Determining the Governance Controllability of Organizations in Supply Chain Management Using Fuzzy Expert System

YU-CHUAN LIN1, CHE-CHEREN LIN2*, CHIEN-CHUNG LIN3

1: Department of Business Administration
Meiho University, Taiwan
2: Department of Software Engineering
National Kaohsiung Normal University, Taiwan
3: Graduate Institute of Business and Management
Meiho University, Taiwan
*; correspondence author
yclinsun@gmail.com1; cclin@nknucc.nknu.edu.tw2*; gendion.lin@gmail.com3

Abstract: - Transaction cost theory has been used to explain the governance of the organization supply chain for decades. However it can not be used to explain the governance change of the organization supply chain in Taiwan’s hi-tech industry. Based on contingency theory, a precious study then adopted two factors to explain the governance changes between upstream and upstream players in a supply chain. The two factors proposed in the study are relative profitability and technology complexity. The previous used a binary value (either 1 or 0) to describe the factors. It however can not describe the gradual changing value between 0 and 1, e.g., 0.12, 0.23, 0.85, etc. To overcome this problem, this study uses fuzzy logic to deal with these gradual change values and proposed a fuzzy-inference-based expert system to determine the governance controllability among the organizations in a supply chain. In the proposed fuzzy expert system, the input fuzzy variables are relative profitability and technology complexity. The output fuzzy variable is governance controllability. Nine fuzzy rules are used in the fuzzy expert system. We use Java programming language to implement the system. We also conducted 20 simulation cases to validate the proposed system and discuss the simulation results. Concluding remarks are finally provided at the end of this paper.

Key-words: - Governance mode, Supply chain, Contingency theory, Fuzzy expert system, Fuzzy logic.

1. Introduction

How transactions are governed between upstream and downstream firms in industries characterized by rapid change has attracted increasing attention from scholars of organizations [1-3] The traditional approach to understand the mechanism governing transactions between different stages of the supply chain is primarily based on transaction cost theory, which demonstrates that the mode of governing the supply chain ranges from market to hierarchy, depending on the transaction cost [4]. Later, Powell proposed that in addition to, and independent of, market and hierarchy, there is a network-based governance mode [5]. However, the types of governance in some newly emerging global industries suggest that the transaction cost perspective and the network-based view may be inadequate to explain or predict the evolution of the governance modes. One anomaly example is in the case of Taiwan’s hi-tech manufacturing sector. Lin, Yeh and Li suggested that the change of the governance mode is shaped by the interaction among four factors: technology uncertainty, technology complexity, capital munificence, and relative profitability [6]. They found that the governance mode in Taiwan’s high-tech industries moves toward a network model with high technology uncertainty and relatively high profitability. The governance mode moves toward the market model if technology is certain and complex, capital is abundant, and profitability is high, or toward the hierarchy model if the technology is certain and simple, capital is abundant, and profitability is low. However, in the study, they used a binary value (either 1 or 0) to describe the situations of these factors. It, however, can not explain the gradual changing values between 0 and 1, e.g., 0.12, 0.23, 0.85, etc. To overcome this problem, this study therefore uses fuzzy logic to deal with these gradual change values. We propose a fuzzy-inference-based expert system to determine the governance controllability among the organizations in a supply chain. Below, we introduce the basic concept of fuzzy logic.

In traditional set theories, one uses a binary
value (1 or 0) to indicate if an element belongs to a traditional set (crisp set). The binary value 1 means this particular element belongs to the set while 0 means it don’t belong to the set. For example, consider the following set of “hot weather”

\[
\text{hot weather} = \{x \mid x \geq 32^\circ C\} \quad (1)
\]

In (1), if \( x = 32^\circ C \), it belongs to the set of “hot weather” and gets a binary value of 1. If \( x = 31.9^\circ C \), it does not belong to the set and gets a binary value of 0. However, in our experience, we can not tell the difference between the temperatures of \( 32^\circ C \) and \( 31.9^\circ C \). However in (1), they are two totally different values: 1 and 0. To overcome this problem, Zadeh proposed the concept of fuzzy set to handle the uncertain situations between 0 and 1. In a fuzzy set, a matching degree \( \mu (0 \leq \mu \leq 1) \) is used to represent the degree of how an element belongs to a fuzzy set. A matching of 1 represents a 100% belonging-to relationship (completely belonging-to) between an element and its associated fuzzy set. A matching degree of 0 means a 0% belonging-to relationship (completely not belonging-to) between the element and its associated fuzzy set. A matching degree between 1 and 0 means a partially belonging-to relationship. The higher the matching degree is, the more belonging-to relationship it has.

Mathematically, a membership function is used to describe the matching degrees for a fuzzy set. Basically, a membership function must be a non-concave function and its range must be real number in a closed interval of \([0,1]\). A membership function is used to map a crisp value to its corresponding matching degree. This mapping process is called “fuzzification”. Practically, two types of membership functions are used in fuzzy logic: trapezoidal functions and triangle functions since they are linear with less computational complexity to get a matching degree.

A trapezoid membership function is specified by four parameters \((a, b, c \text{ and } d)\) and given by the following equation [7]

\[
\text{trapezoid}(x; a, b, c, d) = \begin{cases} 
0 & x < a \\
(x-a)/(b-a) & a \leq x < b \\
1 & b \leq x < c \\
(d-x)/(d-c) & c \leq x < d \\
0 & x \geq d 
\end{cases} \quad (2)
\]

A triangle membership function is specified by three parameters \((a, b, \text{ and } c)\) and defined by the following equation [7]

\[
\text{triangle}(x; a, b, c) = \begin{cases} 
0 & x < a \\
(x-a)/(b-a) & a \leq x < b \\
(c-x)/(c-b) & b \leq x \leq c \\
0 & x > c 
\end{cases} \quad (3)
\]

We use an illustration example to explain a trapezoid membership function and its fuzzification process. Figure 1 is a trapezoid membership function to represent a fuzzy set of “car speed is moderate”, where \( a = 40, b = 60, c = 80, \text{ and } d = 100 \). If the car speed is 50 km, which is a crisp value, we can use a fuzzification process to map 50 km/h to its corresponding matching degree, which is 0.5. It means in the situation of 50 km/h, the car speed is with 50 % belonging-to relationship associated with the fuzzy set of “car speed is moderate”, as shown in Figure 1.

In addition to trapezoid functions and triangle functions, several types of functions can be used as membership functions such as Sigmoidal function, \( \pi \) function, bell-shaped function, etc [7].

Based on fuzzy logic, this study furthermore uses a fuzzy expert system to deal with the governance controllability problem among the firms in a supply chain. The input fuzzy variables are relative profitability and technology complexity. The output fuzzy variable is governance controllability. Nine fuzzy rules are used in the fuzzy expert system. We use Java programming language to implement the system. We also conducted 20 simulation cases to validate the proposed system and discuss the simulation results. Concluding remarks are finally provided at the end of this paper.

2. Relative works

Governance of the organization supply chain is classified into three types: market, hierarchy, and network. If an industry is based on a market governance model, then buyers and sellers will negotiate, through price mechanism, to maximize the economic efficiency of resource allocation. When the transaction costs are too high, a hierarchical model emerges to replace a market model [4]. The generic term “network,” includes: production collaboration, technological cooperation, and equity investment [5].

Cross-holdings and equity investments are commonly seen among the firms in Taiwan. However, it is difficult to explicitly incorporate these investment activities in the hierarchy or network model. This study gives a borderline to explain the hierarchy and network models based on the controllability. The network model includes collaborative production, technology cooperation,
and investment without the intention of control. The hierarchy model, on the other hand, is explained in a broader sense and includes all business divisions and subsidiaries of a company, equity investments with the intention of control, and firms that supply most of their products to a specific manufacturer and get affiliated with that manufacturer.

Furthermore, whether the market, network, and hierarchy models of the governance mechanism form a concept of continuum or they should be treated as three different dimensions is a long-term controversy. Powell [5] and Exworthy et al. [2] found that they are three different governance modes, but Williamson proposed a hybrid model between the market and hierarchy models and treated them as a continuum spectrum [4]. Humphrey and Schmitz [3] and Gereffi et al. [1] are also advocates of the concept of continuum. Lin proposed an empirical research and showed that there certainly exist different levels of coordination, power asymmetry, and resources dependency [8] among the three governance models [6]. A spontaneous coordination mechanism forms based on the market price and, thus, the resources dependency is lower in the market model. In the hierarchy model, however, the resources dependency is higher because the transaction and resource flow are internalized and management is a major resort to coordinate the supply and demand. The network model is in-between [6]. Consequently, this study proposes that the governance modes form a concept of continuum.

Recently, the scholars have furthermore supplemented the three governance modes. They proposed three more detailed categorizations: quasi-market, quasi-hierarchy and quasi-network [2,3]. Gereffi et al. combined all of the above models together with modular organizations, and further proposed five governance models of the global value chain: market, modular, relational, captive and hierarchy, which range from low to high levels of explicit coordination and power asymmetry [1]. Recent researches further analyzed the meanings of the market, network, and hierarchy models and found that their meanings are too complex to be defined separately. To overcome this problem, this study therefore, uses fuzzy logic to deal with the complex and uncertainty with gradual change values.

This study draws on contingency theory to develop our framework on how the external environment affects the choice of governance mode in Taiwan’s high-tech sector. According to contingency theory, an organization adapts its structure to keep a fit with the changing environmental factors to attain high performance [9]. To keep our framework parsimonious, and inspired by Hayek’s forceful argument that states that price is a single variable that can capture all market information [10], we propose a single phenomenon that may serve as a central link to build our framework-- relative profitability--because it captures the environmental information that is related to technology, the supply-demand relationship, and the capital market. A higher profitability implies a more benign environment, which may reflect the condition of some major factors that affect an industry’s competitive structures.

Transaction cost theory is the dominant theory to predict the governance mode of the organization supply chain. However, this theory only focuses on a cost reduction perspective and ignores other possible determinants. Firm strategy and its competitiveness are highly correlated. Governance of the supply chain is part of firm strategy and relative profitability is an indicator of firm competitiveness. Therefore, we believe that relative profitability should be a significant factor in determining the governance model.

D’Aveni indicated that it is difficult to maintain a sustainable competitive advantage under a hypercompetitive environment [11]. This has forced American companies to retreat from the market or to outsource their manufacturing to Asian factories. In this situation, the PC industry illustrates the characteristics of the hypercompetition during the last two decades. The division of labor and a new management model have led to specialization and economies of scales. As a result, technology and quality have improved drastically; cost has decreased dramatically; efficiency has been maximized. These changes destroyed the stable industrial structure that was previously established in the late 1990s, and generated three new development directions, as noted by Dedrick and Kraemer [12]. They are (1) a rapid price drop, (2) a shortened product lifecycle, and (3) success of a direct-sales/build to order (BTO) strategy. The industrial structure under a revolution and a change in profitability will affect the industrial structure. The final goal of enterprises is to pursue profits and to increase the market value of the existing owner’s equity. Transaction theory neglects the rapid changes in the external environment that results in profit variations caused by price fluctuations.

When organizations introduce new technology, they are constrained by the current state of technology [13]. That is to say, organizational forms interact with technology. Generally speaking, the emergence of an industry might also accompany a new organizational form. Furthermore, technology
complexity is also one of the factors that affect governance of the organization supply chain. The technology complexity means that the level that a technology can be applied to diverse products. A higher technology complexity means it can be applied to more products. Therefore, this study proposes that governance of the organization supply chain is influenced by relative profitability and technology complexity.

3. Methodology
The methodology of this study is to use a fuzzy expert system to determine the governance controllability among the firms in a supply chain based on relative profitability and technology complexity. The conceptual diagram of this study is demonstrated in Figure 2. There are two fuzzy input variables (dimensions) are used as inputs of the proposed system including relative profitability and technology complexity. Each of input variables is scaled into an interval from 0 to 10 and has three fuzzy levels: low, medium, and high. One output fuzzy variable is used in the proposed system, which is governance controllability. The output variable is also scaled into an interval from 0 to 10 and has five fuzzy levels: very low, low, medium, high, and very high. Triangle functions are used as membership functions for these input and output variables. Nine fuzzy rules are used in the proposed system, as demonstrated in Table 1.

4. Simulations
In order to perform fuzzy expert system, we built a computer package using Java programming language. The computer package allows users to define fuzzy variables with appropriate membership functions and to generate fuzzy rules. After building the fuzzy expert system we performed simulations to validate the fuzzy expert system.

Table 2 shows the simulation results where 20 artificial data randomly generated by computer are used. From Table 2, the simulation results are quite reasonable.

5. Conclusions
This study is an inter-discipline study covering artificial intelligence method (fuzzy expert system) and management issue. A previous study used a binary value (either 1 or 0) to explain the governance change of the organization supply chain in Taiwan’s hi-tech industry. However, it did not consider the gradual changing values between 0 and 1. Based on fuzzy logic, this study proposed a fuzzy expert system to deal with these gradual changing values. We introduced the fundamental concept about fuzzy logic and discussed relative studies about governance controllability in a supply chain.

The proposed fuzzy expert system used two input variables, relative profitability and technology complexity, to explain the governance changes between upstream and upstream players in a supply chain. Each of input variables is scaled into an interval from 0 to 10 and has three fuzzy levels: low, medium, and high. One output variable, governance controllability, is used in the proposed system. The output variable was also scaled into an interval from 0 to 10 and has five fuzzy levels: very low, low, medium, high, and very high. Nine fuzzy were used in the proposed fuzzy expert system based on the membership functions defined in the input and output variables. We used Java programming language to implement the fuzzy expert system. We also conducted 20 simulation cases to validate the proposed system and discussed the simulation results.

As the directions for future studies, using real world data to validate the proposed system might be a good idea. In addition, adding more input variables into the proposed system might be another good idea.

Acknowledgement
This paper is supported by the National Science Council, Taiwan (ROC) under the project number of NSC 99-2511-S-276-002.

References
[6] Y. C. Lin, K. S. Yeh, S. Li, Change of governance in the organization value chain: the


Figure 1: A trapezoid membership function of “The car speed is moderate”.

Figure 2: Conceptual diagram of this study
### Table 1: Fuzzy rules

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### Table 2: Simulation results

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