

Effort levels of the partners in networked manufacturing

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Abstract: Compared with traditional manufacturing mode, could networked manufacturing improve effort levels of the partners? What factors will affect effort level of the partners? How to encourage the partners to improve their effort levels? To answer these questions, we introduce network effect coefficient to build effort level model of the partners in networked manufacturing. The results show that (1) with the increase of the network effect in networked manufacturing, the actual effort level can go beyond the ideal level of traditional manufacturing. (2) Profit allocation based on marginal contribution rate would help improve effort levels of the partners in networked manufacturing. (3) The partners in networked manufacturing who wishes to have a larger distribution ratio must make a higher effort level, and enterprises with insufficient effort should be terminated in networked manufacturing.

1. Introduction

The concept of networked manufacturing was developed to meet individualized demands under the context of globalization via coordinating resources scattered across regions in the form of dynamic alliances, which is made feasible by recent advancements in information and manufacturing technology. Networked manufacturing challenges the traditional industry structure as it utilizes resources beyond traditional constraints and produces with significantly improved flexibility, efficiency, and responsiveness [1-3]. Many developed countries have already adopted networked manufacturing systems as their national strategies including Germany's Produktion 2000 global production framework program, the EU's Sixth Framework Programme, Japan's Intelligent Manufacturing Systems program, and South Korea's 21st Century Network plan.

There has been some progress on the theory and applications of networked manufacturing as scholars have already studies this phenomenon a variety of areas including systems theory, engineering, sociology, and biology. Scholars generally agree that network effect (value) increases with larger size and optimized network due to cooperation, complementarity, and competition among the partners [4]. However, researchers studying individual effort levels from the perspective of incentive mechanism [5-6] and revenue decisions [7-8] conclude that the partners have a game nature and their efforts level largely affect the overall gain from networked manufacturing.

Based the shared output mode [9], we introduce network effect coefficient to build effort level model of the partners in networked manufacturing, and apply the model to analyze the gap between actual effort level and ideal effort level, and the factors affecting effort level.



2. Basic assumptions

Suppose that network effect coefficient (the integration level of the manufacture network) is λ in a networked manufacturing composed of leader enterprise L and participating enterprise P. For P and L, effort level is δ and $1-\delta$ ($0 < \delta < 1$), respectively. The final value of the networked manufacturing project is determined by network effect coefficient, effort levels and marginal contribution rates of the partners:

$$\tilde{R}(e_L, e_P) = \lambda e_L^\delta e_P^{1-\delta} \quad (1)$$

The ultimate value of the project \tilde{R} is the an increasing function of e_L and e_P , which both have a quadratic differential [10].

In addition, we assume that leader enterprise L and participating enterprise P split revenue at $\varphi: (1-\varphi)$ ($0 < \varphi < 1$), which is often consistent with their shares of ownership. The cooperation effort and cost-efficiency is denoted as u and v ($u > 0, v > 0$), which are measured in reference to their peers average [10, 11]). The disutility of effort is related to level of efforts, efficiency of efforts, and network effect coefficient:

$$C_L(e_L) = e_L^2 / 2u\lambda \quad (2)$$

$$C_P(e_P) = e_P^2 / 2v\lambda \quad (3)$$

3. Effort level model of the partners in networked manufacturing

In networked manufacturing, the partners make decisions to realize profit maximization of their own enterprises, and as a result effort level of each enterprise is a game process [12]. Given the inverse extrapolation nature of Game Theory, the utility function of leader enterprise L and participating enterprise P under initial contract is:

$$U_L = \varphi \tilde{R}(e_L, e_P) - C_L(e_L) \quad (4)$$

$$U_P = (1-\varphi) \tilde{R}(e_L, e_P) - C_P(e_P) \quad (5)$$

When both partners behave in a self-interest manner, the utility functions can be obtained by the equilibrium solution of reaction function. Given φ and effort level e_P of participating enterprise P, leader enterprise L would determine own investment e_L to pursue the maximized utility. e_L and e_P can be calculated from partial differential procedure:

$$e_L = \left[\lambda^2 u \varphi \delta e_P^{1-\delta} \right]^{\frac{1}{2-\delta}} \quad (6)$$

$$e_P = \left[\lambda^2 v (1-\varphi) (1-\delta) e_L^\delta \right]^{\frac{1}{\delta+1}} \quad (7)$$

Then we get the optimal effort level of the partners (where $\mathbb{R} = \lambda^2 (u \varphi \delta)^{\frac{\delta}{2}} [v (1-\varphi) (1-\delta)]^{\frac{1-\delta}{2}}$):

$$e_L = \mathbb{R} [u \varphi \delta]^{\frac{1}{2}} \quad (8)$$

$$e_P = \mathbb{R} [v (1-\varphi) (1-\delta)]^{\frac{1}{2}} \quad (9)$$

4. Comparative analysis of actual and ideal effort level

The actual effort level is calculated based on the assumption that both partners are self-interested such that each of them would determine their effort to maximize their own profit regardless of the overall impact. However, an ideal model will require both partners to cooperate when making effort decisions in order to maximize the value of the networked manufacturing. Below is the value function of the networked manufacturing:

$$\max_{(e_L, e_P)} \left\{ \tilde{R}(e_L, e_P) - C_L(e_L) - C_P(e_P) \right\} = \max_{(e_L, e_P)} \left\{ \lambda e_L^\delta e_P^{1-\delta} - \frac{e_L^2}{2u\lambda} - \frac{e_P^2}{2v\lambda} \right\} \quad (10)$$

The optimal solution satisfies the conditions (where $\tilde{R}_{e_L} = \partial \tilde{R} / \partial e_L$, $\tilde{R}_{e_P} = \partial \tilde{R} / \partial e_P$):

$$u\lambda \tilde{R}_{e_L}(e_L, e_P) = e_L \quad (11)$$

$$v\lambda \tilde{R}_{e_P}(e_L, e_P) = e_P \quad (12)$$

The optimal solution is (e_L^*, e_P^*) (where $\mathbb{Z} = \lambda^2 (u\delta)^{\frac{\delta}{2}} [v(1-\delta)]^{\frac{1-\delta}{2}}$):

$$e_L^* = \mathbb{Z} [u\delta]^{\frac{1}{2}} \quad (13)$$

$$e_P^* = \mathbb{Z} [v(1-\delta)]^{\frac{1}{2}} \quad (14)$$

To analyze the difference between the actual and ideal effort level, we take the ratio:

$$e_L / e_L^* = \varphi^{\frac{1+\delta}{2}} (1-\varphi)^{\frac{1-\delta}{2}} \quad (15)$$

$$e_P / e_P^* = \varphi^{\frac{\delta}{2}} (1-\varphi)^{1-\frac{\delta}{2}} \quad (16)$$

We can easily conclude that $e_L / e_L^* < 1$, $e_P / e_P^* < 1$, which means that both partners are subject to bounded rationality such that the actual effort levels are lower than the ideal ones. We simulate the results using MATLAB 7.0 (Figure 1) to demonstrate how to minimize the deviation of actual effort levels from the ideal ones.

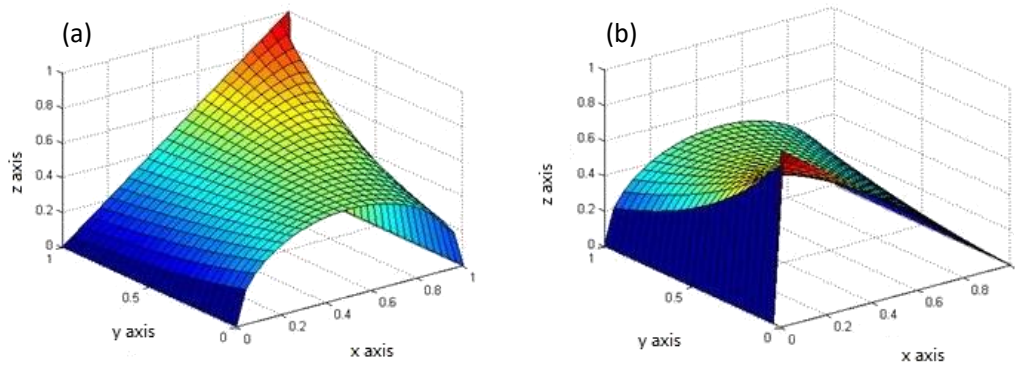


Figure 1. Effort levels of (a) leader and (b) participating enterprise. x axis is φ , y axis is σ , and z axis is (a) e_L / e_L^* (b) e_P / e_P^* .

For a specific networked manufacturing project, marginal contribution rate δ is set for both partners, and therefore the distribution ratio φ indirectly determines the extent to which the actual effort levels are close to ideal effort levels. From Figure 1 we then conclude that in order to achieve ideal effort levels for the partners, the distribution ratio φ should be determined by marginal contribution rate δ . Alternatively, the larger marginal contribution rate, the more benefits should be obtained. This conclusion provides an important basis for profit allocation between the partners.

5. The influence of network effect on effort levels

As shown in Equations (8) and (9), when the partition coefficient φ , marginal contribution rate δ , and effort u and cost-effectiveness v are set, network effect coefficient λ is an essential factor affecting effort levels (e_L, e_P) . The result simulated using MATLAB 7.0 is shown in Figure 2.

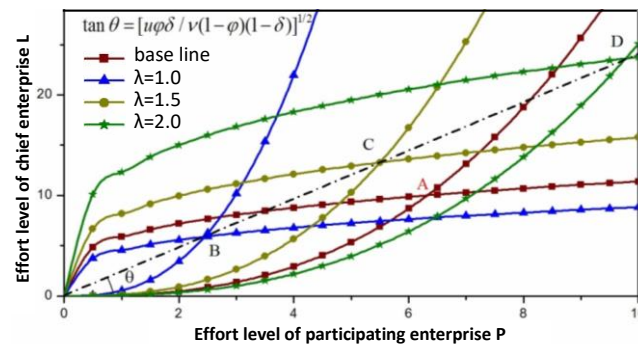


Figure 2. Effort levels under different network effects (assuming that the leader enterprise has a comparative advantage with $u=20$, $v=12$, $\delta=0.6$, $\varphi=0.7$). Point A is the benchmark, representing the ideal effort level in traditional manufacturing ($\lambda=1$) level, and B, C, and D represent the actual effort level when λ is 1.0, 1.5, and 2.0, respectively.

As can be seen in Figure 2, although the actual effort level is less than the ideal level, the actual effort level in networked manufacturing can be higher than the ideal effort level in traditional manufacturing. Further analysis shows that the equilibrium level of actual efforts constitutes a linear line (balanced line), and the slope of the line is determined by factors including effort u , cost efficiency v , partition coefficient φ , and marginal contribution rate δ :

$$\tan \theta = e_L / e_P = [u\varphi\delta / v(1-\varphi)(1-\delta)]^{\frac{1}{2}} \quad (17)$$

Equation (17) shows that when effort, cost efficiency, and marginal contribution rate are set, the slope of the equilibrium distribution coefficient line is determined by distribution coefficient φ , which means that enterprises should improve their effort levels for a higher distribution share.

6. Conclusions and implications

First of all, with the increase of the network effect in networked manufacturing, the actual effort level will be improved, and can go beyond the ideal level of traditional manufacturing. This conclusion shows the superiority of the networked manufacturing and the necessity of improving the network effect. In China, with the rising of labor cost and raw material cost, and the continuous appreciation of RMB, the traditional manufacturing must be transformed into networked manufacturing. The Chinese government should take this trend into consideration when formulating economic development strategy and relevant industrial policies.

Second, profit allocation based on marginal contribution rate would help improve effort levels of the partners in networked manufacturing. Setting profit allocation proportion is a Stackelberg process, in which the leader enterprise would set an initial profit allocation proportion that determines participating enterprises' effort. Participating enterprises' effort will in turn affect effort level of the leader enterprise. As a result, effort levels of both the leader and participating enterprises decide the overall performance of networked manufacturing. Participating enterprises' profit allocation proportion should reflect its marginal contribution rate; otherwise it will discourage its effort levels and subsequent performance of the networked manufacturing.

Third, participating enterprises in networked manufacturing who wishes to have a larger distribution ratio must make a higher effort level, and enterprises with insufficient effort levels should be terminated in networked manufacturing. In the actual operation of networked manufacturing, it is difficult to observe the effort levels of the partners, so the integrity of the partners plays an important role in the healthy development of the manufacturing network. The perfect credit system and incentive mechanism are indispensable to the networked manufacturing.

Acknowledgments

This work is supported by the National Natural Science Foundation of China (Nos. 71472079, 71373108), the Key Project of China Ministry of Education for Philosophy and Social Science (No. 16JZD023), China Postdoctoral Science Foundation (No. 2016M600827), the Fundamental Research Funds for the Central Universities of China (No. 15LZUJBWZD017), and the E-commerce Operation Key Laboratory of Colleges and Universities in Gansu Province (Lanzhou Institute of Technology).

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