Received 1 March 2019
Accepted 9 May 2019

Supply chain coordination of biomass moulding fuel under random supply and cyclical demand

Xinning Li
School of Economics and Management, Beijing Forestry University, Beijing, China, and
Kun Fan, Lu Wang and Lang Zhou
Beijing Forestry University, Beijing, China

Abstract

Purpose – The purpose of this paper is to design a contract to coordinate the biomass molding fuel supply chain consisting of a supplier with uncertain supply and a producer with cyclical demand as well as improve the profit of this supply chain.

Design/methodology/approach – In this paper, the supply chain model was build and all the variables and assumptions are set. Stackelberg game model was used to analyze and solve the problem. Furthermore, the authors give numerical examples and result analysis on the basis of data coming from field study and online information about a real biomass fuel supply chain.

Findings – The wholesale price with shortage penalty contract the authors proposed can coordinate the supply chain. And as the dominator of the supply chain, the producer can realize the redistribution of profits within the supply chain by determine the contract parameters.

Research limitations/implications – This one-to-one supply chain is a basic of complex supply chain system. Multi-to-one, one-to-multi and multi-to-multi supply chain can be studied in the future.

Originality/value – The results obtained in this paper can be used as a reference for enterprises in biomass energy supply chain to make contracts and realize the long-term co-operations among supply chain members.

Keywords Supply chain coordination, Biomass moulding fuel, Wholesale price and shortage penalty

Paper type Research paper

1. Introduction

In the case of the fossil energy crisis and the optimization and adjustment of the energy structure in China, biomass energy has been used by more and more enterprises and industries. The increasing utility of forest biomass raw materials can support the reduction of anthropogenic carbon emission to the environment and help forest-dependent communities achieve energy independence while generating jobs (Cambero and Sowlati, 2014). And it is important for supply chain members to reduce carbon emissions through low-carbon progressing (Ji *et al.*, 2017). Based on the current market environment and government policies, the biomass molding fuel supply chain is forming gradually (Xie, 2016).

Biomass fuel refers to energy that is mainly produced by forestry and agricultural residues. Biomass raw materials can be converted into energy in many ways, including direct

The research is supported by the Fundamental Research Funds for the Central Universities (No. 2017ZY68), Beijing Municipal Social Science Foundation (No. 16GLC059), National Natural Science Foundation of China (No. 71502015), Beijing Higher Education Young Elite Teacher Project (No. YETP0776). At the same time, the authors would like to thank editors and reviewers for their contributions to this paper.

Forestry Economics Review
Vol. 1 No. 1, 2019
pp. 106-118
Emerald Publishing Limited
2631-3030
DOI 10.1108/FER-03-2019-0003

combustion, pyrolysis, fermentation, gasification and anaerobic digestion, etc. (Mafakheri and Nasiri, 2014). Accordingly, there are various types of biomass fuel, such as solid, liquid and gas biomass, and the biomass molding fuel is the most widely utilized in boiler combustion. In China, in order to help the formation and development of biomass molding fuel industrialization, there are some core ministries and departments have made policies and financial subsidies to support the enterprise that mainly produce biomass molding fuel.

Actually, the biomass molding fuel supply chain is still inefficient now. There are still many problems in the management, performance and stability because of the area of production, uncertain supply, diversity of use, high cost of transportation and the limit of product market and other factors (Romijn *et al.*, 2014). On one hand, affected by the climate and the growth cycle, random supply often exists in the supply chain. On the other hand, biomass molding fuel producers face a market with cyclical demand, which drives from each enterprise's or resident's cyclical order decisions. For these reasons, the supply chain is not coordinated. We need to develop suitable contracts to improve the supply chain efficiency.

In this paper, we construct a two-stage supply chain model of one supplier and one manufacturer. We use mathematical modeling method and field research method to design an appropriate contract to realize the coordination of biomass molding fuel supply chain. And then we discuss the setting of contract parameters.

2. Literature review

In this paper, we mainly discuss the coordination of biomass molding fuel supply chain under uncertain supply and cyclical demand, which has barely been studied before. However, there are some literatures about supply chain coordination and biomass fuel.

2.1 Supply chain coordination

One of the most important research fields of supply chain coordination is the contract. Supply chain contract refers to the provision of providing appropriate information and incentives to ensure the coordination of buyers and sellers, and optimize the performance of sales channels. Saha and Goyal (2015) researched an inventory and retail price depend on the demand and evaluated the coordination performance of three different contracts in a two-stage supply chain. The common contracts, including wholesale price, revenue sharing, quantity- discount, buy-back, etc., are usually used either exclusively or combinedly. Hu *et al.* (2013) proved that the revenue sharing, the shortage penalty and the tax rebate contract can achieve the coordination of the supply chain consisting of single manufacturer and single supplier under random demand and supplying them, the wholesale price contract is the most common type. It has been found that the wholesale price contract is more effective in a market with the same infinite continuous sales cycle than in a single sales cycle circumstance (Anupindi and Bassok, 1999).

Another factor that needs to be considered in the supply chain coordination is the characteristic of demand and supply. People who have done researches about this theme can be classified into three main aspects based on different types of demand and supply: uncertain supply and deterministic demand, random supply and random demand, demand with a special distribution (Hu and Feng, 2017; Chen, 2011; Xu *et al.*, 2014; Yang *et al.*, 2007). In particular, the demand for biomass molding fuel is cyclical. It is more difficult to predict period demand. At this stage, studies of cyclical demand are most about inventory models and order strategy (Chang and Chou, 2013; Banerjee and Sharma, 2010).

Because of the asymmetric information, double marginalization exists in most supply chains. In order to maximize the whole profit of supply chain and to realize the coordination, some certain game theories are usually adopted in the process of analysis. Among them, the Stackelberg game is used most frequently. Chen *et al.* (2014) first proposed a Bayesian game model to the equilibrium price to maximum the whole utility. Then taking the random supply and demand into consideration, they modeled a Stackelberg game to get the optimal decision.

At the same time, they proposed a shortage penalty and surplus purchase to coordinate the decentralized supply chain. In addition, it has been found that the Stackelberg game, where the demand side is the leader, is more beneficial for businesses to get more profits when the random supply is uniformly distributed (Zhu and Wang, 2011). This is also an important basis for choosing the Stackelberg game model in this paper.

2.2 Biomass fuel

Most research about biomass fuel were from an environmental or economic perspective and some of them were concentrated on supply chain management or optimization (Zamar *et al.*, 2017; Shabani and Sowlati, 2016). Valente *et al.* (2011) used a life cycle assessment (LAC) to describe the woody biomass supply chain, a forest management network and the operations related to the production from the stands to the delivery of woody biomass at the terminal in the mountainous areas of Hedmark and Oppland counties in Norway. They found that the woody biomass in the mountainous areas is a good raw material for bioenergy if the forest management, logistic and technology will be improved. Chun *et al.* proposed a Biomass Element Life Cycle Analysis approach to improve the main steam biomass supply chain with the underutilised biomass sources. Among all the works searched, application to power generation industry was the most widely investigated, since it is the most sustainable and efficient way to burn biomass as the raw material to generate electricity. Shabani *et al.* (2014) considered a situation of supply uncertainty and presented an analysis of biomass power plant supply chain operations management modeling to maximum the profit and minimize the risk on the basis of a linear programming model. However, supply chain coordination in fuel area, especially about biomass fuel has been barely touched in relevant researches.

2.3 Government policies

In recent years, traditional fossil energy has faced many problems such as resource depletion and environmental pollution. Governments have begun to pay more and more attention to energy issues which have become major constraints on global sustainability. The rapid development of biomass energy enterprises will be one of the ways to solve the shortage of fossil energy reserves and serious environmental damage. Government departments provide policy and economic support, such as the government subsidies and tax incentives for biomass products to speed up the industrialization of biomass energy and the conservation of energy. These policies influence the price of biomass solid fuel and contribute to the coordination of the supply chain (Zhou *et al.*, 2016).

2.4 Literature summary

In general, in order to enable the biomass molding fuel supply chain to be coordinated, we can introduce the supply chain contract used in traditional industries into the biomass molding fuel industry. The purpose is to make a contract through information sharing, so that members of the supply chain will make reasonable decisions on production, order and sales to achieve the promotion of the overall profit of the supply chain and the reasonable distribution of profits among the members of the supply chain.

3. Model formulation

In this paper, a supply chain made up of a supplier and a producer where the biomass molding fuel producer is the leader and supplier is the follower is discussed. Forest households, farmers and intermediate buyers are considered as a whole as the supplier. The manufacturer is the enterprise that uses raw materials to make biomass fuels. The market demand is mainly from small or medium-sized power plants and boiler plants. Both the supplier and producer make decisions independently and take profit maximum as a goal.

In the case of the fossil energy crisis and the optimization and adjustment of the energy structure in China, the country's attention and support to the clean and renewable energy industry provide a powerful development condition for biomass energy. Government departments provide policy and economic support, such as the government subsidies and tax incentives for biomass products to speed up the industrialization of biomass energy and the conservation of energy. In our model, the government provides the manufacturer a percentage of subsidies as a promotion to the clean energy development.

On the basis of the model presented by Chen *et al.* (2014) and Liao *et al.* (2010), we establish our model to discuss the biomass molding fuel supply chain coordination. The one-to-one supply chain model is shown in Figure 1.

3.1 Model descriptions and assumptions

In the model, constants and variables are set and described as follow:

- T: the market demand cycle.
- x: the market demand of solid biomass fuel.
- s: residual value of per overproduced solid fuel.
- α: the incentive price coefficient providing to producer.
- π: the whole profit in integrated system.
- β: the raw materials' conversion efficiency.
- p: the unit price of solid biomass fuel.
- c_m: the unit producing cost of producer.
- c_s: the unit supply cost of supplier.
- π_p、 π_s: the profit of producer and supplier in decentralized system.

Then we set the variables of our model as:

- Q: the planning order quantity of producer.
- y: the planning supply quantity of supplier.
- w: unit wholesale price of raw material.
- h: unit shortage penalty of raw material.

Finally, there are some basic assumptions that need to be considered.

The biomass supplier has a planned supply quantity y, while the actual one is θy. Actual supply quantity is randomly affected by many factors. Random variable θ is uniformly distributed in $[A, B]$ with density function $h(\theta)$ and distribution function $H(\theta)$. The At the same time, $E(\theta) = \mu$.

The market demand is cyclical. In each period T, demand function can be described as $x = \int_0^T f(t)dt$ where $f(t)$ is the density function of time t.

The efficiency factor of transferring unit raw material into biomass fuel is β, and $\beta \in (0, 1)$.

Supplier undertakes transportation cost of raw material, which means that c_s includes both producing cost and transportation cost. And p is the unit price of unit biomass fuel when it arrives to customer or market.

If the amount of fuel produced by the producer is higher than the market demand, there will be a residual value s for per extra production with $s < p$.

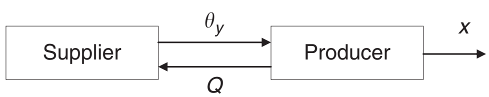

Figure 1. One-to-one supply chain model

3.2 The integrated benchmark

In an integrated supply chain, the whole profit is decided by the cost, income, residual value of biomass fuel and government subsidies. So the profit π is described as:

$$\pi = (1+\alpha)p\,\min(\beta\theta y, x)+s\,\max(\beta\theta y-x, 0)-c_s\theta y-c_m\beta\theta y, \tag{1}$$

The first two items are sales income, government subsidies and residual value of biomass fuel. And the last two items are the costs of providing raw materials and producing biomass fuel. In our model, $x(t)$ is the demand function about time t, so $t(x)$ is the inverse function of $x(t)$. And $t(\beta\theta y)$ represents the value of t where $x = \beta\theta y$.

According to π, the expected profit of integrated supply chain $E(\pi)$ is:

$$E(\pi) = \begin{bmatrix}(1+\alpha)p\\ -s\end{bmatrix}\int_A^B\int_0^{t(\beta\theta y)}(x-\beta\theta y)f(t)dth(\theta)d\theta$$
$$+(1+\alpha)p\beta y\int_A^B\theta h(\theta)d\theta-\ c_s\mu y-c_m\beta\mu y, \tag{2}$$

P1. Expected profit $E(\pi)$ is jointly concave in y, and there exists an exclusive optimal value of y:

$$\frac{dE(\pi)}{dy} = (1+\alpha)p\int_A^B\int_{t(\beta\theta y)}^T\beta\theta f(t)dth(\theta)d\theta$$
$$+s\int_A^B\int_0^{t(\beta\theta y)}\beta\theta f(t)dth(\theta)d\theta-\ c_s\mu-c_m\beta\mu, \tag{3}$$

$$\frac{d^2E(\pi)}{d^2y} = [s-(1+\alpha)p]\beta^2\int_A^B\theta^2h(\theta)d\theta<0. \tag{4}$$

Equation (4) implies the fact that $E(\pi)$ is a strictly concave function about the planning supply quantity y. To get the only solution to the whole profit maximization, Equation (3) is solved as $(\partial E(\pi))/(\partial y)=0$:

$$[s-(1+\alpha)p]\int_A^B\int_0^{t(\beta\theta y)}\beta\theta f(t)dth(\theta)d\theta+(1+\alpha)p\beta\int_A^B\theta h(\theta)d\theta = c_s\mu+c_m\beta\mu. \tag{5}$$

Since $\int_A^B\theta f(\theta)d\theta = \mu$, we have the equation about the optimal order quantity y^* and random yield variable θ that satisfies:

$$\int_A^B\int_0^{t(\beta\theta y)}\theta f(t)dth(\theta)d\theta = \frac{\mu[c_s+c_m\beta-(1+\alpha)p\beta]}{[s-(1+\alpha)p]\beta} = \mu\left[\frac{\frac{c_s}{\beta}+c_m-s}{s-(1+\alpha)p}+1\right]. \tag{6}$$

In the integrated system, the optimal supply quantity y^* has a positive relationship with p and α, and negative correlation with β, which implies that y^* will increase with the increase of incentive price coefficient α, price p. And y^* will increase with the decrease of β.

4. Supply chain coordination

Since the use of biomass raw material is extensive, such as direct combustion, power generation and so on, there is a difference between the supply of the supplier and the order quantity of the producer. Both of them aim at maximizing their own profit. As a result, the double marginal effect emerged. Now, we discuss the problem of coordinating our decentralized supply chain.

To tackle this problem, we proposed a contract called "wholesale price contract with shortage penalty" which means the producer buys the materials from the supplier at a wholesale price. Diverse utilities of biomass raw materials, such as directly burning, power generation and producing other fuels, lead to the supply always being less or nearly equal to producer's order. To guarantee adequate supply of raw material, the supplier will be charged penalty cost if it is out of stock.

In this supply chain, the supplier is the collection of forest households, farmers and intermediate buyers. The number of their raw materials is small, and they have many substitutes. So they are in a bad situation when signing a contract. Therefore, we assume the producer as a leader and the supplier as a follower in a Stackelberg game, which means that the supplier determines its supply according to known information of producer, the market and itself. The producer adjusts its optimal decision and contract terms to maximize its own profit and realize the efficiency of the whole supply chain.

The contract parameters are set as follow:

- *w:* the wholesale price of raw materials.
- *h:* the shortage penalty when the supplier is out of stock.

4.1 Supplier

For supplier, the profit π_s is decided by the sales income, cost of raw materials and shortage penalty. All the revenue of supplier is from raw material sales. In addition to providing biomass raw materials, the cost also includes the shortage penalty of insufficient supply. Then the supplier profit π_s is obtained as:

$$\pi_s = w\min(Q,\theta y) - c_s\theta y - h\max(Q-\theta y, 0). \tag{7}$$

Accordingly, the expected profit of supplier in decentralized supply chain is:

$$\begin{aligned} E(\pi_s) &= w\left[Q\int_{Q/y}^{B} h(\theta)d\theta + \int_{A}^{Q/y}\theta y h(\theta)d\theta\right] - c_s\mu y - h\int_{A}^{Q/y}(Q-\theta y)h(\theta)d\theta \\ &= (w+h)\int_{A}^{Q/y}\theta y h(\theta)d\theta - Q\left[(w+h)H_\theta\left(\frac{Q}{y}\right) - w\right] - c_s\mu y. \end{aligned} \tag{8}$$

In this model, the producer takes the role of a leader and the supplier is a follower. The supplier knows that the producer will determines the order quantity and the contract parameters to maximize the profit of the producer and the whole supply chain. So the supplier will determine its supply to maximize their own profit according to the producer's optimal order quantity. For the supplier, their expected profit $E(\pi_s)$ is strictly concave in y, and the proof is presented as follow:

$$\frac{\partial E(\pi_s)}{\partial y} = (\mathrm{w}+\mathrm{h})\int_{A}^{\frac{Q}{y}}\theta h(\theta)d\theta - c_s\mu, \tag{9}$$

$$\frac{\partial^2 E(\pi_s)}{\partial^2 y} = -\frac{Q^2}{y^3}(w+h)h\left(\frac{Q}{y}\right) < 0. \tag{10}$$

Then Equation (9) can be solved in where $(\partial \mathrm{E}(\pi_s))/(\partial y) = 0$ to get the optimal planning supply y^*.

P2. The supplier's optimal planning supply quantity y^{s*} satisfies:

$$\int_A^{\frac{Q}{y^{s*}}} \theta h(\theta)d\theta = \frac{c_s\mu}{w+h}. \tag{11}$$

From Equation (11), we find that there is an inverse relationship among Q/y^{s*} and w, h that means Q/y^{s*} ratio will increase with a decrease of h or w.

4.2 Producer

In the decentralized system, the whole profit is divided into two parts: supplier profit π_s and producer profit π_p. For producer, the profit π_p is determined by all the revenue from biomass fuel sales, raw materials shortage penalty, residual value of unsold products and the cost of buying raw materials and producing. Given the wholesale price w first decided by producer, unit shortage punishment h and the residual value s, then the profit equation of producer can be expressed as:

$$\begin{aligned}\pi_p &= (1+\alpha)p\min(\beta\theta y, x, \beta Q) + h\max(Q-\theta y, 0)\\ &\quad + s\max(\beta\theta y - x, 0) - w\min(Q, \theta y) - c_p\beta\theta y.\end{aligned} \tag{12}$$

Accordingly, the expected profit of producer in decentralized supply chain is:

$$\begin{aligned}E(\pi_p) &= (1+\alpha)p\left[\int_A^{Q/y}\int_{t(\beta\theta y)}^{T}\beta\theta y f(t)dt h(\theta)d\theta + \int_{Q/y}^{B}\int_{t(\beta Q)}^{T}\beta Q f(t)dt h(\theta)d\theta\right.\\ &\quad \left. + \int_A^{Q/y}\int_0^{t(\beta\theta y)} x f(t)dt h(\theta)d\theta + \int_{Q/y}^{B}\int_0^{t(\beta Q)} x f(t)dt h(\theta)d\theta\right]\\ &\quad + s\int_A^{B}\int_0^{t(\beta\theta y)}(\beta\theta y - x)f(t)dt h(\theta)d\theta + h\int_A^{Q/y}(Q-\theta y)h(\theta)d\theta\\ &\quad - w\left[\int_A^{\frac{Q}{y}}\theta y h(\theta)d\theta + \int_{Q/y}^{B} Q h(\theta)d\theta\right] - c_p\beta\mu y.\end{aligned} \tag{13}$$

To get the optimal planning order quantity Q^*, we can solve Equation (13) by:

$$\frac{\partial E(\pi_p)}{\partial Q} = (1+\alpha)p\int_{Q/y}^{B}\int_{t(\beta Q)}^{T}\beta f(t)dt h(\theta)d\theta + (h+w)H_\theta(Q/y) - w, \tag{14}$$

$$\frac{\partial E(\pi_p)}{\partial Q} = 0 \tag{15}$$

Similar to the proof in *P1* and *P2*, we have $(\partial E^2(\pi_P))/(\partial^2 Q) < 0$. So $E(\pi_p)$ is a concave function about Q:

P3. When the optimal supplying quantity is y^{s*}, the optimal planning order quantity Q^* satisfies:

$$\int_{\frac{Q^*}{y}}^{B}\left[1-F_t(\beta Q)h(\theta)d\theta = \frac{w-(h+w)H(Q^*/y^{s*})}{\beta(1+\alpha)p},\right. \tag{16}$$

where Q^* is the optimal planning order quantity to maximize the producer's profit. Equation (16) implies that the relationship among Q^* and h, w. It shows that Q^* will increase with a decrease of h and w.

The producer takes the role of the leader in this Stackelberg game, which means the supplier makes a decision first, then the producer changes their order decision and contracts terms to coordinate the whole supply chain. In order to realize coordination of the whole supply chain and maximize the profit in the wholesale price contract with shortage penalty, the whole profit in integrated system $E(\pi)$ should be equal to that in decentralized system. So $(\pi) = E(\pi_s)+E(\pi_p)$. At the same time, the optimal supplying quantity is $y^* = y^{s*}$.

We assume that the producer and supplier have full information about the cost and demand, the supplier (follower) adjusts their optimal supply decision to make $y^{s*} = y^*$ while producer (leader) can alter the value of contract terms w and h to increase the supplier's profit and to make sure it not less than the profit without any contracts. So the members will continue to follow the contract:

P4. With the determined y^* and reaction function Equation (11), the producer can adjust his Q^* and contracts terms w and h to reallocate the profit in decentralized system according to the following equation:

$$\frac{\partial E(\pi_s)}{\partial y} = z(w, h, Q) \tag{17}$$

By comparing the problem of integrated supply chain with the decentralized one, coordination performance of wholesale price contract can be measured.

And then a numerical analysis is conducted to verify the research result and get a more intuitive conclusion. From the field research, we get some data and facts about enterprises that mainly produce solid biomass fuels and we take Huibao Energy Ltd and Yongsheng Biomass Fuel Ltd as examples to set the value of some constants in our model.

5. Numerical analysis

The data of this numerical analysis are derived from the production data obtained from a field research of forest product supply chain in Fujian Province, China and the biomass energy development planning "in 13th Five-Year." We integrate the data from 2013 to 2018, and then take the supply chain as an example to verify the research result and get a more intuitive conclusion.

The raw materials' conversion efficiency is approximately 1:0.6, which means a ton of sawdust can be transferred into 0.6 ton of biomass pellet fuel. Then β can be set as 0.6.

The final price of biomass pellet fuel selling to consumers is about RMB1,000–RMB1,500 per ton, and the total unit cost of final production is RMB500, 60 percent of which is producing cost. So the value of p and c_m are set as 1,250 and 300 separately.

For the supplier, the supplying cost c_s of unit raw material is RMB250, and the incentive price coefficient α is assumed as 0.1. Surplus value of unit overproduced fuel s must be smaller than the price p, and it is also lower than the total cost, which means $s < c_s + c_p < p$, so s can be set as 400. In conclusion, according to the survey results and assumptions, the values of some constant variables in the numerical example are presented in Table I.

Variable	cs	cp	s	β	α	p
Value	250	300	400	0.6	0.1	1,250

Table I. Values of some constant variables

Considering the possibility of supply, random yield variable θ is uniformly distributed on $[A, B]$. And $A = 0.7$, $B = 1.0$.

On the other hand, the statistic data from China Information Industry Net and Biomass Energy Development Planning "in 13th Five-Year" shows that the solid biomass fuel demand for one year is almost 30 million tons, and there are about 1,000 companies in the market. We consider 30 days as one order period T, and then the whole demand in a period T is about 2,500 tons for one producer. Therefore, the distribution of x in t is $x = 50 \times t/9$. Then its inverse function is $t = 9 \times x/50$. At the same time, we assume that time t is a discrete variable which is uniformly distributed on [1, 30].

Combining these five conditions, we then get the solution of this research question. In the centralized supply chain, the optimal supply in the integrated system y^* is 218.4, and $\theta y \in [152.88, 218.4]$, $E(\theta y) = 185.64$ according to Equation (6) and the numerical example. In an order period T, the whole profit in the integrated supply chain system is about $E(\pi) = 36{,}662$.

For $y^* = 218.4$, profit of the decentralized system $E(\pi_s) + E(\pi_p)$ will be decided by Q. If we make $E(\pi_s) + E(\pi_p)$ reach the level of $E(\pi)$, which means $E(\pi) = E(\pi_s) + E(\pi_p) = 36{,}662$, then Q would be 217.87. It is almost equal to the optimal supply quantity y^*. At the same time, $w = 250$ and $h = 0$ which means that the supplier's profit in the decentralized system is 0 and the result is showed in Table II.

Under this circumstance, the profit of centralized system and the decentralized are the same, and the supply chain is coordinated by wholesale price contract with shortage penalty. Compared with researches of Liao *et al.* (2010), it seems that the wholesale price contract is able to realize supply chain coordination only under the condition that the wholesale price w is equal to c_s and the producer takes all the profit.

In the decision process of supplier, since $y^{s*} = y^* = 218.4$ is set to realize his profit maximization and the supplier gets almost no profit, the supply chain cooperation will not exist for long. In order to increase supplier's profit and strengthen the cooperation, the producer should adjust their order quantity and contract terms w and h according to the function presented in Equation (17). It is noteworthy that w must be not less than c_s to guarantee supplier's profit and no more than $(p - c_p)$ to keep the producer's profit, so that we set $250 \leqslant w \leqslant 900$. Then we discuss some possible results under different situations.

Situation 1: in Table III, we present the result of different values of *(Q, w, h)* in realizing supplier's optimal profit according to Equation (17). And it also shows the whole profit of decentralized system $E(\pi_s) + E(\pi_p)$.

Table II.
The original coordination result under wholesale price contract

Q*	y^*	w	h	$E(\pi_p)$	$E(\pi_s)$
217.87	218.4	250	0	36,662	0

Table III.
Whole profit of decentralized system $E(\pi_s) + E(\pi_p)$ under different Q and $w{+}h$

y	$w{+}h$	Q	$E(\pi_s) + E(\pi_p)$
218.4	900	173.58	32,598
	800	176	33,091
	700	179.05	33,658
	600	183.05	34,313
	500	188	34,494
	400	196.41	35,851
	300	208.91	36,528
	250	218.4	36,662

From Table III, we can simply get the conclusion that the whole profit of decentralized system will increase with an increase in Q and a decrease in $w+h$. And it will be equal to the integrated supply chain profit when $w+h=250$, that is the wholesale price is 250 and the shortage penalty is 0 ($w=250$, $h=0$). When the value of $w+h$ reaches 900, the whole profit will be down to 32,598 with an order quantity 173.58.

Situation 2: considering a situation close to the real solid biomass fuel industry. $w+h$ is first set a value 650, then the optimal $Q=180.91$ can be directly obtained from Equation (17). The producer can change contract terms (w, h) to reallocate the profit between producer and supplier. And the result is presented in Table IV and Figure 2.

Table IV and Figure 2 show that the profit of producer $E(\pi_p)$ is smaller than 0 when the shortage penalty h is less than 150 in the decentralized system, which is definitely unreasonable. However, for the shortage penalty is higher than 200 and the wholesale price is lower than 450 ($h \geqslant 200$ and $w \leqslant 450$), the producer's profit will increase with an increase of the shortage penalty h and a decrease of the wholesale price w, while the supplier is opposite. Within an appropriate range, the producer is able to choose an enough high value of the shortage penalty h and a lower value of the wholesale price w to raise his own profit.

Situation 3: then we set $w+h=300$ to get a total profit which enough close to the integrated system, and the result is presented in Table V and Figure 3.

It's easy to get the conclusion that the supplier cannot get a reasonable profit for a wholesale price smaller than 250. And when the shortage penalty h goes down and w raises, the supplier can obtain a small part of the profit, but the producer always possesses the most.

y	$w+h$	Q	w	h	$E(\pi_s)$	$E(\pi_p)$	$E(\pi_s)+E(\pi_p)$
218.4	650	180.91	650	0	67,284	−33,310	33,974
			500	150	40,147	−6,173	
			450	200	31,102	2,872	
			400	250	22,057	11,917	
			350	300	13,011	20,963	
			300	350	3,965	30,009	

Table IV.
Values of $E(\pi_p)$ and $E(\pi_s)$ when $w+h=650$

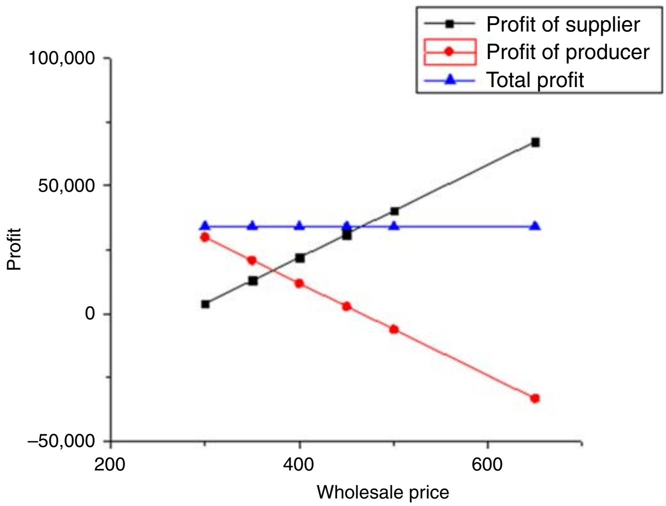

Figure 2.
The changes of profit values when $w+h=650$

In summary, the producer as the leader can choose an appropriate order quantity on the basis of their strategic objectives. For instance, from the perspective of long-term cooperation, the producer can choose the wholesale price is 350 and the shortage penalty is 300 $(w, h) = (350, 300)$, then the expected profit of producer $E(\pi_p)$ is 20,963, and that of supplier $E(\pi_s)$ is 13,011. It is clear that the whole profit of the supply chain is allocated reasonably and this supply chain corporation can last for a long time. However, if the producer occupies almost 92 percent of the whole profit and the supplier thinks this is acceptable, then the supply chain also can realize its coordination when the wholesale price is 270 and the shortage penalty is 30 $(w, h) = (270, 30)$. But the supplier may turn to seek other companies to start another business in order to get more profit.

6. Conclusion

This paper investigates a simple one-to-one supply chain in which the supplier has multiplicative uncertain supply and the producer faces cyclical market demand.

First, the paper analyses the characteristics of biomass solid fuel. Affected by the climate and growth cycle, the supply of raw materials is random. On the other hand, the cyclical order decision makes the market demand of biomass fuel cyclical.

Second, the paper builds the supply chain model according to the characteristics of biomass solid fuel. In the centralized decision-making, it works out the optimal decision of supply, however, there is a difference between the supply of the supplier and the order quantity of the producer. Both of them aim at maximizing their own profit, so the double marginal effect emerged. To solve the problem, a contract of wholesale price with shortage

Table V.
Values of $E(\pi_p)$ and $E(\pi_s)$ when $w+h=300$

y	$w+h$	Q	w	h	$E(\pi_s)$	$E(\pi_p)$	$E(\pi_s) + E(\pi_p)$
218.4	300	208.91	300	0	9,076	27,452	36,528
			290	10	6,987	29,541	
			270	30	2,808	33,720	
			250	50	−5,177	41,705	
			200	100	−11,815	48,343	

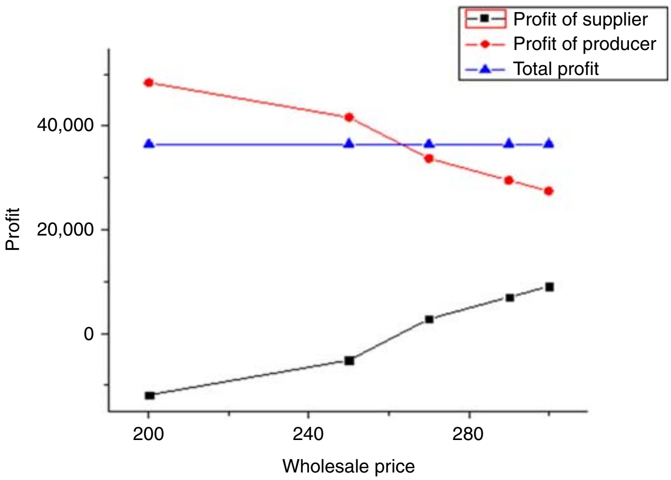

Figure 3.
The changes of profit values when $w+h=300$

penalty is proposed. By analyzing the model, the paper finds that the contract can coordinate this supply chain.

On the basis of model analysis and numerical examples, we find that under the condition of the producer taking the role of a leader, the wholesale price with shortage penalty scheme can realize the supply chain coordination only if the producer occupies the whole profit and the supplier almost gets no profit. And the whole profit in decentralized system can be reallocated when the producer changes his order quantity. The analysis shows that when order quantity increases, the corresponding value of "wholesale price plus shortage penalty" will decrease, and the whole profit will get closer to that in integrated system. As a rational individual, the biomass fuel producer will choose an appropriate range of order quantity to maintain the effectiveness of supply chain. For a producer who aims to get more profit as much as possible and makes the supplier to cooperate, they can choose a value of order quantity in (173.58, 218.4), and accordingly changes the combination of wholesale price and shortage penalty to reallocate the whole profit.

7. Discussion

In this paper, we consider cyclical market demand and uncertain raw material supply in a one to one supply chain, it differs from our research when compared to others in subjects and methods. The results obtained in this paper can be used as a reference for enterprises in biomass energy supply chain to make contracts. The model can be used to determine the contract parameters and the profit distribution of each member. In future researches, a generic function through a demand forecasting method can be simulated, or some typical demand functions and their performance can be designed and compared in the same supply chain. On the other hand, a one to one situation is uncommon in biomass fuel industry, i.e. a producer usually orders from many suppliers, therefore, a supply chain consisting of multi-suppliers and a producer is our next research object. The one-to-one supply chain can be a basis of the research of multi-to-one, one-to-multi and multi-to-multi supply chain. And since the coordination efficiency of wholesale price makes the supplier's profit almost be 0, other contracts like revenue share can be investigated and the coordination performance of these two contracts can also be compared.

References

Anupindi, R. and Bassok, Y. (1999), "Centralization of stocks: retailers vs manufacturer", *Management Science*, Vol. 45 No. 2, pp. 178-191.

Banerjee, S. and Sharma, A. (2010), "Optimal procurement and pricing policies for inventory models with price and time dependent seasonal demand", *Mathematical & Computer Modelling*, Vol. 51 No. 5, pp. 700-714.

Cambero, C. and Sowlati, T. (2014), "Assessment and optimization of forest biomass supply chains from economic, social and environmental perspectives – a review of literature", *Renewable & Sustainable Energy Reviews*, Vol. 36 No. 36, pp. 62-73.

Chang, C.T. and Chou, H.C. (2013), "A coordination system for seasonal demand problems in the supply chain", *Applied Mathematical Modelling*, Vol. 37 No. 6, pp. 3674-3686.

Chen, J. (2011), "Returns with wholesale-price-discount contract in a newsvendor problem", *International Journal of Production Economics*, Vol. 130 No. 1, pp. 104-111.

Chen, Z.M., Chen, Z.X., Business, S.O. and Sun, Y. (2014), "Coordination in a price-negotiable OEM supply chain with random supply and random demand", *Journal of Management Sciences in China*, Vol. 17 No. 5, pp. 43-51.

Hu, B. and Feng, Y. (2017), "Optimization and coordination of supply chain with revenue sharing contracts and service requirement under supply and demand uncertainty", *International Journal of Production Economics*, Vol. 183, pp. 185-193.

Hu, F., Lim, C.C. and Lu, Z. (2013), "Coordination of supply chains with a flexible ordering policy under yield and demand uncertainty", *International Journal of Production Economics*, Vol. 146, pp. 686-693.

Ji, J., Zhang, Z. and Yang, L. (2017), "Carbon emission reduction decisions in the retail-/dual-channel supply chain with consumers' preference", *Journal of Cleaner Production*, Vol. 141, pp. 852-867.

Liao, L., Yao-Hua, W.U. and Sun, G.H. (2010), "Contract coordination for a two-stage supply chain with random yield", *Computer Integrated Manufacturing Systems*, Vol. 16 No. 8, pp. 1733-1741.

Mafakheri, F. and Nasiri, F. (2014), "Modeling of biomass-to-energy supply chain operations: applications, challenges and research directions", *Energy Policy*, Vol. 67 No. 67, pp. 116-126.

Romijn, H., Heijnen, S., Colthoff, J.R., Jong, B.D. and Eijck, J.V. (2014), "Economic and social sustainability performance of Jatropha projects: results from field surveys in Mozambique, Tanzania and Mali", *Sustainability*, Vol. 6 No. 9, pp. 6203-6235.

Saha, S. and Goyal, S.K. (2015), "Supply chain coordination contracts with inventory level and retail price dependent demand", *International Journal of Production Economics*, Vol. 161, pp. 140-152.

Shabani, N. and Sowlati, T. (2016), "A hybrid multi-stage stochastic programming-robust optimization model for maximizing the supply chain of a forest-based biomass power plant considering uncertainties", *Journal of Cleaner Production*, Vol. 112, pp. 3285-3293.

Shabani, N., Sowlati, T., Ouhimmou, M. and Rönnqvist, M. (2014), "Tactical supply chain planning for a forest biomass power plant under supply uncertainty", *Energy*, Vol. 78, pp. 346-355.

Valente, C., Hillring, B.G. and Solberg, B. (2011), "Bioenergy from mountain forest: a life cycle assessment of the Norwegian woody biomass supply chain", *Scandinavian Journal of Forest Research*, Vol. 26 No. 5, pp. 429-436.

Xie, G. (2016), "Cooperative strategies for sustainability in a decentralized supply chain with competing suppliers", *Journal of Cleaner Production*, Vol. 113, pp. 807-821.

Xu, G., Dan, B., Zhang, X. and Liu, C. (2014), "Coordinating a dual-channel supply chain with risk-averse under a two-way revenue sharing contract", *International Journal of Production Economics*, Vol. 147 No. 1, pp. 171-179.

Yang, S., Yang, J. and Abdel-Malek, L. (2007), "Sourcing with random yields and stochastic demand: a newsvendor approach", *Computers & Operations Research*, Vol. 34 No. 12, pp. 3682-3690.

Zamar, D.S., Gopaluni, B., Sokhansanj, S. and Newlands, N.K. (2017), "A quantile-based scenario analysis approach to biomass supply chain optimization under uncertainty", *Computers and Chemical Engineering*, Vol. 97, pp. 114-123.

Zhou, Q., Yabar, H., Mizunoya, T. and Higano, Y. (2016), "Exploring the potential of introducing technology innovation and regulations in the energy sector in china: a regional dynamic evaluation model", *Journal of Cleaner Production*, Vol. 112, pp. 1537-1548.

Zhu, L. and Wang, S.D. (2011), "Game Analysis of a Two-Echelon Supply Chain with Random Yield", *Journal of Systems & Management*, Vol. 20 No. 6, pp. 734-738.

Further reading

Lim, C.H. and Lam, H.L. (2016), "Biomass supply chain optimisation via novel biomass element life cycle analysis (BELCA)", *Applied Energy*, Vol. 161, pp. 733-745.

Corresponding author
Kun Fan can be contacted at: fankun@bjfu.edu.cn