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Optimization of Fuzzy Production and Financial Investment Planning Problems

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Abstract

Production and financial investment planning is the arrangements for the quantity of products and the investment in financial products of a firm. This paper develops a new two-stage fuzzy optimization method for production and financial investment planning problem, in which the exchange rate is uncertain and characterized by possibility distribution. The objective of the problem is to maximize the firm's profit. We use Lebesgue-Stieltjes (L–S) integral to measure the firm's profit in the second stage. When demands are deterministic, we decompose the original feasible region to several subregions, and derive the equivalent linear programming model of the proposed programming problem in each subregion. Furthermore, we employ decomposition method to solve the proposed production and financial investment planning problem. Finally, one numerical example is presented to demonstrate the validity of the proposed model and the effectiveness of the solution method.

Keywords: production and financial planning, option, fuzzy programming, L–S integral, domain decomposition

1 Introduction

Production and financial investment planning can be viewed as the firm's decision about how much to produce and how much funds to invest in each financial markets. With the expansion of the economic, firms locate activities of their supply chain all over the world. In global markets, production and financial investment planning is a complex process, in which the managers may face various uncertainty like exchange rates, market demands, consumption levels and option prices that may affect the production and financial investment planning. For example, Mello and Parsons [15] constructed a model of a multinational firm with flexibility in sourcing its production and with the ability to use financial markets to reduce exchange rate risk. Since current options were frequently used for reducing the risk of uncertain exchange rate [17], Huchzermeier and Cohen [6] developed a stochastic dynamic programming formulation for the valuation of global manufacturing strategy options under exchange rate uncertainty. The production planning problem in [3] was about delaying allocation of the products to the specific markets. Kazaz et al. [7] analyzed the impact of exchange rate uncertainty on the choice of optimal production policies of excess capacity and postponed allocation. Ding et al. [4] considered the production and financial investment planning under uncertain exchange rate and analyzed the impact of delayed allocation and the financial options on the firm's performance.

On the basis of fuzzy theory [10, 25, 26], the production and financial planning problem has also been studied in the literature. Wang and Fang [22] presented a novel fuzzy linear programming method that allowed a decision maker to model a problem according to the current information. According to Black and Scholes [1] and Merton [16], Lee et al. [8] presented a new application of fuzzy theory to the option pricing and combined fuzzy decision theory and Bayes' rule to measure fuzziness in the practice of option analysis. Sun et al. [20, 21] presented two classes of two-stage fuzzy material procurement planning models based on different optimization criteria. Feng and Yuan [5] and Yuan [24] developed two-stage fuzzy optimization methods for multi-product multi-period production planning problem. Sun [19] studied global production planning problem with fuzzy exchange rates. Yang and Liu [23] developed a mean-risk fuzzy optimization

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method for supply chain network design problem. For recent development of two-stage fuzzy optimization theory and its applications, the interested reader may refer to [9, 11, 12, 13, 14, 18] and the references therein.

Motivated by the work mentioned above, the purpose of this paper is to study the production and financial investment planning problems by two-stage fuzzy optimization method. We assume the exchange rates are uncertain and described by possibility distribution, and construct objective function by using L–S integral [2]. When demands are deterministic, we decompose the feasible region to five subregions, and derive the equivalent linear programming problem of the proposed programming model in each subregion. Then, we employ decomposition method to solve the obtained programming model.

The structure of this paper is organized as follows. Section 2 builds a novel model for the production and financial investment planning problem. Section 3 discusses the equivalent linear programming model and design a feasible region decomposition method. Section 4 provides some numerical experiments to illustrate the proposed method. Section 5 gives the conclusions of this paper.

2 Formulation of Problem

The problem we addressed in this section is about the production and financial investment planning of a global firm with a single production facility located in the domestic market. The firm sells product to both home and foreign markets and faces the uncertain exchange rate. The manager decides to buy financial option contracts as the financial investment. To optimize the problem, we employ two-stage optimization method to model a firm's decisions. In the first stage, a capacity plan for the production facility is developed, and appropriate financial hedging contracts on the foreign currency should be decided before the exchange rate is known. In the second stage, after observing the exchange rate, the firm makes production allocation decisions and the financial decisions to optimize its profits. To describe our problem, we adopt the following notations:

Decision variables

X: capacity reserved in the first stage.

$\mathbf{Q}_C$: the row vectors of the call options' contract size in the first stage, $\mathbf{Q}_C = (Q_{C_i})_{i=1}^2$.

$\mathbf{y}$=$(y_j)_{j=1}^2$: represents the products shipped to two markets in the second stage.

Uncertain parameter

$\tilde{\xi}$: fuzzy variable that represents the foreign market currency exchange rate.

Fixed parameters

$\mathbf{d}$=$(d_i)_{i=1}^2$: represents the demands in two markets.

c: unit capacity reservation cost in home currency.

p_i: product price in market i (in market i currency), $i = 1, 2$.

τ_i: relevant unit localization costs for market i shipped (in market 1 currency), $i = 1, 2$.

$C(S_C)$: the price of unit call option with exercise price S_C in stage 1, determined by the option pricing theory.

P: represents the total contract size that the firm plans to invest (determined by the firm's economic strength).

$\mathbf{S}_C$: the row vectors of exercise prices of call options, $\mathbf{S}_C = (S_{C_i})_{i=0}^2$.

The firm's profit in market 2 is related to the exchange rate, so the exchange rate can influence the decisions of the firm. The firm has two markets to supply product. The profits of unit product in market 1 and market 2 are $p_1 - \tau_1$, $\xi p_2 - \tau_2$, respectively, and only the profit in market 2 will be affected by the exchange currency. Comparing two markets returns, we consider the profit in market 2 in the following three special cases.

Case I: the profit in market 2 is larger than market 1, $\xi p_2 - \tau_2 > p_1 - \tau_1$, which implies $\xi > (p_1 - \tau_1)/p_2 + \tau_2/p_2$.

Case II: the profit in market 2 is negative, $\xi p_2 - \tau_2 < 0$, that is, $\xi < \tau_2/p_2$.

Case III: the profit in market 2 is smaller than market 1 but positive, $0 < \xi p_2 - \tau_2 < p_1 - \tau_1$, which implies $\tau_2/p_2 < \xi < (p_1 - \tau_1)/p_2 + \tau_2/p_2$.

In any case mentioned above, the manager will face some loss from market 2 if he makes a wrong decision in the first stage. To reduce the risk from the exchange rate, we choose τ_2/p_2 and $\tau_2/p_2 + (p_1 - \tau_1)/p_2$ as exercise prices of call options, and denote $\mathbf{S}_C = (S_{C_1}, S_{C_2}) = (\tau_2/p_2, \tau_2/p_2 + (p_1 - \tau_1)/p_2)$.

Based on the notations above, we formulate the optimal production and financial planning problem as the following two-stage optimization model:

$$
\begin{array}{ll}
\max & U = -(cX + C(S_{C_1})Q_{C_1} + C(S_{C_2})Q_{C_2})e^{\gamma T} + \int\limits_{\Re} Q(X, Q_{C_1}, Q_{C_2}, \xi)d\alpha(\xi) \\
\text{s.t.} & X \geq 0, \\
& 0 \leq C(S_{C_1})Q_{C_1} + C(S_{C_2})Q_{C_2} \leq P, \\
& Q_{C_i} \geq 0, \quad i = 1, 2,
\end{array}
\tag{1}
$$

where γ is the risk-free interest rate in home currency, T is the time-to-maturity of the option, $Q(X,Q_{C_1},Q_{C_2},\xi)$ is the optimal value of the following programming problem

$$
\begin{array}{rll}
Q(X, Q_{C_1}, Q_{C_2}, \xi) = & \max & (p_1 - \tau_1)y_1 + (\xi p_2 - \tau_2)y_2 + (\xi - S_{C_1})^+Q_{C_1} + (\xi - S_{C_2})^+Q_{C_2} \\
& \text{s.t.} & y_j \geq 0, \quad j = 1, 2, \\
& & y_j \leq d_j, \quad j = 1, 2, \\
& & y_1 + y_2 \leq X,
\end{array}
\tag{2}
$$

and $\alpha(\xi)$ is the credibility distribution of $\tilde{\xi}$, $\alpha(\xi) = \text{Cr}\{\tilde{\xi} \leq \xi\}$.

3 Model Analysis and Solution Method

In this section, we first discuss the equivalent model of problem (1). Our method is based on the assumption that demands are deterministic and decompose the feasible region to several disjoint subregions.

3.1 Equivalent Programming Models

Comparing the demands d_1, d_2 and the capacity X, we divide the capacity into five subregions and discuss the equivalent programming model in each subregion.

Proposition 1. *If $0 \leq X < \min(d_1, d_2)$, then problem (1) is equivalent to the following linear programming*

$$
\begin{array}{ll}
\max & U = a_1X + b_1Q_{C_1} + c_1Q_{C_2} \\
\text{s.t.} & 0 \leq X \leq \min(d_1, d_2), \\
& 0 \leq C(S_{C_1})Q_{C_1} + C(S_{C_2})Q_{C_2} \leq P, \\
& Q_{C_i} \geq 0, \quad i = 1, 2,
\end{array}
\tag{3}
$$

where

$$
\begin{array}{l}
a_1 = -ce^{\gamma T} + (p_1 - \tau_1)\int_{[0,S_{C_2}]} 1d\alpha(\xi) + p_2\int_{[S_{C_2},+\infty)} \xi d\alpha(\xi) - \tau_2(1 - \alpha(S_{C_2}^{-1})), \\
b_1 = -C(S_{C_1})e^{\gamma T} + \int_{[S_{C_1},+\infty)} \xi d\alpha(\xi) - S_{C_1}(1 - \alpha(S_{C_1}^{-1})), \\
c_1 = -C(S_{C_2})e^{\gamma T} + \int_{[S_{C_2},+\infty)} \xi d\alpha(\xi) - S_{C_2}(1 - \alpha(S_{C_2}^{-1})).
\end{array}
$$

Proof. According to the earning in two markets, we divide the exchange rate into three parts. The first part is $[-\infty, S_{C_1})$, the second part is $[S_{C_1}, S_{C_2})$, and the third part is $[S_{C_2}, +\infty)$. When the capacity $X \in (0, min(d_1, d_2))$, we can find the optimal solutions in the second stage.

If $\xi \geq \tau_2/p_2 + (p_1 - \tau_1)/p_2$, then the optimal solutions $y_1 = \min((X - d_2)^+, d_1), y_2 = \min(X, d_2)$. If $\tau_2/p_2 \leq \xi < \tau_2/p_2 + (p_1 - \tau_1)/p_2$, then the optimal solutions $y_1 = \min(X, d_1), y_2 = \min((X - d_1)^+, d_2)$. If $\xi < \tau_2/p_2$, then the optimal solutions $y_1 = \min(X, d_1), y_2 = 0$. As a consequence, we obtain the optimal value function Q of the second stage,

$$
Q = \begin{cases}
(\xi p_2 - \tau_2)X + (\xi - S_{C_1})Q_{C_1} + (\xi - S_{C_2})Q_{C_2}, \ \xi \in [-\infty, S_{C_1}), \\
(p_1 - \tau_1)X + (\xi - S_{C_1})Q_{C_1}, \ \xi \in [S_{C_1}, S_{C_2}), \\
(p_1 - \tau_1)X, \ \xi \in [S_{C_2}, +\infty).
\end{cases}
\tag{4}
$$

The objective function U of problem (1) can be written as

$$U = -(cX + C(S_{C_1})Q_{C_1} + C(S_{C_2})Q_{C_2})e^{\gamma T} + \int_{[0,+\infty)} Q d\alpha(\xi).$$

According to the representation of Q, we have

$$\begin{aligned} U =& (-ce^{\gamma T} + \int_{[0,S_{C_2})} (p_1 - \tau_1) d\alpha(\xi))X \\ &+ (\int_{[S_{C_1},+\infty)} (\xi - S_{C_1}) - C(S_{C_1})e^{\gamma T} d\alpha(\xi))Q_{C_1} \\ &+ (\int_{[S_{C_2},+\infty)} (\xi - S_{C_2}) - C(S_{C_2})e^{\gamma T} d\alpha(\xi))Q_{C_2}, \end{aligned}$$

which completes the proof of proposition. □

Proposition 2. *If $d_1 \le d_2$, and $d_1 < X \le d_2$, then problem (1) is equivalent to the following linear programming*

$$\begin{array}{ll} \max & U = a_2 X + b_2 Q_{C_1} + c_2 Q_{C_2} + d_2 \\ \text{s.t.} & d_1 < X \le d_2, \\ & 0 \le C(S_{C_1})Q_{C_1} + C(S_{C_2})Q_{C_2} \le P, \\ & Q_{C_i} \ge 0, \quad i = 1, 2, \end{array} \tag{5}$$

where

$$\begin{aligned} a_2 &= -ce^{\gamma T} + p_2 \textstyle\int_{[S_{C_1},+\infty)} \xi d\alpha(\xi) - \tau_2(1 - \alpha(S_{C_1}^{-1})), \\ b_2 &= -C(S_{C_1})e^{\gamma T} + \textstyle\int_{[S_{C_1},+\infty)} \xi d\alpha(\xi) - S_{C_1}(1 - \alpha(S_{C_1}^{-1})), \\ c_2 &= -C(S_{C_2})e^{\gamma T} + \textstyle\int_{[S_{C_2},+\infty)} \xi d\alpha(\xi) - S_{C_2}(1 - \alpha(S_{C_2}^{-1})), \\ d_2 &= [(p_1 - \tau_1) \textstyle\int_{[0,S_{C_2})} 1 d\alpha(\xi) - p_2 \textstyle\int_{[S_{C_1},S_{C_2})} \xi d\alpha(\xi) + \tau_2 d_1(\alpha(S_{C_2}^{-1}) - \alpha(S_{C_1}^{-1})). \end{aligned}$$

Proof. The proof is similar to that of Proposition 1. □

Proposition 3. *If $d_2 \le d_1$, and $d_2 < X \le d_1$, then problem (1) is equivalent to the following linear programming*

$$\begin{array}{ll} \max & U = a_3 X + b_2 Q_{C_1} + c_3 Q_{C_2} + d_3 \\ \text{s.t.} & d_2 < X \le d_1, \\ & 0 \le C(S_{C_1})Q_{C_1} + C(S_{C_2})Q_{C_2} \le P, \\ & Q_{C_i} \ge 0, \quad i = 1, 2, \end{array} \tag{6}$$

where

$$\begin{aligned} a_3 &= -ce^{\gamma T} + (p_1 - \tau_1)(1 - \alpha(0^{-1})), \\ b_3 &= -C(S_{C_1})e^{\gamma T} + \textstyle\int_{[S_{C_1},+\infty)} \xi d\alpha(\xi) - S_{C_1}(1 - \alpha(S_{C_1}^{-1})), \\ c_3 &= -C(S_{C_2})e^{\gamma T} + \textstyle\int_{[S_{C_2},+\infty)} \xi d\alpha(\xi) - S_{C_2}(1 - \alpha(S_{C_2}^{-1})), \\ d_3 &= [p_2 \textstyle\int_{[S_{C_2},+\infty)} \xi d\alpha(\xi) - (\tau_2 + p_1 - \tau_1) d_2(1 - \alpha(S_{C_1}^{-1})). \end{aligned}$$

Proof. The proof is similar to that of Proposition 1. □

Proposition 4. *If $\max(d_1, d_2) < X \le d_1 + d_2$, then problem (1) is equivalent to the following linear programming*

$$\begin{array}{ll} \max & U = a_4 X + b_4 Q_{C_1} + c_4 Q_{C_2} + d_4 \\ \text{s.t.} & \max(d_1, d_2) < X \le d_1 + d_2, \\ & 0 \le C(S_{C_1})Q_{C_1} + C(S_{C_2})Q_{C_2} \le P, \\ & Q_{C_i} \ge 0, \quad i = 1, 2, \end{array} \tag{7}$$

where

$$a_4 = -ce^{\gamma T} + (p_1 - \tau_1)\int_{[S_{C_2},+\infty)} 1 d\alpha(\xi) + p_2 \int_{[S_{C_1},S_{C_2})} \xi d\alpha(\xi) - \tau_2(\alpha(S_{C_2}^{-1}) - \alpha(S_{C_1}^{-1})),$$
$$b_4 = -C(S_{C_1})e^{\gamma T} + \int_{[S_{C_1},+\infty)} \xi d\alpha(\xi) - S_{C_1}(1 - \alpha(S_{C_1}^{-1})),$$
$$c_4 = -C(S_{C_2})e^{\gamma T} + \int_{[S_{C_2},+\infty)} \xi d\alpha(\xi) - S_{C_2}(1 - \alpha(S_{C_2}^{-1})),$$
$$d_4 = [(p_1 - \tau_1)\int_{[0,S_{C_2})} 1 d\alpha(\xi) - p_2 \int_{[S_{C_1},S_{C_2})} \xi d\alpha(\xi) + \tau_2 d_1(\alpha(S_{C_2}^{-1}) - \alpha(S_{C_1}^{-1})),$$
$$+[p_2 \int_{[S_{C_2},+\infty)} \xi d\alpha(\xi) - (\tau_2 + p_1 - \tau_1)(1 - \alpha(S_{C_2}^{-1})).$$

Proof. The proof is similar to that of Proposition 1. □

Proposition 5. *If $d_1 + d_2 < X$, then problem (1) is equivalent to the following linear programming*

$$\begin{array}{ll} \max & U = a_5 X + b_5 Q_{C_1} + c_5 Q_{C_2} + d_5 \\ \text{s.t.} & d_1 + d_2 < X, \\ & 0 \le C(S_{C_1})Q_{C_1} + C(S_{C_2})Q_{C_2} \le P, \\ & Q_{C_i} \ge 0, \quad i = 1, 2, \end{array} \tag{8}$$

where

$$a_5 = -ce^{\gamma T},$$
$$b_5 = -C(S_{C_1})e^{\gamma T} + \int_{[S_{C_1},+\infty)} \xi d\alpha(\xi) - S_{C_1}(1 - \alpha(S_{C_1}^{-1})),$$
$$c_5 = -C(S_{C_2})e^{\gamma T} + \int_{[S_{C_2},+\infty)} \xi d\alpha(\xi) - S_{C_2}(1 - \alpha(S_{C_2}^{-1})),$$
$$d_5 = [(p_1 - \tau_1)\int_{[0,+\infty)} 1\alpha(\xi)]d_1 + [p_2 \int_{[S_{C_1},+\infty)} \xi d\alpha(\xi) - \tau_2(1 - \alpha(S_{C_1}^{-1}))]d_2.$$

Proof. The proof is similar to that of Proposition 1. □

Based on the obtained results, we conclude that problem (1) is a piecewise linear programming model provided that the demands are deterministic. Using this structural characteristic, we will discuss the decomposition method for the solution of problem (1) in the next section.

3.2 Decomposition Method

So far, we have derived the equivalent linear programming model of the proposed programming problem in each subregion. Using the obtained results, we next suggest a method to find the global optimal solution and the optimal value. We first divide the original feasible region into four subregions. Then, we derive the equivalent linear programming model in each subregion. After that, we find the local optimal solutions by solving the linear programming in its subregion. Finally, the global optimal solutions can be found from the obtained local optimal solutions. The feasible region decomposition method is summarized as follows.

Step 1. Divide the capacity X into four parts:

$$\text{I: } X \in [0, \min(d_1, d_2)], \qquad \text{II: } X \in [d_1, d_2](or X \in [d_2, d_1]),$$
$$\text{III: } X \in [\max(d_1, d_2), d_1 + d_2], \qquad \text{IV: } X \in [d_1 + d_2, +\infty).$$

Step 2. Solve linear programming (3), (5)(or (6)), (7), (8), respectively.

Step 3. Compare the objective values of local optimal solutions obtained in Step 2.

Step 4. Select the best local optimal solution as the global optimal solution.

Sice the capacity and the investment of contract are always integers, it is required to solve the integral linear programming in Step 2. In the next section, we will give a numerical example to illustrate the developed mathod and use LINDO to solve the integer linear programming.

4 A Numerical Example

In this section, we present an example to illustrate the proposed method in the above section.

4.1 Problem Description

Based on previous experience, a clothing factory decides to invest in the domestic market and New Zealand market. Before the production, two markets provide the demands to the factory. To obtain a satisfactory profit, the factory signs a currency option contract with Bank. The related parameters are shown in Table 1.

Table 1: The values of parameters in numerical experiments

c	p_1	p_2	τ_1	τ_2	$e^{\gamma T}$
30 RMB	60 RMB	25 NZD	5R MB	30 RMB	$e^{0.05}$
S_{C_1}	S_{C_2}	$C(S_{C_1})$	$C(S_{C_2})$	d_1	d_2
1.2	3.4	3.86RMB	1.97RMB	10000	8000

The total money that the firm plans to invest to the currency options is less than the total cost of capacity, i.e. $P \leq 30X$. The New Zealand market currency exchange rate ξ is assumed to follow a logarithmic normal distribution with the following credibility distribution

$$\alpha(\xi) = \mathrm{Cr}\{\xi \leq t\} = \begin{cases} \frac{1}{2}e^{-2(\ln t - 1.6)^2}, & \ln t \leq 1.6, \\ 1 - \frac{1}{2}e^{-2(\ln t - 1.6)^2}, & \ln t > 1.6. \end{cases}$$

Thus, the factory's production and financial planning problem is built as the following mathematical model

$$\begin{aligned} \max \quad & U = -(30X + 3.86Q_{C_1} + 1.97Q_{C_2})e^{0.05} \\ & \quad + \int_{(0,+\infty)} 55y_1 + (25\xi - 30)y_2 + (\xi - 1.2)^+ Q_{C_1} + (\xi - 3.4)^+ Q_{C_2} d\alpha(\xi) \\ \text{s. t.} \quad & 3.86Q_{C_1} + 1.97Q_{C_2} - 30X \leq 0, \\ & y_1 + y_2 \leq X, \\ & y_1 \leq 10000, y_2 \leq 8000, \\ & X \geq 0, Q_{C_i} \geq 0 \quad i = 1, 2. \end{aligned} \tag{9}$$

4.2 Computational Results

In this section, we solve problem (9) by the feasible region decomposition method. First, we divide the feasible region into four subregions:

$$\text{I: } X \in [0, 8000], \qquad \text{II: } X \in (8000, 10000],$$
$$\text{III: } X \in (10000, 18000], \qquad \text{IV: } X \in (18000, +\infty),$$

and solve linear programming (3), (5), (7) and (8), respectively. The obtained optimal solutions and their objective values are collected in Tables (2)–(5).

Table 2: The solution in region I

Optimal Value	U	987725.6 RMB
Optimal Solution	X	8000
	Q_{C_1}	0
	Q_{C_2}	121827

Table 3: The solution in region II

Optimal Value	U	1070422.3 RMB
Optimal Solution	X	10000
	Q_{C_1}	0
	Q_{C_2}	152284

Table 4: The solution in region III

Optimal Value	U	1331159.9 RMB
Optimal Solution	X	18000
	Q_{C_1}	0
	Q_{C_2}	274111

Table 5: The solution in region IV

Optimal Value	U	1331159 RMB
Optimal Solution	X	18000
	Q_{C_1}	0
	Q_{C_2}	274111

By comparing the optimal values in four subregions, we find that the global optimal solution $X = 18000$, $(Q_{C_1}, Q_{C_2}) = (0, 274111)$ in the third subregion, whose objective value is $U = 1331159.9$ RMB. That is, the factory should produce 18000 pieces of products to meet the demands of both markets, and choose the call option 274111 to minimize the risk.

5 Conclusions

In fuzzy decision systems, this paper addressed the production and financial investment planning problem, and obtained the following new results.

(*i*) Based on the credibility distribution, we employed L–S integral to measure the firm's profit and derive the representation of the optimal value function by using the properties of L–S integral.

(*ii*) By decomposing the feasible region, we established five equivalent linear programming models of the original production and financial investment planning problem.

(*iii*) We designed a feasible region decomposition method to solve the original piecewise linear programming model.

The problem of uncertain production and financial investment plan in global market is an important issue for study. This paper has considered the influence of fuzzy exchange rate fluctuations to a global firm and suggested the corresponding strategies. In our future research, we will consider more complex global market situations, and adapt our model to the practical environments.

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