'What-if' approach in modeling the impact of policy: An application of Fuzzy Cognitive Maps in Social Science

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ABSTRACT

Fuzzy cognitive maps or FCM's have been proven to be useful when representing qualitative and uncertain data. This advantage enables FSM to be employed in the field of policy analysis. The goal of this paper is to illustrate a FCM application in measuring the impact of supporting policy on new technology-based firms. The findings reveal the fact that support focusing on knowledge is more prevalent compared with other types of support.

Keywords: Fuzzy cognitive map, new technology-based firm, expert system.

1. INTRODUCTION

Expert system uses expertise as its primary source of problem solving. However, such expertise is mainly uncertain or fuzzy, because most knowledge is described in causal relationships. To respond to that problem, in the field of expert system some theories emerged, such as Neural network, fuzzy logic, genetic algorithm, and many other hybrid methodologies. One of them is Fuzzy cognitive maps (FCM). FCM stems from the implementation of Fuzzy logic that represents knowledge and behavior of a system using a network of interconnected nodes [6]. According to Lee and Kim [2], the advantage of using FCM are (1) FCM are fuzzy signed directed graph structures for representing causal relationship between concepts, (2) their graph structure allows systematic causal propagation in particular backward or forward chaining, and (3) they allow knowledge bases to be created by connecting different FCM [4]. Therefore FCM are especially useful for knowledge acquisition/processing in soft but highly complicated domains (e.g. political science, public policy analysis, etc).

Considering the FCM's capacity above, this paper aims to explore how FCM can be applied in the field of policy analysis. In the policy analysis, approach is based on a systematic and comprehensive approach that helps the decision makers to produce a better decision. One of important steps in the policy analysis approach is designing a model of the real world. By modeling the real world, policy instrument can be experimented, and the future can be predicted. In this particular step, FCM can be used to enhance policies' quality.

The paper is organized as follows. First, we explain the nature of FCMs. We continue with a discussion of our case study. The findings will follow after that. Finally, we will discuss the results and implications for further research and policy making.

2. FUZZY COGNITIVE MAPS

Uncertainty can be represented with fuzzy logic but FCM is more than traditional fuzzy logic. FCM contains feedback, which makes it suitable to represent the dynamic system. Kosko originally developed FCMs to represent concepts in military science, but latter of FCM demonstrate its usefulness in representing arguments in sociology and political science. Figure 1 is an example of a map developed by Kosko representing decisions about driving speed on a California highway. The dynamic nature of the FCM makes it a useful tool for discovering hidden relationships between concepts. Variable values can be entered into the nodes of the map in Figure 1 and analyzed via computer. The feedback systems within the map will gradually converge on a solution, or limit cycle. Interpreting the activation level of each node reveals relationships within the system.

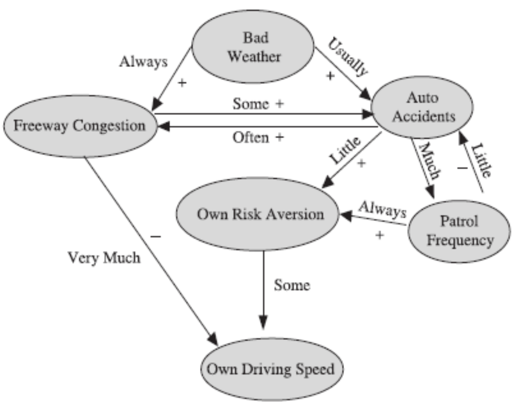

Figure 1. FCM for decision about driving speed (adopted from Kosko)

Like other traditional causal concept maps, FCMs have nodes that represent variable concepts. The links between the concepts are signed + or - to represent the nature of the relationship between nodes. Fuzzy logic allows the representation of fuzzy concepts and degree of causality. Feedback allows the user to explore the hidden properties of the map. By creating a formal representation of causality, FCMs can be used to create and explore models of dynamic events and search for causal explanation.

FCM is intended to model causality, not merely semantic relationships between concepts. FCMs are also allowed for causality effects to fluctuate as values change. By modeling causality over time, FCMs facilitate the exploration of the implications of complex conceptual models, as well as representing them with greater flexibility.

FCM can be used as an artifact for graphically representing, and dynamically modeling, causal links. Computer modeling facilitates ‘‘what-if’’ games; allowing the user to simulate the model. By modeling the system on a computer, the user can rapidly explore a range of possibilities and potential system behaviors. Holding some parameters constant and varying other allows for the exploration of complex relationships that might not otherwise be investigated.

3. CONSTRUCTING THE FCM

Basically, FCM is the fuzzy graph with feedback, consisting of nodes and weighted interconnections. FCM is an n matrix, where F_{ij} indicates the relationship between i and j. F_{ij} can have value [-1,1]. There are three possible types of relation:
$F_{ij} > 0$ indicates a positive causality between i and j. That means increasing in the value of i will leads to an increase in the value of j.
$F_{ij} < 0$ indicates inverse causality between I and j. That means increasing in the value of i will leads to a decrease if the value of j.
$F_{ij} = 0$ indicates no relationship between i and j.

The calculation of this relationship is based on the simple differential Hebbian learning law presented by Dickerson and Kosko. Based on their theory, the weights of edges leaving a node are modified when the node has nonzero state change. The change is

$$e_{ij}(t+1) = e_{ij}(t) + c_t\left[\Delta C_i(x_i)\Delta C_j(x_j) - e_{ij}(t)\right]$$

$$c_t(t) = 0.1\left[1 - \frac{t}{1.1N}\right]$$

where e_{ij} denotes the weight of the edge between the i and j*th* concepts, $C_i(x_i)$ is the change in the *ith* concept’s activation value, and t is the generational time step.

4. ILLUSTRATIVE EXAMPLE

This paper will explore the use of FCM in modeling the growth of new technology-based firms (NTBFs). The role of small high-technology firms in economic growth and innovation has received a great deal of attention in the past two decades. This type of firms is supposed to contribute significantly to the creation of new jobs and to innovation of the (regional) economy through knowledge transfer and linkages with larger firms. Small high-technology firms are often spin-offs from universities and research centers. Fostering spin-off firms is a part of most universities or research centers' policy to commercialize research results, and is today also in the core of the national economic policy in many countries.

More specifically, most founders of high-technology firms originate from universities and research centers, particularly those of a technology signature. They often lack the necessary entrepreneurial knowledge (skills) and routines. A shortage of entrepreneurial knowledge and routines is one of the major obstacles preventing small high-technology firms to grow. Other obstacles are related to resources needed in the development of the firms, including investment capital, research facilities and access to networks in the market, particularly the ability to communicate and negotiate with different worlds.

Incubation policies have emerged already in the early 1980s and regained attention in the past few years. The term incubator is used to indicate the supportive environment created to ensure the survival and growth of new technology-based firms. Incubation policies include a whole range of actions and supportive measures, for example: selection of candidate firms or business ideas by the university through a proactive screening of the faculties; supply of relatively simple seedbed conditions in incubator accommodation, like cheap and flexible space, shared services (secretarial, cleaning, etc.) and standard courses; supply of more advanced supportive conditions like access to research facilities and access to university knowledge through use of patents and licenses, customized courses and mentoring; supply of or mediation for financial capital like "friendly" types of loan, equity shares (by the university) in the firms, e.g. to pay for up-front patenting, and internal venture capital funds.

This research aim to explore the role of support in ensuring the survival and growth of new technology based firms. The approach that we are going to use is 'What-if' approach. There are three dimensions of support that covered: support focused on knowledge, support focus on reducing firm's needs, and support focused on firm's market share. FCM model is developed to picture the relation and causality among the factors, which influence the firm's performance. These causal relationships are depicted from research conducted at university spin-offs at TU Delft, the Netherlands [7]. Support policy is simulated by increasing and decreasing the levels of the factors that are related to the three dimensions of support. Besides, Support policy is verified by introducing some factor scenarios such as economic situation and technological development. The aim is to test how robust support policy will be in the future.

4.1 Modeling the factors that influence NTBFs' performance

The first step in preparing the of simulation using FCM is the selection of the factors that will form part of the model. the following table is a list of the factors that I have selected, according to my understanding of the situation.

Table 1. Variables used in FCM

Factor	Description
Entrepreneurial motivation	Enable entrepreneurs to keep up in business.
Entrepreneurial knowledge	All knowledge to manage businesses, including marketing knowledge, sales skill, leadership, etc.
Firm's performance	Parameter of firms' successful performance measured through some aspects such as turn over, profit, job-growth.
Business strategies	Strategy applied by entrepreneurs to increase profit.
Obstacle	Firms' barriers and needs in the early stage; obstacles in the model refer to financial and location problem.
Profit	Parameter of firms' performance; sales minus costs.
Market share	Percentage of firms' share in market; the bigger the share, the bigger the profit is.
Economic situation	Situation that is plausible to support or inhibit the firms' performance; for instance, the fall of economic situation causes the decrease of demand, and in turn affects the firms' performance.
Technology development	Technological factor influences customers' preference or product development; for instance, a discovery of new radical technology changes product specification and demand.

The second step in the preparation of the fuzzy cognitive map is to set the causal relationships between the factors. In our study there are two factors that become the center of the model, including firm's performance and profit. Therefore the explanation will focus only on these both factors.

Causes of firm's performance

The main factor that influences firm's performance is profit. The relation is high; the bigger the profit, the better the performance is. The entrepreneurs' personal knowledge and obstacles also largely affect the spin offs' performance. Motivation has been proven to have a low correlation with the firms' performance. On the contrary, the firms' performance can influence the entrepreneurs' motivation and goal.

Causes of Profit

The model projects that market share, business strategy, and obstacles influence the profit. The increasing market share will increase the profit. Better business strategy will likely give a positive influence on the profit.

Finally, the FCM for our more is presented in figure 2 below.

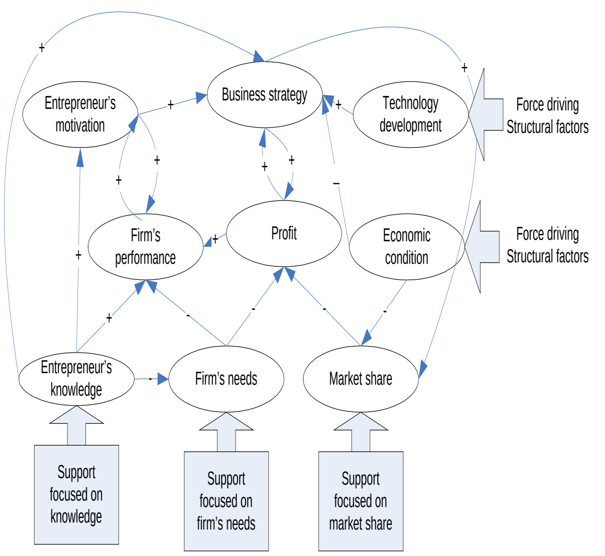

Figure 1. FCM for support policy

The FCM shown in the figure has been stored in the matrix and calculated repeatedly for each change on variables. Assuming that the situation of entrepreneurship is steady, the fuzzy cognitive map assigns the level on 50 (out of 100) to represent the levels of all factors. These results in a steady situation in which there is no factor's level trigger a variation in the level of any other factors. Assigning levels on 50 to all factors does not mean that the levels of all factors, in absolute units, are the same. In fact, every factor has its own level and is measured in units that may not be applicable to other factors

In this research, we focus on three different types of support and two external factors that are technology development and economic condition. In brief, the supports are explained as follows:

Support focused on knowledge enhancement

The support aims to increase entrepreneurial knowledge. Thus, the simulation of support on knowledge was done by increasing the level of entrepreneur's knowledge.

Support focused on reducing firm's needs

This type of support will minimize the entrepreneurs' problem. The simulation was conducted by decreasing the level of the problems.

Support focused on increasing firm's market share

Through alliance and merger with other firms, the spin offs firm can increase their market share and in turn give a positive impact to the performance. The simulation was conducted by increasing the level of market share.

The impact of firms' performance (profit) will be measured as the system is injected by support (knowledge, needs and market share). To validate the role of support, then the different economic condition and technology development are employed.

4.2 Result

The simulation was first conducted by inputting the variation of the external factors in the model. Economic situation and technology development are two external factors that are capable of influencing firms' performance. The result shows that a new technology development, when responded by an appropriate strategy, will increase the firms' performance. On the contrary, economic trend does not directly influence the firms' performance, shown by the non-linearity of the increase of economic trend towards the firms' performance (figure 2 and 3).

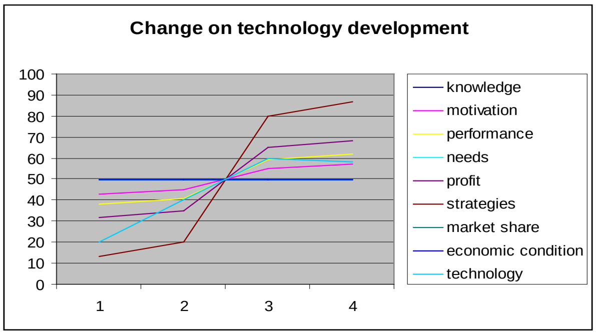

Table 2. Impact of the different level of technology development

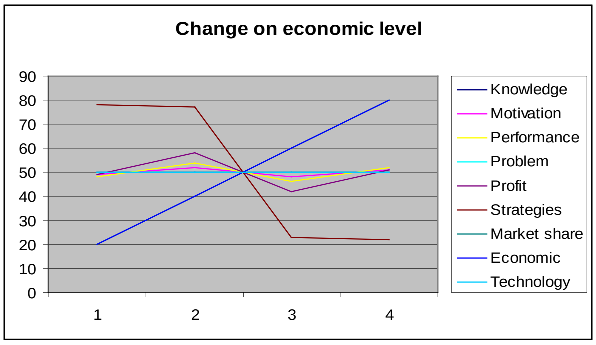

Figure 3. Impact of the different level of economic condition

The result (table 4-9) reveals that support on knowledge is the most effective and the most influential one on the firms' performance. Below knowledge is support focused on firm's needs, also positively influencing the firms' performance. Network that is assumed to increase market share has been proven to give less impact.

The simulation also combined two policies, for instance support on knowledge and support on network. The result shows that support on knowledge is likely to give a positive impact on the firms' performance as entrepreneurs' knowledge has a direct causality with firms' performance. The complete result of the simulation can be seen in the tables below.

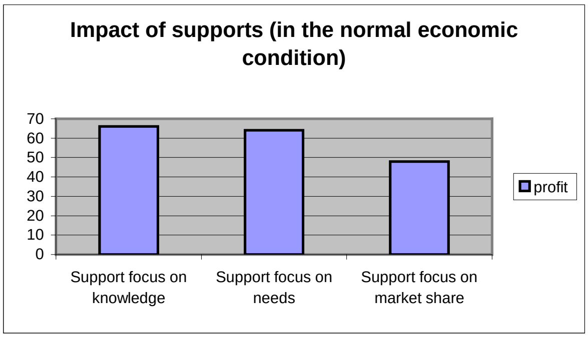

Table 4. Impact of three types of supports in the normal economic condition

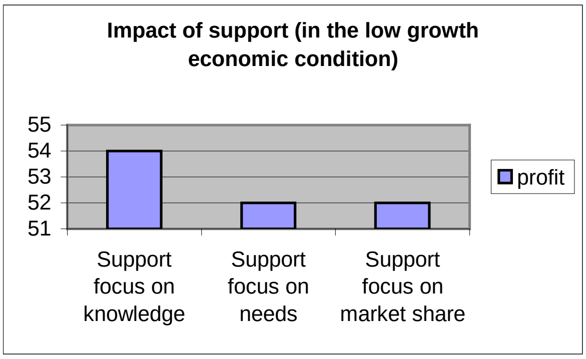

Table 5. Impact of three types of supports in the low growth economic condition

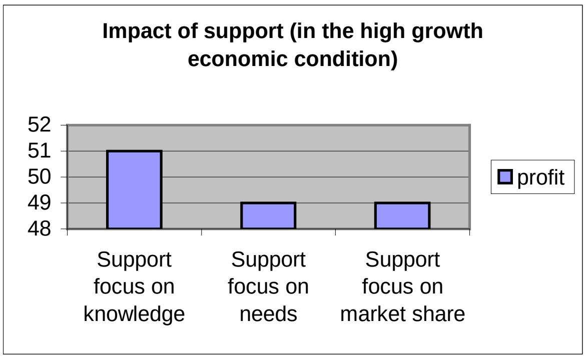

Table 6. Impact of three types of supports in the high growth economic condition

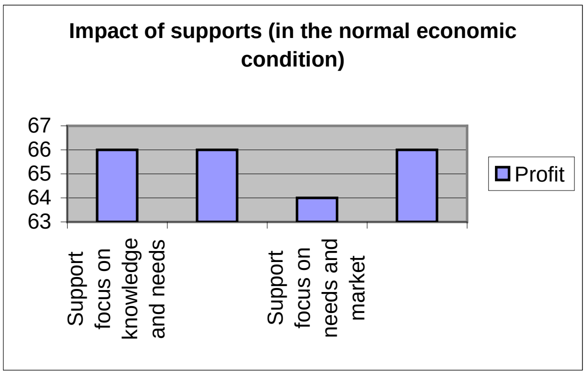

Table 7. Impact of the combination of supports in the normal economic condition

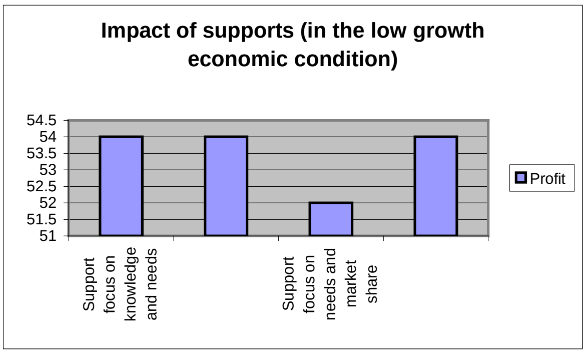

Table 8. Impact of the combination of supports in the low growth economic condition

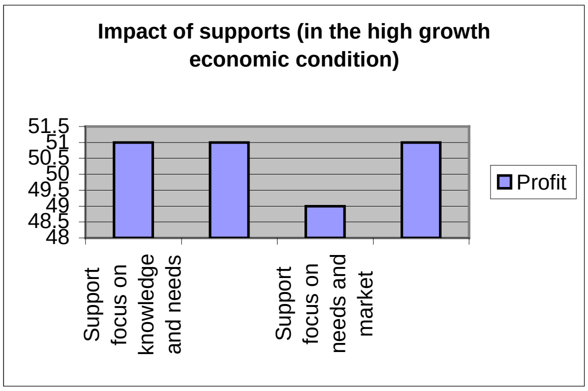

Table 9. Impact of the combination of supports in the high growth economic condition

5. CONCLUSION

In conclusion, this research managed to produce the FCM for policy analysis. Our model shows certain advantages with respect to other policy analysis models and proves FCM is a powerful representation technique in the policy analysis domain. The findings of the simulation brings forth some conclusions. The knowledge support seems to be the best policy because it gives the biggest impact on the performance. Although increasing the performance can also be achieved by combining two alternatives, as shown by the result, the result of combining two alternatives is no better than the knowledge support.

Finally, FCMs provide the foundation for the development of appropriate computer support of the policy planning process. The paradigm of our model paves the way for new directions in policy modeling and simulation.

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