Based on data envelopment analysis to evaluate agricultural product supply chain performance of agricultural science and technology parks in China

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Abstract

In face of the advance of information technology and the emergence of Internet in the 21st century, the advance of technology and transportation has the demand and supply of agricultural products no longer be restricted to various countries or certain areas. It becomes urgent to ensure the quality (guarantee), integrity, safety, diversity, and relevant information (service) of agricultural products. Consumers' consumption ideas and habits have been largely changed. The marketing principles simply stressing on "quality" and "price satisfaction" could no longer satisfy customers' requirements. The circulation and supply processes of agricultural products therefore should be controlled to ensure the excellent quality. The agricultural product supply chain management is relatively important. Taking Nanping City Supply and Marketing Cooperatives as the research sample, Data Envelopment Analysis (DEA) is applied to evaluate the efficiency in this study. The variable data are acquired from open statistical data. The research results are summarized as below. 1. One DMU presents strong execution efficiency on agricultural product supply chain, showing the better agricultural product supply chain; 4 DMUs reveal the agricultural product supply chain execution efficiency in 0.9~1, showing that the agricultural product supply chain execution efficiency could be easily promoted; 5 DMUs appear the agricultural product supply chain efficiency lower than 0.9, which is obvious inefficient. 2. Sensitivity analysis is used for finding out key factors in the execution of agricultural product supply chain in order to understand the sensitivity to efficiency. The sensitivity factors contain production cost, labor cost, response efficiency, and profit. Finally, suggestions are proposed according to the results. It is expected to enhance the quality, logistic, and information system of agricultural product supply chain, during the integration and innovation of agricultural product supply chain, for the coordination and integration to more effectively execute the frequent

transaction.

Keywords: Agricultural product. Supply chain management. Performance evaluation.

1. Introduction

In face of the advance of information technology and the emergence of Internet in the 21st century, the enhancement of consumers' living standards have largely changed the consumption ideas and habits. Original marketing emphasis on "quality" and "price satisfaction" could no longer satisfy customers' requirements; instead, new competition rules should cover "quality", "price", "flexible delivery", and "service speed and efficiency".

The competitive environment in the market is getting fierce, and the competition gradually changes from enterprises to supply chains and the market production and marketing changes from traditional producer orientation to customer needs orientation. To rapidly respond to the change in the market environment and customer needs, the supply chain management (SCM) system is introduced into the production and marketing systems of enterprises, and the competition among enterprise changes from manufacturing costs to supply chain management. Enterprises practice supply chain management to relocate, reorganize, and re-establish systems through process reengineering and apply five major elements of supply chain management, namely information integration, collaboration, optimal arrangement, real-time response, and customer satisfaction, to effectively execute corporate resource planning and enhance the internal operation efficiency.

Moreover, the information and communication technology of e-commerce and e-business is applied to integrate the real-time interaction among partners in the upstream-downstream supply chain systems in order to reduce stock risks and operating costs, shorten delivery, flexibly respond to customer needs, as well as effectively enhance customer satisfaction and the maximal benefit of the entire competitive advantage of the enterprise. Along with the advance of technology and transportation, agricultural product demand and supply is no longer restricted to various countries or certain areas.

It becomes urgent to ensure the quality (guarantee), integrity, safety, diversity, and relevant information (service) of agricultural products. The selection of key measuring indices is rather important in order to measure the product supply performance. Being the research object, agricultural products could easily corrode and go bad that the circulation and supply process should be controlled in order to ensure the excellent quality.

The management of agricultural product supply chain is therefore critical. The

enhancement of agricultural product supply chain management presents significant meanings on the implementation of national "three issues" policies to enhance farmers' income and improve rural production conditions. The quality, logistic, and information systems should also be enhanced during the integration and innovation of agricultural product supply chain for the coordination and integration in order to more effectively execute frequent transaction. The agricultural product supply chain performance is therefore evaluated in this study.

2. Literature Review

2.1 Supply chain

Cheng et al. (2018) regarded supply chain as the relationship between an enterprise and the upstream suppliers, downstream customers; a supply chain could shorten product distribution periods, reduce supply chain costs, accelerate the development of new products, and enhance the supply chain flexibility and customer satisfaction.

Calantone et al. (2014) indicated that the source of supply chain was logistics, as the logistics supply in militaries, which was gradually applied to commercial activity along with the boom of business. Logistics systems aimed to satisfy consumers. "Supply chain" was developed when expanding the focus of logistics and integrating upstream and downstream members of an enterprise. Gross (2013) explained supply chain as to enhance the management performance and service standards through the effective cooperation among members.

In other words, it was expected to integrate relevant enterprises and processes to reduce wastes and repetition as well as to promote management performance by tight cooperation. To effectively enhance performance and service and reduce relevant costs, each enterprise should devote to reinforcing the cooperation with other members in the supply chain, i.e. supply chain management (Koksal, 2014). Guchhait et al. (2013) pointed out supply chain as the network cooperation among enterprises, including the combination of programs and activity to produce value with products and services.

Agustina et al. (2014) proposed the ideal supply chain model as to equivalently and real-time get into and circulate in the supply chain with high integration of products and information; meanwhile, all participants (or members) in the supply chain could contact the same information. To effectively enhance performance and service and reduce relevant costs, each enterprise should devote to reinforcing the cooperation with other members in the supply chain, integrating the operation, technology, and cooperation among members in the supply chain, as well as sharing information to develop the function of the supply chain.

Lengler et al. (2013) mentioned that a supply chain was the set of enterprise activities for the implementation of corporate objectives to achieve customer satisfaction with the quality. In traditional supply chains, the source of information was the indirect delivery process that neighboring members should cultivate partnership with mutual trust and respect. Vinayak & Kodali (2014) mentioned that network integrated the information among enterprises in the supply chain into the real-time, correct, and rich environment to enhance the close coordination among members. The direct information source, for the organizations, had the information network present the benefits of enhancing productivity, reducing costs, shortening period, improving quality, and reinforcing relationship with customers. Chen & Cui (2012) referred supply chain to the network cooperation among organizations, containing the combination of programs and activities to produce value with products and services from upstream to downstream.

This study intends to evaluate agricultural product supply chain performance, where agricultural product supply chain is the supply chain specifically engaging in the supply, production, and sales of agricultural products; the managed objects are special, as the quality & safety and logistics efficiency are two important elements in the fresh agricultural product supply chain.

2.2. Performance evaluation

Social resources are limited that the optimal utilization of limited resources has been the concern of managers. Efficiency and effectiveness are often used for measuring the resource application ability and the objective attainment degree of an organization, which are also the points in performance evaluation. Chang et al. (2013) regarded efficiency as doing things right, which focused on the use of correct means (Katok & Pavlov, 2013), measured the degree of internal resources in an organization being effectively applied in short terms (Liang et al., 2013), acquired the most outputs with the least inputs by discussing the relationship between inputs and outputs (Bloodgood et al., 2013), or found out the way to reduce production costs in order to enhance the cost effectiveness of resource use (Chen et al., 2013), and regarded the results as the reference for improving organizational productivity (Taticchi et al., 2014).

Chang et al. (2013) defined effectiveness as doing the right thing, referring to an organization, under the premise of the customers acquiring the maximal value, utilizing the ability of generating income with external operation, which stressed on the measurement of ends and mainly discussed the organization effectively achieving the set objectives within a period of time (Vinayak & Kodali, 2014).

Efficiency could be the performance on the process transforming inputs into outputs, which stresses on the effective utilization of present production resources. In economics, the idea of Pareto Optimality (Rivera-Gómez et al., 2013) could be used for the explanation. From the aspect of input orientation, it refers to an organization, under the same outputs, could not increase outputs without increasing input resources or reducing other outputs; the organization therefore is efficient. From the aspect of output orientation, an organization, under the same inputs, could not reduce inputs without reducing outputs or increasing other inputs; in this case, the organization is efficient (Vinayak & Kodali, 2014).

In regard to the research on supply chain performance evaluation, Xi et al. (2007) evaluated supply chain performance with user satisfaction, information sharing, logistics integration, and partnership. Wang et al. (2015) established a performance evaluation index system of agricultural product supply chain for a supermarket and calculated the factor score in 2007~2012. Chang (2017) evaluated supply chain management performance based on rough set and Markov chain.

2.3. Data Envelopment Analysis

Data Envelopment Analysis first appeared in the article published by Charnes, Cooper, and Rhodes in 1978 (Chiu et al., 2013), which promoted the efficiency idea of single input, single output to the effectiveness evaluation system of decision-making units (DMU) of the same type with multi-input, multi-output. Data Envelopment Analysis is a non-parametric method. That is, without preset production function, it could calculate the points on the production boundary of the multi-input and multi-output data of decision making units through linear planned mathematical operations. The points on the production boundary are economically referred to the most beneficial input/output combination of the DMU, i.e. relatively efficient units. Such efficient units are linked to construct the efficiency frontier, i.e. envelope. The observed value of the input/output ratio of DMUs is further compared with the efficiency frontier to measure the relative efficiency of DMUs and the improvement direction for achieving efficiency.

The theory of data envelopment enriches the theory of production function; meanwhile, the theory and application are rapidly developed to avoid subjective factors and reduce errors. Four classical models of CCR, BCC, FG, and ST are covered. From economy, supply chain operation, innovation, and environment, Cao et al. (2017) used BCC model in DEA for evaluating the supply chain performance of green agricultural products in 10 cities in Shandong Province. Fang et al. (2017) evaluated the operation efficiency of green supply chain based on DEA.

According to the systematic Data Envelopment Analysis applications organized by Lee et al. (2013), four major points are discussed.

- Definition and selection of decision-making unit: Decision-making units are the evaluated objects of Data Envelopment Analysis. To have DMUs be evaluated at the same standpoint, each DMU should present homogeneity, i.e. the same objectives, executing similar work, and operating under the same market conditions. According to the empirical law proposed by Mukerjee (2013), the number of evaluated DMUs should be at least twice the sum of the numbers of inputs and outputs.
- Selection of input/output: Inputs/outputs are closely related to the evaluation of relative efficiency of DMUs that the selection should be based on the operation characteristics of DMUs and the operation objectives of the organizations. The

correlation of inputs/outputs should be tested for the selection, i.e. isotonicity between inputs and outputs. It reveals that the outputs could not be reduced when increasing inputs.

- Selection of evaluation model: The research objective and information for decision making are required for selecting the suitable evaluation model.
- Result analysis and explanation: The Data Envelopment Analysis result should be able to explain the performance of DMUs, provide suggestions for improvement, and offer reference, with feedback, for decision makers improving the management. The analysis results therefore should contain efficiency analysis and slack variable analysis, and provide suggestions for management.

3. Research Design

3.1. Selection of input/output

To combine the selection of inputs/outputs with expert opinions, reduce input costs, and avoid fuzziness in the survey process, Modified Delphi Method is used for selecting inputs/outputs. Based on special considerations on parts of the research, brainstorming open-ended questionnaire is omitted. After referring to large amount of literatures, a structured questionnaire is directly developed for the first run questionnaire survey.

It is regarded as Modified Delphi Method. Directly preceding the structured questionnaire for the first run survey could save lots of time; and, the structured questionnaire could have the research experts immediately focus on the research subject, without making guesses on open-ended questionnaire. Total 30 copies of questionnaire are distributed and 23 valid copies are retrieved, with the retrieval rate 77%. Since Nanping City is an agricultural city, the farmers possessing mountain areas and cultivated areas are ranked on top in the province. Located on the north of Fujian Province and the upstream of Min River, Nanping city is the “granary of Fujian”. Nanping City Supply and Marketing Cooperatives are therefore selected as the research sample in this study, and the used variable data are acquired from open statistical data.

Definition of variable:

Input variable:

(1) Production cost: All costs for agricultural products in the production process.

(2) Labor cost: All labors (number of people) invested in the process from production

to products delivered to the customers.

Output variable:

(1) Response efficiency: Delivery time in the order.

(2) Profit: Acquired income after selling agricultural products.

3.2. Efficiency evaluation analysis

From the perspective of economics, fewer inputs for more outputs reveal the better "performance" of an operation unit; "efficiency" could be used for evaluating such performance. With the comparison between inputs and outputs, efficiency is defined as efficiency=weighted sum of outputs/weighted sum of inputs; the function to acquire the maximal output with different input combination is called "production function".

The generally acquired maximal outputs are smaller than the production function outputs that production function is the maximal frontier of various outputs, which is called "production frontier". Geometrically, efficiency maps the inputs and outputs of DMUs to the space with envelope to evaluate the relative efficiency of the organization, find out the envelope, which could envelope the efficiency of all observation data, to form efficiency frontier, and calculate the distance between the observation value and efficiency envelope of a DMU for the efficiency standard.

Data Envelopment Analysis (DEA) is used in this study for evaluating efficiency. Unlike traditional regression analysis, which simply seeks for the average path among the points in a series of data, it envelopes the data of various samples and attempts to find out the relationship that it presents the advantages required for a good efficiency evaluation model. Such a method applies linear planning, considers the factors which could be used for measuring the performance among DMUs, and compares the performance of units with similar features.

4. Empirical Analysis of Agricultural Product Supply Chain Performance

4.1. Performance analysis of agricultural product supply chain

By substituting various inputs/outputs into CCR and BCC models, the overall production efficiency and pure technical efficiency could be calculated. The returns to scale of agricultural product supply chain could be acquired by divided the two. Overall production efficiency, pure technical efficiency, scale efficiency, and returns to scale are organized in

Table 1.

From Table 1, Urban supply and marketing cooperatives, with the overall efficiency=1, is relatively the most efficient cooperatives, while the rest agricultural product supply chain shows lower overall production efficiency. Especially, Daheng supply and marketing cooperatives, with the lowest overall production efficiency, is relatively the most inefficient cooperatives. In other words, 1 DMU reveals the overall production efficiency=1, while the rest 9 DMUs are relatively inefficient. The inefficiency might be not effectively applying inputs or not achieving the optimal production scale. It requires further analyses.

Table 1: Relative efficiency of agricultural product supply chain

Cooperatives in various areas	overall efficiency	technical efficiency	scale efficiency
Urban supply and marketing cooperatives	1.00	1.00	1.00
Xiqin supply and marketing cooperatives	0.83	0.84	0.83
Sizdao supply and marketing cooperatives	0.90	0.89	0.91
Zhanghu supply and marketing cooperatives	0.96	0.94	0.98
Nanshan supply and marketing cooperatives	0.88	0.87	0.89
Xiayang supply and marketing cooperatives	0.80	0.80	0.80
Daheng supply and marketing cooperatives	0.73	0.72	0.74
Taiping supply and marketing cooperatives	0.93	0.92	0.93
Luxia supply and marketing cooperatives	0.85	0.86	0.84
Wangtai supply and marketing cooperatives	0.92	0.92	0.92

4.2. Sensitivity analysis

This study aims to analyze and find out key factors in agricultural product supply chain through sensitivity analysis. Various inputs and outputs are gradually removed for DEA to understand the sensitivity to efficiency. The research result is evaluated based on the changes in sensitivity, including sensitivity factors of production cost, labor cost, response efficiency, and profit. From Table 2,

(1) The efficiency of all DMUs reduces after removing “production cost” that R&D capitals show higher importance on all DMUs.

(2) The efficiency of all DMUs reduces after removing “labor cost” that R&D time reveals higher importance on all DMUs.

(3) The efficiency of all DMUs reduces after removing "response efficiency" that R&D results present higher importance on all DMUs.

(4) The efficiency of all DMUs reduces after removing "profit" that operating performance appears higher importance on all DMUs.

Table 2: Sensitivity analysis after gradually removing inputs and outputs

DMU	Original relative efficiency	Removing production cost	Removing labor cost	Removing response efficiency	Removing profit
Urban supply and marketing cooperatives	1.00	0.96	0.95	0.88	0.86
Xiqin supply and marketing cooperatives	0.83	0.80	0.81	0.75	0.78
Sizdao supply and marketing cooperatives	0.90	0.87	0.86	0.82	0.84
Zhanghu supply and marketing cooperatives	0.96	0.92	0.90	0.84	0.85
Nanshan supply and marketing cooperatives	0.88	0.85	0.83	0.80	0.80
Xiayang supply and marketing cooperatives	0.80	0.77	0.76	0.76	0.75
Daheng supply and marketing cooperatives	0.73	0.70	0.70	0.68	0.66
Taiping supply and marketing cooperatives	0.93	0.90	0.90	0.88	0.85
Luxia supply and marketing cooperatives	0.85	0.80	0.81	0.79	0.75
Wangtai supply and marketing cooperatives	0.92	0.84	0.85	0.83	0.82
Number of efficient DMU	1	0	0	0	0

Data source: Self-organized in this study.

5. Conclusion

From the efficiency acquired from DEA and the information of variables, 1 DMU, about 10% of all DMUS, presents strong efficiency, with the efficiency=1, revealing the better efficiency of agricultural product supply chain; 4 DMUs, about 40% of all DMUs, show marginal inefficiency, with the efficiency in 0.9-1, revealing that the efficiency of

agricultural product supply chain could be more easily enhanced; and, 5 DMUs, about 50% of all DMUs, present obvious inefficiency, with the efficiency lower than 0.9, where Daheng supply and marketing cooperatives appear the lowest efficiency of agricultural product supply chain.

In the DEA result, Urban supply and marketing cooperatives fully utilizes existing operation networks and storage facilities to overall short capitals, market price fluctuation, and rising transportation cost, focuses on agricultural product storage, adopts various fund raising measures, and solves the "bottleneck" of capitals to establish the basic guarantee of purchase source.

Besides, more purchase personnel are sent to the producers of agricultural products for connection and communication as well as sign purchase and sales agreements with the producers to ensure stable product sources and prices. It also adopts federal reserve between the supply and marketing cooperatives, cooperative reserve between the supply and marketing cooperatives and basic supply network, as well as deposit reserve between the basic cooperatives and major planters to solve the problem of agricultural product warehouse shortage.

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7. Accommodation

Aiming at agricultural product supply chain, the following suggestions are proposed in this study.

(1) Full cognition of supply chain being cooperative partners, but not transaction relationship. It is difficult to do so, especially on mutual trust, commitment, profit sharing, and technology sharing. However, it is the cognition change. Managers of supply and marketing cooperatives in the e-environment should thoroughly change the thoughts. The integration, mutual trust, long-term commitment, and partnership in the supply chain system as well as the risk sharing and profit sharing among enterprises could develop the best effectiveness of the supply chain to generate the maximal competitive advantage of the entire agricultural product supply chain system.

(2) Supply and marketing cooperatives could achieve real-time information flow and rapid responses by the information connection, information sharing, and information support and integration between upstream and downstream of the supply chain system. Technology sharing is the basis to promote the entire supply chain performance. Open technology instruction and information sharing between upstream and downstream of the supply chain system could enhance the effectiveness at each point in the supply chain and further promote the entire supply chain performance.

(3) Supply and marketing cooperatives should find out the weakness of the supply chain,

rationally invest in resources, and dig out more valuable production potential through the information sharing and advantage complementation between the upstream and downstream of the supply chain.

(4) Supply and marketing cooperatives should utilize high technology to monitor the production of agricultural products in order to guarantee the quality. Constantly enhancing the proportion of cold chain logistics to reduce the loss of agricultural products could guarantee the quality and safety of agricultural products.

(5) The management of supply chain is not simply the application of information technology, but is also the management technique. The introduction of supply chain management is the change of management philosophy and the reengineering of management process. In addition to the establishment and use of information systems, the adjustment of attitudes, concepts, and operation processes as well as the education of personnel of supply and marketing cooperatives are more important. Especially, the idea and determination of managers as well as the consensus and support of all employees are the change of cognition; and, the reengineering of processes is the basis of the success of supply chain management.

(6) Supply and marketing cooperatives should stress on talent pool, including e-commerce talents and agricultural technology talents to optimize the supply chain management and enhance the core competitiveness of the supply chain. It does not simply cultivate agricultural technology managers, but should precede technological guidance of farmers. Such cultivation and guidance could be internal or integrated with college resources.

(7) For the establishment of regulations and common agreements on information communication and Internet, the government should play the role of coordination and integration and accelerate the establishment of information communication protocols for supply and marketing cooperatives proceeding agricultural product B2B, B2C and electronic agriculture.