capital constraints, to some extent, happen to both the supplier and the distributor in a supply chain. Ref. [23] points out that bank is also willing to grant loans to the distributor as it does for the supplier. Ref. [24] analyzes the decisions involved in optimally structuring the trade credit contract from the supplier's perspective, while the supplier needs borrow a bank loan. They conclude that a risk-neutral supplier should always finance the distributor at rates less than or equal to the risk-free rate.

Several literatures study the operation strategy and coordination mechanism for the coal supply chain. Ref. [25] analyzes the impact of Air Pollutant Emission Policies on Thermal Coal Supply Chain Enterprises in China. Ref. [26] examines a resource constrained production planning and scheduling problem motivated by the coal supply chain. Ref. [27] researches a dynamic optimization model of an integrated coal supply chain system. Ref. [28] designs the peak shaving reserve mechanism to probe into the countermeasures against the coal-electricity price conflicts.

In existing literatures on financing strategy for supplier, the financing problem of the supply chain with uncertain yields hasn't been reported so far. In fact, suppliers in many supply chains have the yields uncertainty [29–32]. For example, there is yields uncertainty in coal-electricity supply chain because of the impact of geological conditions. It is necessary to research the financing strategy of the coal-electricity supply chain with uncertain yield. Based on this background, we consider a coal-electricity supply chain in which the coal company has capital constraint and faces yield uncertainty. The optimal operation strategies for the coal company and the electricity company are derived under the bank loan financing case and the advance payment. We have found that the advance payment mechanism have realized Pareto improvement in the supply chain system over the bank financing case.

The contributions of this paper are listed as follows. First, we consider the yield uncertainty for the coal company. Second, we study the supply chain finance modes for the coal-electricity supply chain. Third, we have found that, the advance payment mechanism have realized Pareto improvement in the coal-electricity supply chain over the bank financing case.

2. Basic assumptions and notations

We consider a coal-electricity supply chain including one coal company and one electricity company. Subscript s indicates the coal company, subscript d indicates the electricity company, and subscript b indicates the bank.

We denote the random variable of productivity yield fluctuation of coal as X. Further, we denote its probability density function as $f(x)$, its distribution function as $F(x)$, and its survive function as $\overline{F}(x)$. We assume that X is positive continuous type random variable. Therefore, $F(x)$ is monotonic increasing, and $\overline{F}(x)$ is monotonic decreasing. The planned production quantity of the coal company is q_s. So the actual yield quantity of the coal is q_sX. q_s is the decision variable of the coal company.

Further, we denote the demand for electricity during the decision period as Y. Further, we denote its probability density function as $g(y)$, its distribution function as $G(y)$, and its survive function as $\overline{G}(y)$. We assume that Y is positive continuous type random variable. Therefore, $G(y)$ is monotonic increasing, and $\overline{G}(y)$ is monotonic decreasing. The price of the coal is p.

We assume that the wholesale price and the production cost of coal are w and c, respectively. The ordering quantity of coal is q_d and q_d is the decision variable of the electricity company. We assume that the output quantity of the electricity from a unit of the coal is 1. In fact, if it is not 1, we can adjust the unit of the electricity to ensure that one unit of the coal can generate one unit of electricity.

The initial cash of the coal company is ς. We assume that $\varsigma < cq_s$, that is, the coal company faces a capital deficit. In this paper, we focus on the effect of the coal company's capital deficit. Therefore, we assume that the initial capital of the electricity company is enough.

We consider a single period. During the period, the expected interest rate of the bank loan is r_1. We do not consider the opportunity cost of the capital. We also assume that both the coal company and the electricity company are risk neutral, thus the coal company and the electricity company make their decisions according to their expected profits.

We propose an advance payment mechanism described as follows. In the coal company's initial production period, the electricity company provides advance payment to the coal company so as to mitigate the coal company's capital constraint (the expected interest rate of the advance payment $r_2 = 0$. To compensate the bankruptcy risk, the coal company pays interest to the electricity company as compensation at the rate of $\bar{r}_2$.

We use subscript $i = 1$ of decision variables and profit variables for the bank financing situation and $i = 2$ for the advance payment situation. First, we will figure out the interest rate decision for the bank under the bank financing and for the electricity company under the advance payment. We assume that interest rate of the bank loan (or the advance payment) $\bar{r}_i$ is chosen so that the bank can earn the expected rate r_i [24]. Then,

$$(1 + r_i)(cq_{si} - \varsigma) = E[\min\{w\min(q_{di}, q_{si}X), (1 + \bar{r}_i)(cq_{si} - \varsigma)\}] \tag{1}$$

It is a two-player game between the coal company and the electricity company, in which the electricity company is the leader and the coal company is the follower. We start with the optimal strategy for the coal company first, then we derive the optimal strategy for the electricity company.

3. Production strategy of the coal company

We consider the optimization problem faced by the coal company. Due to the capital constraint, the coal company needs to apply for a bank loan or an advance payment with the amount of $cq_{si} - \varsigma$. The expected profit of the coal company is (Kouvelis and Zhao, 2012)

$$\pi_{si}(q_{si}) = E[w\min(q_{di}, q_{si}X) - (1 + \bar{r}_i)(cq_{si} - \varsigma)]^+ - \varsigma \tag{2}$$

Among them, $w\min(q_{di}, q_{si}X)$ is the sales income of the coal company. $[w\min(q_{di}, q_{si}X) - (1 + \bar{r}_i)(cq_{si} - \varsigma)]^+$ is the coal company's terminal cash flows. If the fluctuation of yield results in bad revenue, which means that the coal company cannot repay the principal and interest of bank loan (or advance payment), it will receive bankruptcy protection, and its residual asset becomes zero. Then its profit will be $-\varsigma$.

Define

$$\theta_i = \frac{(1 + \bar{r}_i)(cq_{si} - \varsigma)}{wq_{si}} \tag{3}$$

Then it is easy to verify that θ_i is the critical value of X, and $X < \theta_i$ will cause the coal company bankruptcy. Together with Eq. (1), we can rewrite Eq. (2) as

$$\begin{aligned}\pi_{si}(q_{si}) &= E[w\min(q_{di}, q_{si}X)] - (1 + r_i)(cq_{si} - \varsigma)] - \varsigma \\ &= w\int_0^{\frac{q_{di}}{q_{si}}} \overline{F}(x)dx - (1 + r_i)(cq_{si} - \varsigma)] - \varsigma\end{aligned} \tag{4}$$