APEM journal
Advances in Production Engineering & Management ISSN 1854-6250
Volume 12 | Number 1 | March 2017 | pp 51–61 Journal home: apem-journal.org
https://doi.org/10.14743/apem2017.1.239 Original scientific paper

Reconsidering production coordination: A principal-agent theory-based analysis

Gong, D.[a,b,c]**, Tang, M.**[b,c,*]**, Liu, S.**[b,c]**, Li, Q.**[b,c]

[a]School of Economics and Management, Tsinghua University, China
[b]School of Economics and Management, Beijing Jiaotong University, China
[c]International Center for Informatics Research, Beijing Jiaotong University, China

ABSTRACT

Production coordination is a common phenomenon in supply chains. Unlike the existing literature, we examine the production coordination problem from the perspective of asymmetric information: how a manufacturer (leading firm) coordinates the relationships with its subsidiary firm(s) and, subsequently, how market returns influence the leading firm's expected utilities, agency cost and the subsidiary firm's expected incomes. We develop an incentive contract model with asymmetric information based on principal-agent theory. Comparative analysis and simulations are conducted to test the model. Results show that the leading firm's expected utilities and agency cost and the subsidiary firm's expected incomes are significantly affected by the subsidiary firm's capability, cost coefficient, absolute risk aversion factor and output variance (common factors); sharp differences among the leading firm's expected utilities and agency cost and the subsidiary firm's expected incomes were found due to different market returns. Thus, the proposed approach (incentive contract model) can help leading firms apply incentives to optimize production modes to obtain production coordination while considering common factors; market returns differences are included in the new model, in contrast to previous approaches.

ARTICLE INFO

Keywords:
Principal-agent theory
Production coordination
Market returns
Information asymmetry
Incentive

**Corresponding author:*
mincong@bjtu.edu.cn
(Tang, M.)

Article history:
Received 17 November 2016
Revised 20 December 2016
Accepted 9 February 2017

1. Introduction

Production coordination is related to demand, inventory status, production plan, production time, promotion plan, demand forecast and sharing transportation routes (Lee, 2000) [1]. With the development of the supply chain, production coordination will become increasingly complex, and production activities of the supply chain cannot be achieved until bodies of resources (the principal: leading firm, and agent: subsidiary firm) are motivated. Therefore, the problem of production coordination urgently needs to be solved. An optimizing algorithm and tools have been developed to solve the production coordination problem; for example, Matičević, et al. (2007) used the theory of ERP (enterprise resource planning) to achieve internal supply chain coordination for production[2]; Gong, et al. (2015) created a mathematical model and performed a simulation for the resource sharing model's impact on supply chain efficiency[3]; Galić, et al. (2016) put forward multiple criteria solver (MCS) optimizations to solve an asphalt supply chain problem, and simulation results justified that the proposed model can eliminate the lack of an original model [4].

Incentive theory is an important way to solve the production coordination problem. With the background of the global manufacturing network, Jiao, You and Kumar (2006) established an agent-based (leading firms and subsidiary firms involved in production coordination) and contracted-based (market demand) model, which is a useful method to address the production coordination problem[5]. Sahay (2003) believed that the mechanism design was important for the production coordination, and the sharing of information, risk and revenue was essential [6]. With the help of cooperative game theory, Nagarajan and Sosˇic´(2008) analyzed the integration problem of production coordination and proposed the theory of 'vision', which provided a new mode of production coordination[7]. Brintrup (2008) established an agent-based, target-based and role-based model to select suppliers to reduce transaction time and increase corporate revenue[8]. In order to meet customers' needs, Akanle and Zhang (2008) proposed optimizing the configuration for production coordination, so they built an agent-based model to coordinate bidding and obtained the optimum based on a genetic algorithm[9]. Yi, et al. (2016) combined put options and selective returns in a proposed contract model and constructed a two-echelon supply chain to analyze risk coordination in supply chains[10]. By applying bargaining theory, Saha, et al. (2014) found that inventory-level and retail-price-dependent demand can play an important role in supply chain coordination contracts[11]. Xu, et al. (2015) analyzed consumer return behavior's effect on buy-back contracts in order to coordinate a robust supply chain[12].

To some extent, the focus of production coordination is principal-agent. In production coordination, principal-agent theory can be developed to cope with the contract relations problem. Principal-agent theory is derived from rational choice model, in which the principal's initial actions are available for agent(s) as incentives to help them make decisions that the principal prefers. Principal-agent theory focuses on the responsive decisions of the agents to to the principal's goal and on how the responsive decisions can be mediated by their actions. In order to operate an effective production coordination network, the leading firm should conduct a comprehensive analysis of actors' (agents') decisions (Compte and Jehiel, 2008) [13]. For the analysis of principal-agent problems in the production coordination network, we focus on the understanding of different roles and their power positions (Kulp, 2002) [14]. In the view of adaptive contract design, Ho, et al. (2016) considered Bandit algorithms to solve repeated principal-agent problems in crowd-sourcing markets[15]. When there exists asymmetric information between the principal and agent, the agent must try its best to achieve his own maximum benefit. With asymmetric information, a distinct strategy should be determined due to the agent's hidden intentions. Consequently, adverse selection and moral hazard arise (Herwig and Sascha, 2011) [16]. Therefore, there is a need to formulate proper conduct regulations for production coordination in business activities (Keser and Willinger, 2007) [17]. Rubin, et al. (2016) focused on the principal–agent algorithm itself, and the results of a gift-exchange experiment showed that the introduction of shocks can significantly reduce the likelihood that the agent will fulfill the contract[18].

To sum up, existing literatures focus mainly on resource configuration, production management, the trust mechanism and the agent model, and the full qualitative descriptions of the principal-agent problem (Herwig and Sascha, 2011) [16]. A wide spectrum of goals, such as wages and premiums, are used as the utility function of the principal and agents (Mukherji et al., 2007) [19]. However, there is a gap in the literature related to production coordination and market returns' effect, that is, in asymmetric information, how a manufacturer (leading firm) coordinates the relationships with its subsidiary firm(s) and, subsequently, how market returns influence the leading firm's expected utilities and agency cost and the subsidiary firm's expected incomes.

In this paper, based on principal-agent theory, the incentive contract model is constructed in the context of asymmetric information. Additionally, a comparative analysis and simulations are carried out for the leading firm's expected utilities, the subsidiary firm's expected incomes and the leading firm's agency cost. Thus, this chapter is organized as follows: we first conduct a comprehensive review that forms the theoretical foundation of this study. Section 2 discusses applications of principal-agent models to production coordination. Section 3 discusses solutions of principal-agent models for production coordination. Section 4 presents the simulations. Section 5 concludes.

2. Principal-agent model of production coordination

2.1 The factors related to the model

The principal-agent theory focuses on the rational choice model in which the agent has several tasks to fulfill for the principal. In order to fulfill the tasks, the agent has free access to several means and tools. However, the principal expects the agent to make decisions that the principal prefers. Inevitably, objective conflicts between the principal and agent often arise, and both of them want their maximum benefit; in particular, opportunistic practices of deceit and fraud are possible. Mechanism design is effective way of tackling the principal-agent problem by looking for the common factors related to both the principal and the agent in the context of asymmetric information (Lal and Srinivasan, 1993) [20]. The factors related to both actors consist of the leading firm's expected utilities, the subsidiary firm's expected incomes and the leading firm's agency cost. In this paper, one leading firm is assumed (the principal), and one subsidiary firm is assumed (the agent).

(1) The leading firm's expected utilities

The leading firm provides products or services to its departments, the subsidiary firm is responsible for the provision of products or services, and the total utilities that the product or service brings about will be owned by the leading firm. In order to stimulate the subsidiary firm, the leading firm needs to pay for the subsidiary firm, which is called remuneration. Therefore, the leading firm's utilities are obtained by deducting from the total utilities. The leading firm is risk neutral, and its utilities can be made by market sales (considering the service price only) or profits (considering the service cost and service price), but the market profit method is more scientific.

(2) The subsidiary firm's expected incomes

The subsidiary firm can obtain incomes by gaining market share or other ways; at the same time, it must pay a certain cost, including economic cost and risk cost, so the subsidiary firm is risk averse, and it will not make enough efforts to conduct innovation due to the structure of income; thus, it is not conducive to the leading firm's utilities.

(3) The leading firm's agency cost

The subsidiary firm possesses private information, and it will avoid making efforts. Therefore, the leading firm needs to monitor the subsidiary firm, thus guaranteeing that the subsidiary firm makes as much effort as possible to increase the utilities of its products or services. However, the monitoring will inevitably increase the leading firm's agency cost, which includes the risk cost and the incentive cost (referring to the different utilities that the subsidiary firm brings about in the context of symmetric information and asymmetric information).

In the production coordination process, the leading firm wants to increase its own utilities and decrease its agency cost, and the subsidiary firm tries its best to avoid working but wants to gain market share. The goal of cooperative production is to look for the common factors related to the leading firm's expected utilities, the subsidiary firm's expected incomes and the leading firm's agency cost. Based on common factors, the leading firm creates industry policy to realize cooperative production (Fig. 1).

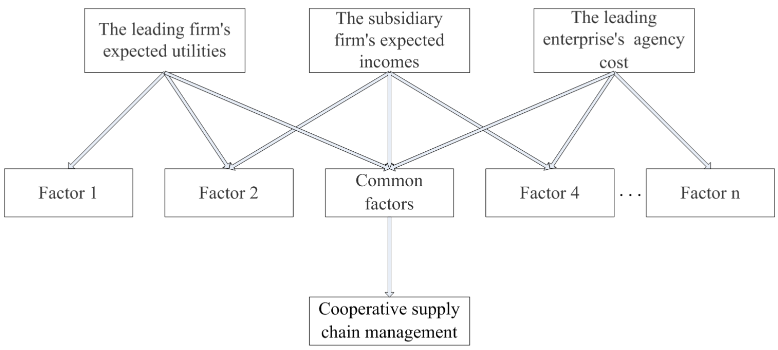

Fig. 1 The common factors

In Fig. 1, many factors affect the leading firm's expected utilities, the subsidiary firm's expected incomes and the leading firm's agency cost in production coordination. The common factors related to the leading firm's expected utilities, the subsidiary firm's expected incomes and the leading firm's agency cost can be calculated based on a mechanism design.

2.2 The improved model

(1) Market returns model 1 (the price p and cost c are not considered)

The utilities U (that yield Q) are the market gains when the subsidiary firm provides products or services to the users with a certain level of effort, and U is subjected to the subsidiary firm's ability, market prosperity and market randomness. Therefore, $U = Af(e) + B + \theta$,where A is the subsidiary firm's ability $(A > 0)$; e is the effort, $f(e)$is the function, and $f'(e) > 0$, which means that marginal yields are positive and that yields are positive with subsidiary firm ability; $f''(e) < 0$, which means that the rate of yields is decreasing; The constant B is market prosperity; θ is market randomness， and $\theta \sim N(0, \sigma^2)$($\sigma^2$is the output variance).

Theorem 1: The linear relation of the model is still reasonable when $f(e) = e$.

Proof: If $f(e) = e^{r1}$， where $0 < r1 < 1$， equation $f(e) = e^{r1}$ is consistent with the restrictions above. Supposing $E = e^{r1}$, so $U = AE + B + \theta$. Additionally, we can see the full linear relations in expression $e^{r1} \rightarrow E \rightarrow U$, so $U = Af(e) + B + \theta$ is simplified as $U = Ae + B + \theta$ when $f(e) = e$.

The subsidiary firm generates sales with a certain level of effort, so the leading firm needs to pay for the subsidiary firm's work $s(U) = \alpha + \beta U$,where α is the fixed income, β is the user's share gains.

Theorem 2: The subsidiary firm and the leading firm will obtain the same market gain share β when the gain in market share is normally distributed.

Proof: The leading firm wants β_f, while the subsidiary firm wants β_u ($\beta_f < \beta_u$), the third party could supposedly decide the reasonable market share gain β when knowing $\beta_f$and β_u. By differentiating $\beta_f$and β_u, we can obtain

$$F\left(\frac{{\beta_f}^* + {\beta_U}^*}{2}\right) = 1/2, {\beta_U}^* - {\beta_f}^* = 1/f\left(\frac{{\beta_f}^* + {\beta_U}^*}{2}\right) \tag{1}$$

And $\beta \sim N(\mu, \sigma^2)$, so

$$\frac{{\beta_f}^* + {\beta_U}^*}{2} = \mu, {\beta_U}^* - {\beta_f}^* = 1/f(\mu) = \sqrt{2\pi}\sigma \tag{2}$$

The optimum market share gain for the subsidiary firm and the leading firm will be

$${\beta_u}^* = \mu + \sqrt{\frac{\pi}{2}}\sigma, {\beta_f}^* = \mu - \sqrt{\frac{\pi}{2}}\sigma \tag{3}$$

Finally, the subsidiary firm and the leading firm will gain the same market share μ $(\sigma = 0)$. Therefore, the leading firm's expected utilities are

$$E(U - s(U)) = -\alpha + E(1 - \beta)U = -\alpha + (1 - \beta)(Ae + B) \tag{4}$$

The subsidiary firm's direct cost is $C(e)$ when providing products or services, and $C^{'}(e) > 0, C^{''}(e) \geq 0$. We set $C(e) = me^{r2}$， where $m > 0, r2 > 1$， and $E = e^{r1}$, so $C(e) = mE^{r3}$ $(r3 = r2/r1 > 1)$. $C(e) = mE^{r2}$ is consistent with the restrictions above, so $C(e) = mE^{r3}$ can be simplified as $C(e) = be^2/2$ when $m = b/2, r3 = 2$, where b is the cost coefficient.

In addition, the subsidiary firm must pay the risk cost when participating in collaborative incentive contracts, and the subsidiary firm's certainty equivalent profits (I) can reflect its actual income. Set the utilities $u = -e^{rI}$ (exponential distribution) for the subsidiary firm, where r is the absolute risk aversion factor, and $r > 0, z \sim N(m, n^2)$. The subsidiary firm's expected utilities are

$$E(u) = \int_{-\infty}^{+\infty} -e^{-rz} \frac{1}{\sqrt{2\pi}n} e^{-\frac{(z-m)^2}{2n^2}} dz = -e^{-r(m-\frac{rn^2}{2})} \tag{5}$$

$E(u) = u(I)$, so $-e^{-r(m-\frac{rn^2}{2})} = -e^{r(I)}$, $I = m - \frac{rn^2}{2}$. $\theta \sim N(0, \sigma^2)$, so random variable $I_1 = \alpha + \beta(Ae + B + \theta) - be^2/2$ obeys a normal distribution, and the subsidiary firm's expected profits are

$$EI_1 = \alpha + \beta(Ae + B) - be^2/2 \tag{6}$$

The variance of the subsidiary firm's profits is $DI_1 = \beta^2\sigma^2$, and in equation $I = m - \frac{rn^2}{2}$, m is the mean (EI_1), $n$is the variance(DI), so the subsidiary firm's certainty equivalent profits are

$$I = \alpha + \beta(Ae + B) - be^2/2 - r\beta^2\sigma^2/2 \tag{7}$$

Where $r\beta^2\sigma^2/2$ is the risk cost. s is the lowest profit that the subsidiary firm requires, and the subsidiary firm will not participate in an incentive contract when the equivalent profit is less than s. Therefore, the prerequisite that the subsidiary firm participates in the incentive contract is

$$\alpha + \beta(Ae + B) - be^2/2 - r\beta^2\sigma^2/2 \geq s \tag{8}$$

Combined with our previous research [21], the production coordination model based on principal-agent theory is

$$E\big(U - s(U)\big) = \max\{-\alpha + (1 - \beta)(Ae + B)\}$$
$$s.t.\begin{cases} \arg\max\{\alpha + \beta(Ae + B) - be^2/2 - r\beta^2\sigma^2/2\} \\ \alpha + \beta(Ae + B) - be^2/2 - r\beta^2\sigma^2/2 \geq s \end{cases} \tag{9}$$

(2) Market returns model 2 (the price p and cost c are considered)

In model 1, the utilities U are calculated by yield Q; in this model, p is the price of products or services,$(p - c)Q$ is the user's returns, and therefore, leading firm utilities are

$$E(U) = E((p - c)Q - s(Q)) = -\alpha + (1 - \beta)(p - c)(Ae + B) \tag{10}$$

The subsidiary firm's certainty equivalent profits are

$$I = \alpha + \beta(p - c)(Ae + B) - be^2/2 - r(p - c)^2\beta^2\sigma^2/2 \tag{11}$$

Additionally, the production coordination model based on principal-agent theory is

$$E\big(U - s(U)\big) = \max\{-\alpha + (1 - \beta)(p - c)(Ae + B)\}$$
$$s.t.\begin{cases} \arg\max\{\alpha + \beta(p - c)(Ae + B) - be^2/2 - r(p - c)^2\beta^2\sigma^2/2\} \\ \alpha + \beta(p - c)(Ae + B) - be^2/2 - r(p - c)^2\beta^2\sigma^2/2 \geq s \end{cases} \tag{12}$$

3. The solution for the production coordination model

3.1 Market returns model 1 (the price p and cost c are not considered)

(1) Symmetric information

The leading firm can monitor the subsidiary firm in the case of symmetric information, and the leading firm will not motivate subsidiary firm. At the same time, the leading firm must pay the least even if the subsidiary firm wants the most. Based on the game relations, the subsidiary firm will gain the least in the end (s). Therefore, the cooperative production coordination model including the leading firm and the subsidiary firm changes as follows:

$$E(U - s(U)) = \max\{-\alpha + (1-\beta)(Ae + B)\}$$
$$s.t. \;\; \alpha + \beta(Ae + B) - be^2/2 - r\beta^2\sigma^2/2 = s \tag{13}$$

The differentiation for e yields

$$\{\alpha + \beta(Ae + B) - be^2/2 - r\beta^2\sigma^2/2 - s\}' = 0 \tag{14}$$

So $e_1^* = \frac{A\beta}{b}$.In the case of symmetric information, market share gains β cannot change regardless of whether the subsidiary firm works hard or not, and the leading firm will not motivate the subsidiary firm to gain market share, and the subsidiary firm will obtain unchanged revenue in the end. So, $e_1^* \approx e^* = A/b$, β is neglected. Then, $\alpha_1^* \approx \alpha^* = s + A^2/2b$.

(2) Asymmetric information

In the case of asymmetric information, the subsidiary firm will try its best to increase s when (α, β) is given. Do differentiation for e,

$$\{\alpha + \beta(Ae + B) - be^2/2 - r\beta^2\sigma^2/2 - s\}' = 0 \tag{15}$$

so $e = A\beta/b$. Then, the leading firm takes actions to increase its expected utilities when observing e, that is,

$$E(U - s(U)) = \max\{-\alpha + (1-\beta)(Ae + B)\}$$
$$s.t. \begin{cases} \alpha + \beta(Ae + B) - be^2/2 - r\beta^2\sigma^2/2 = s \\ e = A\beta/b \end{cases} \tag{16}$$

The differentiation for β yields

$$\{-\alpha + (1-\beta)(Ae + B)\}' = 0 \tag{17}$$

so,

$$\beta_1 = (A^2 - Bb)/2A^2 \tag{18}$$

Actually, a rational subsidiary firm will obtain s at most, that is,

$$\alpha + \beta(Ae + B) - be^2/2 - r\beta^2\sigma^2/2 = s \tag{19}$$

Both the subsidiary firm and the leading firm will determine β, and market share gain β is known by the leading firm and the subsidiary firm. The differentiation for β yields

$$\{\alpha + \beta(Ae + B) - be^2/2 - r\beta^2\sigma^2/2\}' = 0 \tag{20}$$

so,

$$\beta_2 = Bb/(rb\sigma^2 - A^2) \tag{21}$$

And $\beta_1 = \beta_2$, $B = (A^2 - 2A^2\beta_1)/b$, therefore,

$$\beta = 1/(1 + rb\sigma^2/A^2) \tag{22}$$

$$\alpha = s + be^2/2 + r\beta^2\sigma^2/2 - \beta(Ae + B) \tag{23}$$

$$e = A\beta/b \tag{24}$$

And $s(U) = s + be^2/2 + r\beta^2\sigma^2/2$. Eventually, the leading firm's expected utilities (α, β are known) are

$$E\big(U - s(U)\big) = B - s + A^2/2b(1 + rb\sigma^2/A^2) \tag{25}$$

The subsidiary firm's expected incomes (α, β are known) are

$$E\big(s(U)\big) = s + A^2/2b(1 + rb\sigma^2/A^2) \tag{26}$$

The subsidiary firm's expected profits must be s regardless of whether it works hard or not, and the leading firm should motivate the subsidiary firm through expected incomes instead of expected profits, so this paper will discuss the subsidiary firm's expected incomes. In the case of asymmetric information, the principal cannot observe the agent's effort. Therefore, there are two additional kinds of agency costs compared with symmetric information: one is the risk cost; another is the incentive cost. In the case of symmetric information, the leading firm's risk cost is 0; in the case of asymmetric information, the leading firm's risk cost is

$$R = \frac{r\beta^2\sigma^2}{2} = \frac{r\sigma^2}{2\left(1 + \frac{rb\sigma^2}{A^2}\right)^2} \tag{27}$$

The incentive cost refers to the difference between high expected revenue with symmetric information and low expected revenue with asymmetric information. For this reason, the subsidiary firm works harder in the case of symmetric information than in the case of asymmetric information. Therefore, the leading firm's expected utilities will decrease in the case of asymmetric information. Therefore, the leading firm's incentive cost is

$$E(L) = \big(Ae^* + B - C(e^*)\big) - \big(Ae + B - C(e)\big) == \frac{br^2\sigma^4/A^2}{2(1 + rb\sigma^2/A^2)} \tag{28}$$

Then, the leading firm's agency cost is

$$TC = R + E(L) = \frac{r\sigma^2}{2(1 + rb\sigma^2/A^2)} \tag{29}$$

3.2 Market returns model 2 (the price p and cost c are considered)

Similarly, the leading firm's expected utilities are

$$E\big(U - s(U)\big) = (p - c)B - s + \frac{(p - c)^2A^2}{2b(1 + rb\sigma^2/A^2)} \tag{30}$$

The subsidiary firm's expected incomes are

$$E\big(s(U)\big) = s + \frac{(p - c)^2A^2}{2b(1 + rb\sigma^2/A^2)} \tag{31}$$

The leading firm's agency cost is

$$TC = R + E(L) = \frac{(p - c)^2r\sigma^2}{2(1 + rb\sigma^2/A^2)} \tag{32}$$

4. The simulation

In order to clarify the factors' relations, the paper conducts a mathematical simulation of the leading firm's expected utilities $E\big(U - s(U)\big)$, the subsidiary firm's expected incomes $E\big(s(U)\big)$ and the leading firm's agency cost TC $(A, b, r, B, s, \sigma^2 > 0)$ based on MATLAB.

4.1 The simulation of the leading firm's expected utilities $E(U - s(U))$, the subsidiary firm's ability A and the absolute risk aversion factor r

(1) Market returns model 1 (the price p and cost c are not considered)

The simulation setting is shown below: cost coefficient $b = 0.5$, output variance $\sigma^2 = 20000$, market prosperity $B = 10000$, subsidiary firm lowest profit $s = 100000$.The MATLAB simulation procedure is as follows: Initialization (B, s, the interval for A: $i \in [1000{,}11000]$, the interval for r: $j \in [0{,}10000]$, array computations (input i, j and function), the interval check (if $i < Max(i)$ and $j < Max(j)$, computing continues, otherwise computing ends) The code for the function is as follows (others omitted):

$$Sf(i,j) = ((a(1,i) * a(1,i))/(1 + \left(10000 * \frac{b(1,j)}{a(1,i)} * a(1,i)\right))) + (x - y) \quad (33)$$

The relations between $E(U - s(U))$, A and r are shown in Fig. 2.

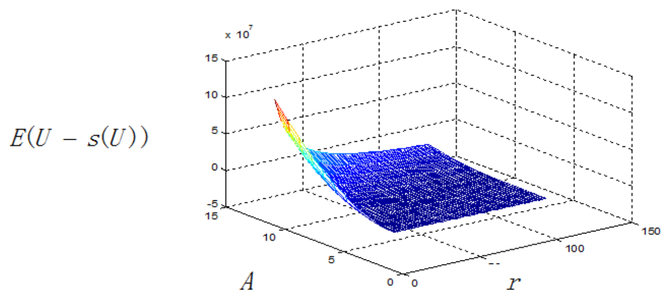

Fig. 2 The relations between $E(U - s(U))$, A and r (1)

Fig. 2 indicates that $E(U - s(U))$ is positive with A; $E(U - s(U))$is negative with r.

(2) Market returns model 2 (the price p and cost c are considered)

The simulation setting is shown below: $p = 100$, $c = 50$; the others are the same as above. The code for the function is as follows (others omitted):

$$Sf(i,j) = (2500 * (a(1,i) * a(1,i))/(1 + \left(10000 * \frac{b(1,j)}{a(1,i)} * a(1,i)\right))) + ((50 * x) - y) \quad (34)$$

The relations between $E(U - s(U))$, A and r are shown in Fig. 3. In Fig. 3, the results are similar to those in Fig. 2, but the magnitude of relations between $E(U - s(U))$, A and r is times greater in Fig. 4 compared with Fig. 3, so p and c affect the model most.

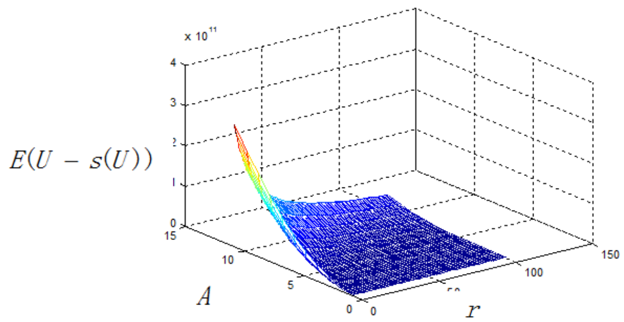

Fig. 3 The relations between $E(U - s(U))$, A and r (2)

4.2 The simulation of the leading firm's expected utilities $E(U-s(U))$, cost coefficient b, and market prosperity B

(1) Market returns model 1 (the price p and cost c are not considered)

The simulation setting is shown below: subsidiary firm ability $A=5000$, output variance $\sigma^2=20000$, subsidiary firm absolute risk aversion factor $r=500$, subsidiary firm lowest profit $s=100000$.The code for the function is as follows (others omitted):

$$Sf(i,j)=(25000000/(2*b(1,j)*(1+0.4*b(1,j)))+(a(1,i)-100000) \quad (35)$$

The relations between $E(U-s(U))$, B and b are shown in Fig. 4.

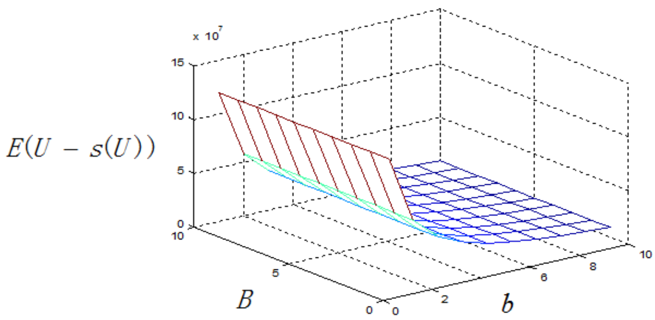

Fig. 4 The relations between $E(U-s(U))$, B and b (1)

Fig. 4 indicates that $E(U-s(U))$ is negative with b; $E(U-s(U))$ is positive with B.

(2) Market returns model 2 (the price p and cost c are considered)

The simulation setting is shown below: $p=100$, $c=50$; the others are the same as above. The code for the function is as follows (others omitted):

$$Sf(i,j)=(2500*25000000/(2*b(1,j)*(1+0.4*b(1,j)))+(50*a(1,i)-100000) \quad (36)$$

The relations between $E(U-s(U))$, B and b are shown in Fig. 5. In Fig. 5, the results are similar to those in Fig. 4, but the magnitude of relations between $E(U-s(U))$, B and b is 10^4 times greater, so p and c affect the model most. Additionally, we find that $E(U-s(U))$is negative with s; $E(U-s(U))$ is negative with σ^2; and p and c affect the model most. Based on the analysis above, the relations between factors (A,b,r,B,s,σ^2), $E(s(U))$ and TC can be calculated as well.

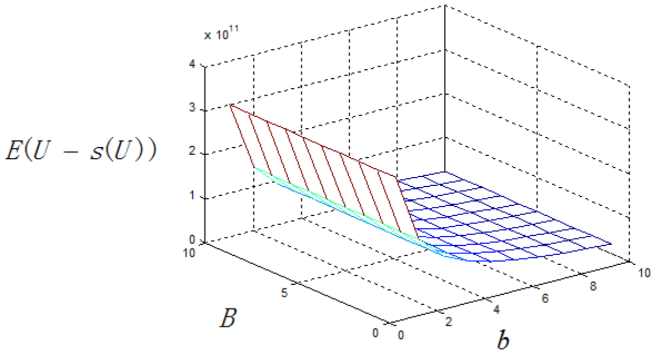

Fig. 5 The relations between $E(U-s(U))$, B and b (2)

To sum up, the leading firm's expected utilities $E(U - s(U))$, the subsidiary firm's expected incomes $E(s(U))$ and the leading firm's agency cost$TC$are all affected by the subsidiary firm's ability A, the cost coefficient b, the absolute risk aversion factor r and the output ance σ^2; $E(U - s(U))$, $E(s(U))$ and TCdiffer $(p - c)^2$ times due to the market returns model 1 (the price p and cost c are not considered) compared with the market returns model 2 (the price p and cost c are considered).

5. Conclusion

Production networks are an effective way to realize production coordination. The leading firm and the subsidiary firm comprise production networks and enhance production networks' core competencies if parties are united. In the production networks, the leading firm has a special market position due to its access to critical resources. Additionally, the leading firm greatly determines the goals followed by the subsidiary firm in production networks. Inevitably, objective conflicts between the principal and agent often arise, as both of them want their maximum benefit, and in particular, opportunistic practices of deceit and fraud are possible.

Mechanism design is an effective way to tackle the principal-agent problem by looking for the common factors related to both the principal and the agent in the case of asymmetric information. The paper develops a principal-agent theory for production coordination. The goal of the principal-agent theory is to analyze the problems occurring between the leading firm and the subsidiary firm and to find the common factors of production coordination, develop solutions for these problems, and the needs of incentive contracts to fulfill the leading firm's requirements and the subsidiary firm's profit. The findings of the simulation help to illuminate the potential behavioral uncertainties between the leading firm and the subsidiary firm and to apply the optimal kinds of measures in production coordination. The leading firm's expected utilities, the subsidiary firm's expected incomes and the leading firm's agency cost are all affected by the subsidiary firm's ability A, cost coefficient b, absolute risk aversion factor r and output variance σ^2. The leading firm's expected utilities, the subsidiary firm's expected incomes and the leading firm's agency cost differ thousands of times due to the different market returns (the price p and cost c are considered or not). The common factors related to both actors are the leading firm's expected utilities, the subsidiary firm's expected incomes and the leading firm's agency cost; in particular, the difference in market returns is included in the new model, in contrast to previous approaches. Thus, the proposed approach (incentive contract model) can help the leading firm apply incentives to optimize production modes to achieve production coordination while taking into account these common factors and market returns.

In the model of Pareto loss, the leading firm and the subsidiary firm will make efforts to renegotiate jointly to increase the effort e ($e = \beta A/b$); in Pareto improvement, the utilities for the leading firm and the subsidiary firm will increase. Therefore, we should improve the subsidiary firm's ability, reduce the subsidiary firm's cost coefficient, lower the subsidiary firm's absolute risk aversion, and pay attention to random market factors. The leading firm can take on incentive measures to optimize production coordination based on the common factors.

Acknowledgement

The study is supported by a project funded by the China Postdoctoral Science Foundation (2016M591194) and the National Natural Science Foundation (71132008,71390334). We appreciate their support very much.

References

[1] Lee, H.L. (2000). Creating value through supply chain integration, *Supply Chain Management Review*, 30-36.

[2] Matičević, G., Lovrić, T., Čičak, M. (2007), Using ERP system to improve internal supply chain coordination, *Tehnički vjesnik – Techical Gazette*, Vol. 14, No. 3-4, 11-21.

[3] Gong, D., Liu, S., Lu, X. (2015). Modelling the impacts of resource sharing on supply chain efficiency, *International Journal of Simulation Modelling*, Vol. 14, No. 4, 744-755, doi: 10.2507/IJSIMM14(4)CO20.

[4] Galić, M., Završki, I., Dolaček-Alduk, Z. (2016), Methodology and algorithm for asphalt supply chain optimization, *Tehnički vjesnik – Techical Gazette*, Vol. 23, No. 4, 1193-1199, doi: 10.17559/TV-20150623140015.

[5] Jiao, J.(R.), You, X., Kumar, A. (2006). An agent-based framework for collaborative negotiation in the global manufacturing supply chain network, *Robotics and Computer-Integrated Manufacturing*, Vol. 22, No. 3, 239-255, doi: 10.1016/j.reim.2005.04.003.

[6] Sahay, B.S. (2003). Supply chain collaboration: The key to value creation, *Work Study*, Vol. 52, No. 2, 76-83, doi: 10.1108/00438020310462872.

[7] Nagarajan, M., Sošić, G. (2008). Game-theoretic analysis of cooperation among supply chain agents: Review and extensions, *European Journal of Operational Research*, Vol. 187, No. 3, 719-745, doi: 10.1016/j.ejor.2006.05.045.

[8] Brintrup, A. (2010). Behaviour adaptation in the multi-agent, multi-objective and multi-role supply chain, C*omputers in Industry*, Vol. 61, No. 7, 636-645, doi: 10.1016/j.compind.2010.03.010.

[9] Akanle, O.M., Zhang, D.Z. (2008). Agent-based model for optimising supply-chain configurations, *International Journal of Production Economics*, Vol. 115, No. 2, 444-460, doi: 10.1016/j.ijpe.2008.02.019.

[10] Yi, H.Y., Guo, P. (2015). Modelling risk coordination of supply chains with put option contracts and selective return policies, *International Journal of Simulation Modelling*, Vol. 14, No. 3, 551-562, doi: 10.2507/IJSIMM14(3)CO15.

[11] Saha, S., Goyal, S.K. (2015). Supply chain coordination contracts with inventory level and retail price dependent demand, *International Journal of Production Economics,* Vol. 161, 140-152, doi: 10.1016/j.ijpe.2014.12.025.

[12] Xu, L., Li, Y., Govindan, K., Xu, X. (2015). Consumer returns policies with endogenous deadline and supply chain coordination, *European Journal of Operational Research*, Vol. 242, No. 1, 88-99, doi: 10.1016/j.ejor.2014.09.049.

[13] Compte, O., Jehiel, P. (2008). Gathering information before signing a contract: A screening perspective, *International Journal of Industrial Organization*, Vol. 26, No. 1, 206-212, doi: 10.1016/j.ijindorg.2006.11.002.

[14] Cohen Kulp, S. (2002). The effect of information precision and information reliability in manufacturer-retailer relationships, *The Accounting Review*, Vol. 77, No. 3, 653-677, doi: 10.2308/accr.2002.77.3.653.

[15] Ho, C.-J., Slivkins, A., Wortman Vaughan, J. (2016). Adaptive contract design for crowdsourcing markets: Bandit algorithms for repeated principal-agent problems, *Journal of Artificial Intelligence Research*, Vol. 55, 317-359, doi:10.1613/jair.4940.

[16] Winkler, H., Kraus, S. (2011). Management of principal-agent problems in supply chains, *International Journal of Business Research*, Vol. 11, No. 2, 12-22.

[17] Keser, C., Willinger, M. (2007). Theories of behavior in principal-agent relationships with hidden action, *European Economic Review*, Vol. 51, No. 6, 1514-1533, doi: 10.1016/j.euroecorev.2006.10.007.

[18] Rubin, J., Sheremeta, R. (2015). Principal-agent settings with random shocks, *Management Science*, Vol. 62, No. 4, 985-999, doi: 10.1287/mnsc.2015.2177.

[19] Mukherji, A., Wright, P., Mukherji, J. (2007). Cohesiveness and goals in agency networks: Explaining conflict and cooperation, *The Journal of Socio-Economics*, Vol. 36, No. 6, 949-964, doi: 10.1016/j.socec.2007.01.024.

[20] Lal, R., Srinivasan, V. (1993). Compensation plans for single- and multi-product salesforces: An application of the Holmstrom-Milgrom model, *Management Science*, Vol. 39, No. 7, 777-793, doi: 10.1287/mnsc.39.7.777.

[21] Xu, W.Y., Zhang, Z.J., Gong, D.Q. (2014). Cooperative supply chain management under asymmetric information, *Journal of Applied Research and Technology*, Vol. 12, No. 2, 182-191 doi: 10.1016/S1665-6423(14)72334-X.