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Development of a Cause-and-Effect Model for Analyzing National Competitiveness of the Electric Vehicle Industry

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In a world where energy conservation and environmental protection are growing concerns, the development of electric vehicles (EVs) has taken on an accelerated pace and drawn high levels of interest across many developed and developing countries. The purpose of this study is to explore what constitutes national competitiveness in EVs development and how one nation can efficiently achieve that development in its EV industry. We used Porter's diamond model as an underlying theory to describe the sources of national competitiveness. The DEMATEL method was employed to analyze the structural model and reveal the cause-and-effect relationships of the sources of competitiveness. Having identified the causal relationships and strengths of those competitiveness sources, we formulated a path with clear and logical links that lead a nation to achieve the best results when establishing an emerging industry.

Keywords: Electric Vehicles (EVs), Diamond Model, Decision-Making Trial and Evaluation Laboratory (DEMATEL)

Introduction

Electric vehicles (EVs) have been around since before the turn of this century. However, the use of EVs for transportation dwindled when gasoline powered internal combustion engine began to dominate automobiles' propulsion systems. The major reasons behind renewed interest in EVs are environmental in nature: the use of electricity is environmentally superior to the use of gasoline[1]. Historically, the automobile industry has been dominated by a few giant automakers in several industrialized countries. New entrants continue to find it difficult to be part of the automobile supply chain if they do not possess niche technologies. Taiwan has been widely recognized as a nation with strong manufacturing capabilities of electric and related technology in the past few decades. Following the trend of EVs, Taiwan's government launched a series of national policies in 2010 to foster the EV industry[2]. That process required subsidies up to NT$ 3 billion and included the R&D of key components, such as batteries, inverters, chassis systems, electric motors and power control systems. This leapfrogging policy is expected to create a pathway for a latecomer so that a new entrant can avoid making heavy investments in legacy technology and catch up with leading countries of automobile manufacturing. As with the country's development focus, the sources of national competitiveness need to be strategically identified and cultivated[3]. The diamond model[4], proposed by Michael Porter, has been widely applied in various kinds of industrial research[5-8]. The diamond model suggests that a nation would succeed in a particular industry if it possesses competitive advantages relative to its competitors. Employing a multi-criteria decision making method, this study aims to develop a model exploring what constitutes the national competitiveness in an emerging industry and the relative importance and cause-and-effect relationship of these constitution elements.

Methodology

In an interdependent system where all factors of the system are mutually related, it is difficult to find priorities for decision making[9]. The Decision-Making Trial and Evaluation Laboratory (DEMATEL) method, originating from the Geneva Research Centre of the Battelle Memorial Institute[10], has typically served to address the question of "whether solving one problem can help to solve another one?" The aim of the method is to identify cause-and-effect relationships of interrelated factors in a complex system and quantify their strengths of influence. By

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applying matrix computations and comparing the interrelations among factors, DEMATEL can convert complex systems into a clear causal structure. Unlike the classic approach of structural equation modeling (SEM), which requires large research sample sizes for deriving causal relationships among variables, DEMATEL can yield accurate research results from limited sample sizes.

In recent years, DEMATEL has been popularly applied to diverse research fields including industrial policy[11], technological innovation development[12], science park establishment[13], sustainable development strategy formulation[14], airline safety management[15], etc. The following steps briefly describe the calculation process of DEMATEL:

Step 1: Build an initial direct-relation matrix

The initial direct-relation matrix is obtained by pairwise comparisons where a_{ij} expresses the extent to which factor i affects factor j; the value of a diagonal line is 0 as the factor z_{ii} compares with itself.

$$Z = \begin{bmatrix} 0 & a_{12} & \cdots & a_{1n} \\ a_{21} & 0 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 0 \end{bmatrix}$$ n is the number of consideration factors … (1)

Step 2: Normalize the direct-relation matrix

The normalized direct-relation matrix X is obtained through equation (2) and (3).

$$X = y \cdot Z \quad \ldots (2)$$

$$y = \min_{i,j}\left[\frac{1}{\max\limits_{1\le i\le n}\sum\limits_{j=1}^{n} z_{ij}}, \frac{1}{\max\limits_{1\le j\le n}\sum\limits_{i=1}^{n} z_{ij}}\right] \quad \ldots (3)$$

Step 3: Build a total relation matrix T.

Once the normalized direct-relation matrix X has been obtained, the total-relation matrix T is acquired by equation (4):

$T = X(I - X)^{-1}$ I is the identity matrix … (4)

Step 4: Compute the strength of influence of factors

Aggregate the values of the rows and columns in matrix T to obtain a value d and r through the equation (5) and (6) respectively. The d represents the level of direct or indirect impacts on other factor, and r represents the level to which it is affected by other factor:

$$d = \left[\sum_{j=1}^{n} t_{ij}\right]_{nx1} = \left[t_i\right]_{nx1} \quad \ldots (5)$$

$$r = \left[\sum_{j=1}^{n} t_{ij}\right]_{1xn} = \left[t_i\right]_{nx1} \quad \ldots (6)$$

Step 5: Produce a causal diagram

A causal diagram can be created by mapping out a data set (d+r, d-r). The horizontal axis (d+r) is made by adding d to r, and the vertical axis (d–r) is made by subtracting r from d. The value of d+r, called prominence, shows the degree of importance, indicating the strength of influence of a factor. The value of d-r, called relation, shows the direction of influence, indicating the causal relationship between two factors. If d-r is positive, then the factor is a cause factor that dispatches influence to the others. If d-r is negative, the factor is an effect factor that receives influence from others. Theoretically, efforts aimed at improving on cause factors will yield an immediate impact on effect factors [9,10].

Results and discussion

This study conducted a survey with 26 experts who had been actively participating in R&D and market research in the EV industry. We used Porter's diamond model as an underlying theory to describe the sources of national competitiveness. The diamond model identifies six sources of national competitiveness: They are demand conditions, factor conditions, related and supporting industries, frm strategy, structure and rivalry, government, and chance. In this study, chance was removed from the survey questions because chance events were occurrences outside of firms' control and hard to be evaluated by industrial domain experts. Complying with the principle and calculation process of DEMATEL, we obtained the results described below.Table 1 is the initial direct-relation matrix Z of the five competitive factors according to the pairwise comparison results of interviewed experts. Based on the initial direct-relation matrix, we obtained the normalized direct-relation matrix X by applying equations (2) and (3). Subsequently, we calculated the total relations of the five competitive factors using equation (4). Table 2 presents the resulting matrix T. We then calculated the values of d and r by applying equations (5) and (6) respectively. The values are listed in the right-hand column and on the bottom row in Table 2. Finally, the values of d+r (i.e. prominence,

indicating the influence strength of a factor) and d-r (i.e. relation, indicating the causal relationship between factors) were derived, as shown in Table 3.According to Table 3, the rankings of the prominence values d+r of the five competitiveness sources are as follows: Government support (20.54), Firm strategy, structure, and rivalry (20.03), Related and supporting industries (19.77), Factor conditions (17.97) and Demand conditions (17.64). The higher prominence values indicate that the competitive factor is either a relatively strong influence driver (cause) or a relatively strong influence receiver (effect). Alternately, it may have a reasonable stance as both an influence driver and an influence receiver. To identify whether a factor is an influence driver or an influence receiver, we have to look at the relation value: the difference d–r. A positive relation value indicates the dominant nature of an influence driver (cause) and a negative relation value indicates the dominant nature of an influence receiver (effect). The relation d-r values of the five competitive factors are: Government support (0.30), Factor conditions (0.21), Firm strategy, structure, and rivalry (0.07), Related and supporting industries (-0.17), and Demand conditions (-0.42). It indicates that Government support, Factor conditions, and Firm strategy, structure, and rivalry are attributed to the influence drivers (cause), whereas Related and supporting industries and Demand conditions are attributed to the influence receivers (effect).

Table 1— The initial direct-relation matrix (Z)

	A	B	C	D	E
Factor conditions (A)	0	2.19	2.8	2.77	2.81
Demand conditions (B)	1.89	0	2.5	2.5	3
Related and supporting industries (C)	2.65	2.65	0	3.23	3.07
Firm strategy, structure, and rivalry (D)	2.77	2.69	3.27	0	3.23
Government support (E)	2.96	2.96	3.27	3.35	0

Table 2 — Total-relation matrix (T)

	A	B	C	D	E	Row sum (d)
Factor conditions (A)	1.55	1.73	1.93	1.93	1.95	9.09
Demand conditions (B)	1.60	1.50	1.82	1.82	1.87	8.61
Related and supporting industries (C)	1.85	1.88	1.88	2.09	2.11	9.80
Firm strategy, structure, and rivalry (D)	1.90	1.92	2.14	1.93	2.16	10.05
Government support (E)	1.97	2	2.21	2.21	2.03	10.42
Column sum (r)	8.88	9.03	9.97	9.98	10.12	

Table 3 — Results of d+r (prominence) and d-r (relation) values

	d	*r*	*d* + *r* (prominence value)	*d* – *r* (relation value)
Factor conditions (A)	9.09	8.88	17.97	0.21
Demand conditions (B)	8.61	9.03	17.64	-0.42
Related and supporting industries (C)	9.80	9.97	19.77	-0.17
Firm strategy, structure, and rivalry (D)	10.05	9.98	20.03	0.07
Government support (E)	10.42	10.12	20.54	0.30

Corresponding to the data in Table 3, Figure 1 depicts causal diagram mapping in terms of d+r (X-axis) and d-r (Y-axis). The factors located in the upper level of the diagram—those with positive d+r and d-r values—are Government support, Factor conditions, and Firm strategy, structure, and rivalry. These factors have relatively high prominence and relation values. They are categorized as the main cause group insofar as they exhibit relatively strong relationships and influence to other factors. Within this main cause group, Government support has the highest d+r and d-r values, which indicates that this factor holds the strongest degree of influence over all others. The competitive factors located in the lower level of the diagram—those with positive d + r and negative d – r values—are Related and supporting industries and Demand conditions. They are

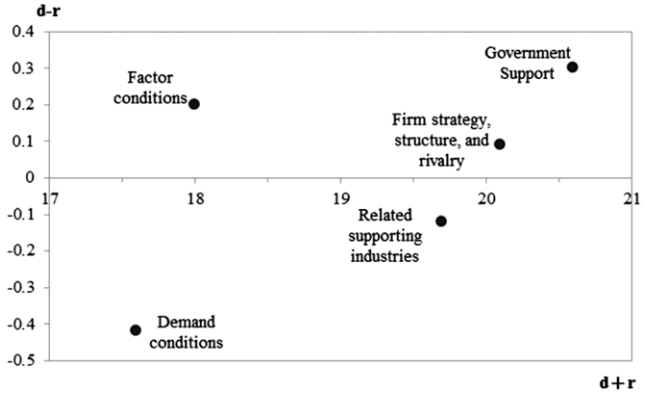

Fig. 1 — Causal diagram

categorized as the main effect group insofar as they exhibit a strong relationship and are influenced by factors in the cause group. With these points in mind, researchers that apply DEMATEL to decision making have suggested that primary efforts should be directed at the main cause factors[9,11,12]. Thus, the efforts will quite likely result in immediate effects on the main effect factors. In the context of the research subject in concern, to achieve the best development outcome in the EV industry, a nation should act on the cause factors: Government support, Factor conditions, and Firm strategy, structure, and rivalry. The factor of Government support should especially be acted on with the highest priority because it possesses the highest degree of influence over all other factors.

Conclusion

Across many developed and developing countries EVs are drawing a tremendous level of interest. As with the economic development focus that has been emerging in a country, sources of national competitiveness need to be strategically prioritized. Most prior industrial research works that were based on Porter's diamond model only focused on the impact relationship between the competitiveness sources and industrial performance results. Employing the DEMATEL method, this study extends existing research by dividing the relationships between the sources of national competitiveness into two groups: cause and effect. By quantifying the degree of reciprocal influence among them, one can easily identify their relative importance and direct critical resources toward areas that require the most attention. To achieve the best possible result in establishing the EV industry, our research results suggest that a nation should pay greater attention to competitive factors in the cause group. Like all empirical research, there are some limitations in this study that open up avenues for future studies. The current study collected empirical data from a limited number of domain experts. Although the DEMATEL method can yield good research results from a small sample size, it is worth conducting a similar empirical study by employing classic statistics methods with a larger sample size and comparing the research results. Moreover, future research may extend the research scope over a larger geographic area and compare the results by different industries in multiple nations.

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