

Efficiency of the Supply Chain Collaborative Technological Innovation in China: An Empirical Study Based on DEA Analysis

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Abstract:

Purpose: This paper is an attempt to investigate the current issues and efficiency of the supply chain collaborative technological innovation in China.

Design/methodology/approach: DEA is employed to measure the efficiency of the supply chain collaborative technological innovation.

Findings: From the results of this research, we can see the large gap among the selected companies and there are big spaces for improvement for them in terms of supply chain collaborative technological innovation, especially in the collaborative benefit aspect.

Research limitations/implications: More industries are suggested to be investigated to generalize the conclusions in this paper.

Practical implications: Our practical implications for the companies to improve their supply chain collaborative technological innovation efficiency are: (1) expanding the cooperative scope; (2) optimizing the collaboration operations; (3) improving the compactness in supply chain; (4) increasing the innovation input; and (5) improving the knowledge exchange capacity.

Originality/value: The evaluation and the measure of the efficiency of the supply chain collaborative technological innovation both in theory and in practice have been proven to be very important and quite complex. From the observation, however, there have been limited researches in the current literature. This research investigates the current issues and development of the supply chain collaborative technological innovation in China, and provides

the guideline in terms of improving the efficiency of supply chain collaborative technological innovation

Keywords: collaborative technological innovation, supply chain, DEA, empirical study

1. Introduction

As the global competition and the world economic integration, enterprises pay more attention to obtain advantages from innovation instead of the aspects of price or cost, and market has shifted from competition between enterprises to the competition between supply chains. The increasing complexities of competitive environment put forward higher requirements for supply chain members. Previous research supports the value of such practices, including supplier selection (Wong, Boon-itt & Wong, 2011; Carey, Lawson & Krause, 2011; Lawson, Tyler & Cousins, 2008; Zhou, Zhang, Sheng, Xie & Bao, 2014) Considering the limitations of available resources, increasing personalized customer demands and shortening of product life cycle, it is difficult for companies alone to produce the product meeting the demands of market and customers. Increasingly, firms are relying on external sources of technology to drive new product innovations (Ellis, Henke & Kull, 2012). Thus, the collaboration between enterprises will become more and more extensive (Zhang, Zhang & Zhong, 2008). In many technology areas, the research and development costs grow up at an unprecedented rate, such as, the R&D costs of a complex product is high to hundreds of millions or even billions of dollars. The failure risks of the huge money input and the uncertainties of the R&D activity are often impossible to bear for enterprises regardless of their scale. There is no company having R&D ability of all fields, so in the time of product life cycle getting shorter and competition getting more intense, collaborative innovation becomes the inevitable choice (Yang, 2007b).

From the perspective of supply chain, the final product is actually the completion between different supply chains. The profitability of the enterprise is increasingly depending on its overall competitiveness of its supply chain. The economic globalization has formed the global distribution network of the industrial chain, bring a more fine professional division of labor, and putting forward higher requirements on the supply chain integration ability-collaboration ability. Technological innovation is the key to enhance the competitiveness of enterprises and the important condition to realize the shift from high yield to high quality. The collaboration innovation of supply chain enterprises is an important prerequisite (Zhong, 1999). Especially for technological intensive industries, improving the ability of technological innovation not only includes the independent innovation of enterprise but also is an engineering system which a number of companies in a supply chain participate in. In this process of innovation, there is no doubt that collaboration among supply chain enterprises is essential. Therefore, for the knowledge intensive and the technological intensive industry chain, collaboration on technological innovation in supply chain tends to be more urgent. Especially for the industries

with complicated final product or production process, such as cars, machinery, petrochemical, semiconductor etc., as the increasing of the technical complexity and the division of professional link, the collaboration on Technological Innovation in Supply Chain is inevitable (Lou, 2009).

There are many papers study the supply chain collaboration, and most of them focused on the information sharing and inventory management. There is little quantitative analysis literature about the collaboration on product technological innovation from the supply chain perspective, especially the efficiency of the collaboration. From observations, however, there exist many issues and challenges in the current supply chain collaborative technological innovation process. In order to provide practical insight and guidelines for improving the promotional effectiveness of the supply chain collaborative technological innovation, an investigative empirical study to measure the efficiency and the performances of the collaborative technological innovation is needed, which is the primary motivation of this research.

The paper is organized as follows. The next section introduces the related literature about supply chain product technological innovation collaboration. Following is a brief introduction about the DEA method used in this research. Section 4 describes an empirical analysis of evaluating the performances of technological innovation in the selected 20 supply chains in China's automobile industry. The primary data for this research are collected through a comprehensive questionnaire. Finally, major issues and challenges for these companies in improving their supply chain collaborative technological innovation efficiency are identified and discussed along with the related managerial implications.

2. Literature Review

2.1. Collaborative Supply Chain Technological Innovation

More and more firms have looked outside their organizations for chances to collaborate with partners to ensure that the supply chain is efficient and responsive to dynamic market needs (Fawcett & Magnan, 2004). Effective supply chain management has become a potentially valuable way of improving organizational performance and securing competitive advantages (Li, Nathan, Nathan & Rao, 2006). Through a large-scale survey with manufacturers across the US, Cao & Zhang suggest that supply chain collaboration improves collaborative advantage and indeed has a bottom-line influence on company performance (Cao & Zhang, 2011). Due to technology environment has changed, like the increasing of the technical complexity, it is difficult for enterprises alone to deal with the technical problems. Not only small business but also the giant enterprises are facing the declining technical self-sufficiency (Dachs, Ebersberger & Pyka, 2008).

In recent years, the method through technological innovation to improve the overall performance of the collaborative supply chain gain researchers' attention. The contribution of technological innovation to enterprises or supply chain can be divided into: new product

development, quality improvement, and cost reduction. Gilbert and Cvas point out that through collaboration on technological innovation between enterprises in supply chain, the production cost of the whole supply chain can be reduced (Gilbert & Cvas, 2003). Collaborative technological innovation may not necessarily lead to innovation, but with the cost saving effect. In other words, collaboration on technological innovation in supply Chain may not enhance the innovation ability, but can make the enterprises innovate at a lower cost (Schilling & Phelps, 2007). Through an empirical analysis of 133 usable sets of data collected from manufacturing firms in Malaysia, Lee, Ooi, Chong and Seow identify the relationship between the green supply chain management practices and technological innovation (Lee, Ooi, Chong & Seow, 2014). In the empirical research on American iron and steel enterprises, Von find that there ten of eleven firms having the high production efficiency are exchanging knowledge and technologies frequently in each other (Hippel, 1988). Also, through providing new equipment and encouraging technology transfer, technological alliances among Italian traditional small firms arouse area competition ability (Rosenfeld, 1996).

2.2. Evaluation of Collaborative Product Technological Innovation in Supply Chain

The collaboration in supply chain helps to enhance the members' performance. Collaboration in supply chain can make all members benefit from coordination (Harryson, Kliknaite & Dudkowski, 2007). Most companies want their supply chain partners devote more efforts into innovation, so in reality, this fact is that "one pay effort, others benefit" (Mentzer, Min & Zacharia, 2000). In order to make the most use of collaboration on technological innovation in supply chain, reasonable evaluation model is needed, which is the premise and bases for the correct evaluation of collaboration capabilities and performance of technological innovation in the supply chain.

The main methods of evaluation of collaboration in supply chain are: analytic hierarchy process (Yang, 2007a), fuzzy comprehensive evaluation method, data envelopment analysis (Charles, Cooper & Rhodes, 1978), and principal component analysis. Bhagwat & Sharma propose the analytic hierarchy process and evaluate the collaboration of the supply chain systematically (Bhagwat & Sharma, 2007). Philbin establishes evaluation model of collaboration innovation based on the conversion process (Philbin, 2008). Lu, Liu and Wang explain the connotation of the performance of industrial chain collaboration and build photovoltaic industry collaborative performance evaluation index system on the basis of the four dimensions of value chain, supply chain, technology chain, and space chain (Lu, Liu & Wang, 2013). Kexin, Ping and Hui (in press) analyze and evaluate the risk of low-carbon technological innovation in emerging economies under globalization by integrating the method of global value chain and technological innovation linear progress into a new analytical framework (Kexin, Ping & Hui, in press). Yange values the collaboration performance in supply chain based on combination of traditional analytic hierarchy process and fuzzy evaluation method (Yang, 2007a). In order to

solve the problem that work efficiency is difficult to evaluate in collaboration innovation, Zhao, Yang and Zeng construct an evaluation system of a collaboration product innovation to customers based on genetic algorithm to optimize neural network (Zhao, Yang & Zeng, 2010).

In summary, the evaluation and the measure of the efficiency of performance of the collaborative technological innovation both in theory and in practice has proven to be very important and quite complex, and there have been limited researches in the current literature.

3. Methodology

3.1. Data Envelopment Analysis

An efficiency score of a Decision Making Units (DMU) is generally defined as the weighted sum of outputs divided by the weighted sum of inputs, while weights need to be assigned. To avoid the potential problems in assigning these weights among various DMUs, a DEA model computes weights that give the highest possible relative efficiency score to a DMU while keeping the efficiency scores of all DMUs less than or equal to 1 under the same set of weights. The partial CCR form of a DEA model is summarized as follows:

$$\max h_k = \frac{\sum_{r=1}^s u_r y_{rk}}{\sum_{i=1}^m v_i x_{ik}} \quad (1)$$

$$s.t. \frac{\sum_{r=1}^s u_r y_{rj}}{\sum_{i=1}^m v_i x_{ij}} \leq 1, \quad j=1,2,\dots,n \quad (2)$$

$$u_r \geq \varepsilon > 0, \quad r=1,2,\dots,s \quad (3)$$

$$v_i \geq \varepsilon > 0, \quad i=1,2,\dots,m \quad (4)$$

where:

y_{rj} = the amount of output r of DMU $_j$;

x_{ij} = the amount of input i of DMU $_j$;

u_r = the weight for output r ;

v_i = the weight for input i ;

ε = a small positive number.

The above objective function is to maximize the efficiency score of a DMU k by choosing a set of weights for all inputs and outputs. The first constraint set of objective function ensures that, under the set of chosen weights, the efficiency scores of all DUMs are no more than 1. The

second and third constraint sets of objective function ensure that no weights are set to 0 for a consideration of all inputs and outputs in the model. A DMU k is considered efficient if the associated function results in an efficiency score of 1, otherwise it is considered to be inefficient.

By moving the denominator in the first constraint set objective function to the right-hand side and setting the denominator in the objective function to 1, objective function can be converted into a linear programming problem as follows:

$$\max h_k = \sum_{r=1}^s u_r y_{rk} \quad (5)$$

$$\text{s.t.} \quad \sum_{i=1}^m v_i x_{ij} = 1 \quad (6)$$

$$\sum_{r=1}^s u_r y_{rk} - \sum_{i=1}^m v_i x_{ij} \leq 0 \quad (7)$$

$$u_r, v_i \geq \varepsilon \quad (8)$$

$$j = 1, 2, \dots, n, r = 1, 2, \dots, s, i = 1, 2, \dots, m.$$

The dual model of above function can be then given as follows:

$$\min z_k = \Phi - \varepsilon \left(\sum_{i=1}^m s_i^- + \sum_{r=1}^s s_r^+ \right) \quad (9)$$

$$\text{s.t.} \quad \Phi x_i - \sum_{j=1}^n x_{ij} \lambda_j - s_i^- = 0 \quad (10)$$

$$\sum_{j=1}^n y_{rj} \lambda_j - s_r^+ = y_{rk} \quad (11)$$

$$\lambda_j, s_i^-, s_r^+ \geq 0$$

where $\Phi, \lambda_j, s_i^-, s_r^+$ are the dual variables.

3.2. Perfect DMU Ordering Rule

The traditional DEA model can only evaluate the relative effectiveness of DMU, and divide all DMU into two kinds of effective and non-effective. We can't get the order of all DMU by traditional DEA model. In some cases, there are many DMU are effective that evaluated by traditional DEA model. So a perfect DMU is introduced into traditional DEA model to improve the ranking of DMU. The basic idea of perfect DMU ordering is: Suppose there is a minimum input and maximum output DMU, which called perfect DMU. Obviously, compared with other DMU, the perfect DMU is effective. So the weight that calculated by maximum the efficiency

index of the perfect DMU is a group of relatively reasonable. And relative efficiency index of all DMU that obtained based on this group of weight can be used to order them.

Let $x_{i,\min}$ as the minimum value of input index i of all DMU, and let $y_{r,\max}$ as the maximum value of input index r of all DMU. Then we can get the perfect DMU _{$n+1$} . And the input index value and output index value of DMU _{$n+1$} are as follow:

$$x_{i,n+1} = \min_{1 \leq j \leq n} x_{i,j}, i = 1, 2, \dots, m \quad (12)$$

$$y_{r,n+1} = \max_{1 \leq j \leq n} y_{r,j}, r = 1, 2, \dots, s \quad (13)$$

Obviously, the DMU _{$n+1$} is the best evaluation unit, and all DMU in the original system are ineffective. Then the difference degree of all DMU can be evaluated, and we can get the order of all DMU.

3.3. Perfect DMU Ordering Rule

The traditional DEA is only suitable for input and output data in one moment, and it's a static model. In supply chain collaborative technological innovation system, we need to analyze the efficiency of DMU in multiple time periods. Therefore, it is necessary to develop a new dynamic DEA model based on the traditional DEA model. In dynamic DEA mode, we consider two type of input: variable inputs and quasi-fixed inputs. Set some new variable as follow:

$x_{i,j}^t$: the input i in period t of DMU _{j} ,

$z_{k,j}^t$: the input k in period t of DMU _{j} , and it's also the input in period $t+1$,

$y_{r,j}^t$: the input r in period t of DMU _{j} ,

$$I = \{1, 2, \dots, m\}, I_1 \cup I_2 = I, I_1 \cap I_2 = \Phi, i \in I_1, k \in I_2, t = 1, 2, \dots, T.$$

For the choice of decision variable above, the dynamic efficiency measures in different periods are inherent relevance. The dynamic efficiency measures are shown in Figure 1.

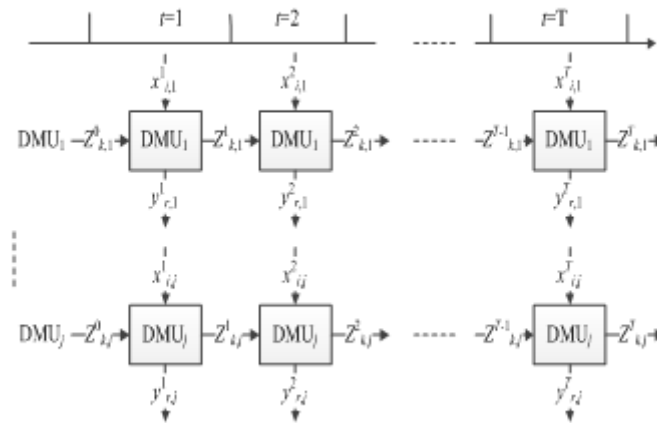


Figure 1. The flow figure of the dynamic evaluation of DMU efficiency

From the horizontal orientation of Figure 1, the dynamic efficiency of each DMU in different periods can be measured. And the dynamic efficiency of DMU is measured from the whole time, considering the special requirements of the decision variables on the front. From the vertical orientation of Figure 1, the different DMUs are evaluated in the same evaluation system. The shortcoming of previous dynamic DEA can only measure the efficiency of one DMU in different periods and the efficiency of many DMU in the same period is solved.

In order to measure the relative efficiency θ_j^t of DMU_j in each period and dynamic comprehensive efficiency in whole time ($t = 1, 2, \dots, T$). The function of dynamic DEA model is as follow:

$$\min \theta_j = \sum_{t=1}^T \theta_j^t / \left(T - \varepsilon \left(\sum_{t=1}^T \sum_{i=1}^s s_{i,j}^{t-} + \sum_{t=1}^T \sum_{k \in I_2} s_{k,j}^{t-} + \sum_{t=1}^T \sum_{r=1}^s s_{r,j}^{t+} + \sum_{t=1}^T \sum_{i \in I_1} s_{i,j}^{t-} \right) \right) \quad (14)$$

$$s.t. \quad \sum_{j=1}^{n+1} \lambda_j x_{i,j}^{t-} = \theta_j^t x_{i,j}^t, \quad i \in I, \quad t = 1, 2, \dots, T, \quad (15)$$

$$\sum_{j=1}^{n+1} \lambda_j z_{k,j}^{t-1} + s_{k,j}^{t-} = \theta_j^t z_{k,j}^{t-1}, \quad k \in I_2, \quad t = 1, 2, \dots, T, \quad (16)$$

$$\sum_{j=1}^{n+1} \lambda_j y_{r,j}^t - s_{r,j}^{t+} = y_{r,j}^t, \quad r = 1, 2, \dots, s, \quad r = 1, 2, \dots, T, \quad (17)$$

$$\sum_{j=1}^{n+1} \lambda_j z_{k,j}^t - s_{k,j}^{t+} = z_{k,j}^t, \quad k \in I_2, \quad t = 1, 2, \dots, T, \quad (18)$$

$$\sum_{j=1}^{n+1} \lambda_j = 1, \quad (19)$$

$$\lambda_j \geq 0, \quad s_{i,j}^{t-} \geq 0, \quad s_{k,j}^{t-} \geq 0, \quad s_{r,j}^{t+} \geq 0, \quad i+k=m.$$

Let $\theta_j^*, \theta_j^{t*}, \lambda_j^{t*}$ are the optimal solution of above function. Then θ_j^{t*} is the pure technical efficiency (PTE) of DMU_j in period t, and θ_j^* is the comprehensive technical efficiency of DMU_j in whole time ($t = 1, 2, \dots, T$). If we remove the function $\sum_{j=1}^{n+1} \lambda_j = 1$, then we can get the scaling efficiency (SE) of DMU.

4. Methodology

According to the research of Lou (Lou, 2009), there are three dimensions to evaluate the technological innovation collaboration on supply chain, including the collaboration foundation, technological innovation and supply chain collaboration. So we identify six criteria as the input index and three criteria as the output index based on the research of Lou (Lou, 2009), and the specific criteria are shown in Table 1. A questionnaire including the criteria is designed to collect the related information and data from the companies in ten supply chains in China. All of the companies are manufacturers or supplier in automobile industry. Two raters are participated in each company to make an appropriate rating, and the selected items from all websites are rated with the widely used Little Scale, i.e., from a scale of 1 (being the worst) to 5 (meaning excellent) accordingly. The original data is provided with this paper (see Appendix A).

Objective	Dimensions	Criteria
Input Index	Collaboration Foundation (A1)	The extent of cooperation (C1)
		Compactness in supply chain (C2)
	Technology Innovation (A2)	Innovation input (C3)
		Innovation implementation (C4)
	Supply Chain collaboration (A3)	Collaboration operations (C5)
		Knowledge exchange capacity (C6)
Output Index	—	Collaborative benefit (R1)
	—	Capability improvement (R2)
	—	Supply chain benefits (R3)

Table 1. Dimensions and criteria of the evaluating system

4.1. Result of Traditional DEA Model

It can be seen from the Table 2 that when take the collaborative benefit as the output, only two DMU are efficient, while when take capability improvement or supply chain benefits as output, there are four DMU are efficient. Both of DMU₉ and DMU₁₉ have two efficient indexes, and no DMU has three efficient indexes, which means that there are big spaces for improvement for the selected twenty supply chains, especially in the collaborative benefit aspect.

DMU	Efficiency		
	Collaborative benefit	Capability improvement	Supply chain benefits
DMU ₁	0.55	0.76	0.68
DMU ₂	0.57	0.63	0.48
DMU ₃	0.57	0.84	0.71
DMU ₄	0.61	0.68	0.76
DMU ₅	0.64	0.47	0.8
DMU ₆	0.78	0.58	1
DMU ₇	0.36	0.8	0.67
DMU ₈	0.72	0.8	0.69
DMU ₉	0.74	1	1
DMU ₁₀	0.57	0.63	1
DMU ₁₁	0.38	0.42	0.79
DMU ₁₂	0.34	0.38	0.64
DMU ₁₃	0.62	1	0.77
DMU ₁₄	0.68	0.76	0.64
DMU ₁₅	1	0.82	0.61
DMU ₁₆	0.72	0.6	0.45
DMU ₁₇	0.6	0.67	1
DMU ₁₈	0.49	1	0.4
DMU ₁₉	1	1	0.75
DMU ₂₀	0.68	0.46	0.51

Table 2. Dimensions and criteria of the evaluating system in 2014

DMU	Input						Output			Scalebenefit
	s_1^-	s_2^-	s_3^-	s_4^-	s_5^-	s_6^-	s_1^+	s_2^+	s_3^+	
DMU ₁	0.391	0.435	0.061	0.438	0.304	0.047	0.134	0.263	0.460	Increase
DMU ₂	0.714	0.117	0.718	0.708	0.359	0.592	0.105	0.312	0.678	Increase
DMU ₃	0.254	0.307	0.210	0.011	0.272	0.299	0.217	0.242	0.238	Increase
DMU ₄	0.188	0.315	0.082	0.339	0.015	0.133	0.022	0.047	0.395	Increase
DMU ₅	0.278	0.127	0.380	0.014	0.175	0.153	0.306	0.318	0.075	Increase
DMU ₆	0	0	0	0	0	0	0	0	0	Same
DMU ₇	0.048	0.199	0.384	0.136	0.234	0.090	0.301	0.102	0.202	Increase
DMU ₈	0.280	0.365	0.384	0.219	0.055	0.060	0.013	0.336	0.121	Increase
DMU ₉	0	0	0	0	0	0	0	0	0	Same
DMU ₁₀	0	0	0	0	0	0	0	0	0	Same
DMU ₁₁	0.032	0.025	0.223	0.327	0.392	0.055	0.239	0.197	0.005	Increase
DMU ₁₂	0.243	0.117	0.572	0.224	0.381	0.119	0.422	0.189	0.471	Increase
DMU ₁₃	0	0	0	0	0	0	0	0	0	Same
DMU ₁₄	0.478	0.038	0.212	0.051	0.462	0.002	0.372	0.392	0.417	Increase
DMU ₁₅	0	0	0	0	0	0	0	0	0	Same
DMU ₁₆	0.076	0.487	0.325	0.308	0.081	0.478	0.348	0.197	0.287	Increase
DMU ₁₇	0	0	0	0	0	0	0	0	0	Same
DMU ₁₈	0	0	0	0	0	0	0	0	0	Same
DMU ₁₉	0	0	0	0	0	0	0	0	0	Same
DMU ₂₀	0.226	0.526	0.010	0.028	0.108	0.415	0.468	0.415	0.289	Increase

Table 3. Slack variable of input and output indexes in 2014

It can be seen from Table 3 that there is no change regarding the scale benefits in DMU₆, DMU₉, DMU₁₀, DMU₁₃, DMU₁₅, DMU₁₇, DMU₁₈, while others increase in the scale benefits.

4.2. Result of Dynamic DEA Model

Using the dynamic DEA model, we can get the comprehensive technical efficiency of the whole time from 2012 to 2014 and the order of all DMU. As shown in Table 4 and Table 5.

DMU	Efficiency								
	Collaborative benefit			Capability improvement			Supply chain benefits		
	TE	PTE	SE	TE	PTE	SE	TE	PTE	SE
DMU ₁	0.52	0.75	0.87	0.72	0.75	0.87	0.65	0.76	0.85
DMU ₂	0.54	0.64	0.79	0.60	0.76	0.79	0.46	0.64	0.76
DMU ₃	0.53	0.54	0.73	0.80	0.85	0.86	0.68	0.84	0.95
DMU ₄	0.58	0.65	0.86	0.65	0.71	0.87	0.72	0.84	0.81
DMU ₅	0.61	0.71	0.74	0.45	0.64	0.89	0.76	0.78	0.78
DMU ₆	0.74	0.85	1	0.55	0.68	0.75	0.91	0.92	0.86
DMU ₇	0.34	0.38	0.48	0.76	0.8	0.87	0.64	0.67	0.79
DMU ₈	0.69	0.72	0.86	0.77	0.85	0.92	0.66	0.86	0.83
DMU ₉	0.95	1	1	0.94	1	1	0.97	1	1
DMU ₁₀	0.53	0.56	1	0.61	0.76	0.84	0.93	0.97	0.95
DMU ₁₁	0.36	0.48	0.68	0.42	0.67	0.76	0.75	0.82	0.85
DMU ₁₂	0.32	0.39	0.75	0.36	0.48	0.58	0.61	0.76	0.79
DMU ₁₃	0.59	0.61	0.78	0.93	1	1	0.73	0.81	0.83
DMU ₁₄	0.64	0.74	0.86	0.72	0.86	0.93	0.63	0.73	0.84
DMU ₁₅	0.95	1	1	0.98	1	1	0.88	1	1
DMU ₁₆	0.69	0.77	0.78	0.58	0.78	0.82	0.43	0.56	0.63
DMU ₁₇	0.57	0.62	1	0.64	0.82	0.85	0.95	0.96	0.97
DMU ₁₈	0.47	0.53	0.76	0.96	1	1	0.38	0.75	0.68
DMU ₁₉	0.96	1	1	0.94	1	1	0.91	1	1
DMU ₂₀	0.65	0.79	0.87	0.44	0.48	0.56	0.49	0.65	0.78
Mean	0.61	0.69	0.84	0.69	0.79	0.86	0.71	0.82	0.85

Table 4. The comprehensive technical efficiency of three years (from 2012 to 2014)

DMU	Order			
	Collaborative benefit	Capability improvement	Supply chain benefits	Comprehensive
DMU ₁	16	10	13	12
DMU ₂	13	14	18	17
DMU ₃	14	6	11	9
DMU ₄	11	11	10	11
DMU ₅	9	17	7	13
DMU ₆	4	16	5	5
DMU ₇	19	8	14	15
DMU ₈	5	7	12	7
DMU ₉	2	4	1	1
DMU ₁₀	15	13	3	8
DMU ₁₁	18	19	8	19
DMU ₁₂	20	20	16	20
DMU ₁₃	10	5	9	4
DMU ₁₄	8	9	15	10
DMU ₁₅	3	1	6	3
DMU ₁₆	6	15	19	16
DMU ₁₇	12	12	2	6
DMU ₁₈	17	2	20	14
DMU ₁₉	1	3	4	2
DMU ₂₀	7	18	17	18

Table 5. The order of comprehensive technical efficiency of all DMU

From Table 5, we can get the Top five DMU is: DMU₉, DMU₁₉, DMU₁₅, DMU₁₃, DMU₆. And the worst five DMU is: DMU₁₂, DMU₁₁, DMU₂₀, DMU₂, DMU₁₆.

5. Conclusions

This paper is an attempt to investigate the current issues and development of the supply chain collaborative technological innovation in China. The objectives for this research are threefold:

- to examine and evaluate the effectiveness of 20 supply chains in automobile industry in China;
- to identify major issues and challenges for those companies in utilizing their supply chain management in promoting the technological innovation; and
- to discuss and explore the potential managerial implications for future research.

DEA is employed not only to measure the efficiency of the supply chain collaborative technological innovation, but also information regarding how to improve the efficiency and reduce the undesirable outputs. An empirical study is illustrated to testify the effectiveness of this method. The primary data for this research are collected through a comprehensive questionnaire.

From the results of this research, we can get the conclusion that there are big spaces for improvement for the selected companies in terms of supply chain collaborative technological innovation, especially in the collaborative benefit aspect. The efficiency of the supply chain collaborative technological innovation in the selected companies vary a lot. Our recommendations for improving supply chain companies in terms of improving their collaborative technological innovation efficiency are:

- expanding the cooperative scope;
- optimizing the collaboration operations;
- improving the compactness in supply chain;
- increasing the innovation input; and
- improving the knowledge exchange capacity.

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References

- Bhagwat, R., & Sharma, M.K. (2007). Performance measurement of supply chain management using the analytical hierarchy process. *Production Planning & Control*, 18, 666-680. <http://dx.doi.org/10.1080/09537280701614407>
- Cao, M., & Zhang, Q.Y. (2011). Supply chain collaboration: impact on collaborative advantage and firm performance. *Journal of Operations Management*, 29, 163-180. <http://dx.doi.org/10.1016/j.jom.2010.12.008>
- Carey, S., Lawson, B., & Krause, D. (2011). Social capital configuration, legal bonds and performance in buyer-supplier relationships. *Journal of Operations Management*, 28(4), 277-288. <http://dx.doi.org/10.1016/j.jom.2010.08.003>
- Charles, A., Cooper, W.W., & Rhodes, B. (1978). Measuring the Efficiency of Decision Making Units. *European Journal of Operational Research*, 3(4), 429-444. [http://dx.doi.org/10.1016/0377-2217\(78\)90138-8](http://dx.doi.org/10.1016/0377-2217(78)90138-8)
- Dachs, B., Ebersberger, B., & Pyka, A. (2008). Why do firms cooperate for innovation? A comparison of Austrian and Finnish CIS3 results. *Discussion Paper*, 4(3-4), 200-229. <http://dx.doi.org/10.1504/ijfip.2008.017577>
- Ellis, S.C., Henke, J.W., & Kull, T.J. (2012). The effect of buyer behaviours on preferred customer status and access to supplier technological innovation: an empirical study of supplier perceptions. *Industrial Marketing Management*, 41, 1259-1269. <http://dx.doi.org/10.1016/j.indmarman.2012.10.010>
- Fawcett, S.E., & Magnan, G.M. (2004). Ten guiding principles for high-impact SCM. *General Information*, 47, 67-74. <http://dx.doi.org/10.1016/j.bushor.2004.07.011>
- Gilbert, S.M., & Cvas, V. (2003). Strategic commitment to price to stimulate downstream innovation in a supply chain. *European Journal of Operational Research*, 150, 617-639. [http://dx.doi.org/10.1016/S0377-2217\(02\)00590-8](http://dx.doi.org/10.1016/S0377-2217(02)00590-8)
- Harryson, S., Klikaite, S., & Dudkowski, R. (2007). Flexibility in innovation through external learning: exploring two models for enhanced industry university collaboration. *International Journal of Technology Management*, 41, 109-137. <http://dx.doi.org/10.1504/IJTM.2008.015987>
- Hippel, E.A.V. (1988). The Sources of Innovation. *Social Science Electronic Publishing*, 387-392.
- Kexin, B., Ping, H., & Hui, Y. (in press). Risk identification, evaluation and response of low-carbon technological innovation under the global value chain: A case of the Chinese manufacturing industry. *Technological Forecasting & Social Change*. <http://dx.doi.org/10.1016/j.techfore.2015.07.005>

- Lawson, B., Tyler, B.B., & Cousins, P.D. (2008). Antecedents and consequences of social capital on buyer performance improvement. *Journal of Operations management*, 26(3), 446-460. <http://dx.doi.org/10.1016/j.jom.2007.10.001>
- Lee, V., Ooi, K., Chong, A.Y., & Seow, C. (2014). Creating technological innovation via green supply chain management: An empirical analysis. *Expert Systems with Applications*, 41, 6983-6994. <http://dx.doi.org/10.1016/j.eswa.2014.05.022>
- Li, S.H., Nathan, B.R., Nathan, T.S.R., & Rao, S.S. (2006). The impact of supply chain management practices on competitive advantage and organizational performance. *The International Journal of Management Science*, (34), 107-124.
<http://dx.doi.org/10.1016/j.omega.2004.08.002>
- Lou, G.X. (2009). *Research on collaboration on technological innovation in supply chain*. Shanghai Jiao Tong University, 4-56.
- Lu, Z.N., Liu, C.Q., & Wang, G.D. (2013). Research on performance evaluation index system of photovoltaic industry chain collaboration. *Science & Technology and Economy*, 26(1), 106-110.
- Mentzer, J.M., Min, S., & Zacharia, Z.G. (2000). The nature of inter firm partnering in supply chain management. *Journal of Retailing*, 76, 549-568. [http://dx.doi.org/10.1016/S0022-4359\(00\)00040-3](http://dx.doi.org/10.1016/S0022-4359(00)00040-3)
- Philbin, S. (2008). Process model for university-industry research collaboration. *European Journal of Innovation Management*, 11(4), 488-521. <http://dx.doi.org/10.1108/14601060810911138>
- Rosenfeld, S.A. (1996). Does cooperation enhance competitiveness? Assessing the impacts of inter-firm collaboration. *Research Policy*, 25(95), 247-263. [http://dx.doi.org/10.1016/0048-7333\(95\)00835-7](http://dx.doi.org/10.1016/0048-7333(95)00835-7)
- Schilling, M.A., & Phelps, C.C. (2007). Interfirm Collaboration Networks: The Impact of Large-Scale Network Structure on Firm Innovation. *Management Science*, 53(7), 1113-1126. <http://dx.doi.org/10.1287/mnsc.1060.0624>
- Wong, C., Boon-itt, S., & Wong, C. (2011). The contingency effects of environmental uncertainty on the relationship between supply chain integration and operational performance. *Journal of Operations management*, 29(6), 604-615.
<http://dx.doi.org/10.1016/j.jom.2011.01.003>
- Yang, H. (2007a). The evaluation of supply chain on Analytic Hierarchy Process. *Logistics Science Technology*, 29, 91-94.
- Yang, L.W. (2007b). Research on synergy collaboration innovation in supply chain. *Industrial Technology & Economy*, 11, 54-55.
- Zhang, X.M., Zhang, K., & Zhong, H.P. (2008). Research on collaboration innovation in supply chain and its implementation strategies. *Modern Management Science*, 5, 9-11.

Zhao, C., Yang, J., & Zeng, Q. (2010). Application of BP neural network improved genetic algorithm in evaluation of collaborative innovation. *Machinery*, 37(8), 5-9.

Zhong, X.B. (1999). The collaborative innovation process simulation. *Digest of Management Science*, 4.

Zhou, K.Z., Zhang, Q., Sheng, S., Xie, E., & Bao, Y. (2014). Are relational ties always good for knowledge acquisition? Buyer-supplier exchanges in China. *Journal of Operations management*, 32(3), 88-98. <http://dx.doi.org/10.1016/j.jom.2014.01.001>

Appendix A

Original data of input and output index from 2012 to 2014

Year	DMU	Input						Output		
		C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	R ₁	R ₂	R ₃
2012	DMU ₁	4	4	4	4	4	5	4	5	4
	DMU ₂	3	3	4	3	3	2	3	3	2
	DMU ₃	2	3	2	3	4	4	3	4	3
	DMU ₄	4	5	5	5	5	4	5	5	5
	DMU ₅	2	3	3	3	2	3	3	2	3
	DMU ₆	1	1	2	3	2	4	3	2	3
	DMU ₇	3	2	3	4	3	4	2	4	3
	DMU ₈	4	3	3	2	3	4	4	4	3
	DMU ₉	4	3	4	3	3	2	4	5	4
	DMU ₁₀	5	3	3	4	5	4	4	4	5
	DMU ₁₁	5	5	3	5	5	4	3	3	5
	DMU ₁₂	4	2	5	4	2	3	2	2	3
	DMU ₁₃	3	4	3	2	5	5	4	5	4
	DMU ₁₄	3	3	4	3	4	3	4	4	3
	DMU ₁₅	3	2	4	2	1	2	4	3	2
	DMU ₁₆	3	3	3	4	3	3	4	3	2
	DMU ₁₇	2	1	4	3	4	3	3	3	4
	DMU ₁₈	5	4	4	3	2	3	3	5	2
	DMU ₁₉	5	2	5	2	2	1	5	4	3
	DMU ₂₀	3	4	4	5	4	5	5	3	3
2013	DMU ₁	3	2	3	4	4	5	4	5	4
	DMU ₂	5	5	5	4	5	3	3	2	3
	DMU ₃	3	3	2	3	3	4	3	2	3
	DMU ₄	2	3	2	4	3	4	2	4	3
	DMU ₅	3	4	3	4	2	4	4	4	3
	DMU ₆	3	2	3	4	4	2	4	5	4
	DMU ₇	4	3	3	2	3	4	4	4	5
	DMU ₈	3	2	2	2	1	5	4	4	3
	DMU ₉	5	4	5	3	3	3	3	4	3
	DMU ₁₀	5	3	3	4	5	2	3	2	3
	DMU ₁₁	5	5	3	5	5	4	5	5	5
	DMU ₁₂	4	2	5	4	2	2	3	3	3
	DMU ₁₃	5	3	4	5	5	5	4	5	4
	DMU ₁₄	5	5	5	3	3	2	3	3	3
	DMU ₁₅	4	3	3	2	3	2	4	3	2
	DMU ₁₆	3	4	3	3	4	3	4	2	2
	DMU ₁₇	2	1	4	3	2	3	4	4	4
	DMU ₁₈	5	4	4	3	4	4	3	4	2

Year	DMU	Input						Output		
	DMU ₁₉	5	5	5	5	4	5	3	2	3
	DMU ₂₀	3	3	3	2	3	3	2	2	3
2014	DMU ₁	4	2	3	2	4	3	5	3	4
	DMU ₂	3	3	4	3	4	2	3	3	2
	DMU ₃	2	3	2	3	4	4	3	4	3
	DMU ₄	4	5	5	5	5	4	5	5	5
	DMU ₅	2	3	3	3	2	3	3	2	3
	DMU ₆	1	1	2	3	2	4	3	2	3
	DMU ₇	3	2	3	4	3	4	2	4	3
	DMU ₈	4	3	3	2	3	4	4	4	3
	DMU ₉	4	3	4	3	3	2	4	5	4
	DMU ₁₀	5	3	5	5	5	4	5	4	5
	DMU ₁₁	4	4	3	3	2	3	3	3	5
	DMU ₁₂	4	5	2	3	2	4	3	2	3
	DMU ₁₃	4	4	3	4	3	4	2	5	4
	DMU ₁₄	4	4	3	2	5	5	5	4	5
	DMU ₁₅	3	4	4	5	3	3	2	3	3
	DMU ₁₆	3	4	4	4	2	3	2	4	3
	DMU ₁₇	2	1	4	5	3	4	3	4	2
	DMU ₁₈	5	4	4	4	3	2	3	4	4
DMU ₁₉	5	2	4	4	4	4	5	4	3	
DMU ₂₀	3	4	4	5	4	4	3	3	3	

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