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Designing a key Performance Indicator System for Technological Innovation Audit at Firm's Level: A Framework and an Empirical Study

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Abstract - This research aims at taking a further step in developing a methodology framework of innovation performance audit. With adopting the ideology of performance measurement system, a framework of key performance indicator(KPI) system including three level issues of 'what is input', 'what is done' and 'what happens' is designed for technological innovation audit, which can reflect the performance of technological innovation at firm's level comprehensively. Furthermore, a questionnaire survey on line is conducted to test the validity of the key performance indicator system. Based on data analysis, the KPI system is proved to be effective as a whole, of which most indicators not only are important, but also could be measured easily in firms. Finally, in-depth innovation performance audit of four hi-tech firms is taken as a case study to verify the validity of the KPI system.

Keywords -Technological innovation audit, performance measurement, key performance indicator

I. INTRODUCTION

Regarded as the most crucial dynamic force leading to economic growth [1], technological innovation has been playing a more and more important role for a firm to survive and develop in this intensively competitive global environment. A number of authors point out that it is very useful for the firms to audit the activities of technological innovation based on benchmarking and performance measurement to improve innovation performance and upgrade innovation capabilities[2][3][4].

The theory of technological innovation audit (TIA) has been developed since the end of 1980s, which is regarded as a kind of management audit. Numerous studies have concentrated on developing success-failure reasons for technical innovations and proposed many technical performance measures at the project level or firm levels [5][6], which set up the framework of TIA based on benchmarking analysis. The main audit models can be classified into two primary categories: one is to audit the firm's technological and functional capabilities by building an innovative capabilities framework; the other is the model based on auditing the core process of firm's technological innovation, which go beyond simply performance measurement by highlighting problems and needs and providing information that can be used in developing an action plans for improving performance[2][3]. The perspective of auditing taken by Chiesa et al. (1996) is widely accepted: instead using measurement as a mere foundation, an audit purpose is to identify the gaps between current and desired

performance [2]. While present researches have established a basic theoretical framework of TIA, there are no more effective tools for innovation audit as the financial audit or quality audit in firms, especially for innovation performance audit.

This paper aims at contributing to a better understanding of the concept and measurement of innovation performance. For the object of technological innovation audit, our research enables the internal and external audit of innovation performance much easier to be evaluated. Moreover, it satisfies the requirements of MBO (Management By Objectives), which consequently makes the objectives of technological innovation plan at firm's level and project's level more detailed and measurable. Our basic research objective is to develop the innovation performance audit system based on measurement and to test its validity via data obtained from a survey, which is carried out in Hi-Tech industry.

II. A THEORETICAL FRAMEWORK

A review of literature concerning innovation revealed that OECD (1991) study on technological innovations best captures the essence of innovation from a comprehensive perspective: 'innovation' is an iterative process initiated by the perception of a new market and/or new service opportunity for a technology-based invention which leads to development, production, and marketing tasks striving for the commercial success of the invention[7][8]. The performance measurement of technological innovation at firm's level or at project's level has been studied quite extensively during the last thirty years. Most of the related researches have expanded from the cognition of the key success-failure factors influencing technical innovations. Referring to recent researches, the scope of which on R&D performance measurement has been extended to the whole process of technological innovation, which was limited to the R&D project and R&D department before [9]. However, most of the studies have not yet led to a generally accepted indicator of innovative performance or a common set of indicators [10][11]. There are still some problems need to be solved. Firstly, many studies paid highly attention to the direct output of technological innovation such as patents and new products, ignored the assessment of the efficiency of innovation process. Secondly, many studies have evaluated new product performance mainly in terms of business performance in the market, which regarded new products as important competitive weapons in the

market. They ignored the measurement of knowledge performance which would bring sustainable competitive advantage for the company [12].

Adopting the ideology of performance management system in this research, we develop a performance measurement indicator system for technological innovation audit at firm's level [13]. Fig.1 shows the relationships among these three dimensions of innovation performance. There are three kinds of fundamental issues to be considered as dimensions of innovation performance: 'What is input' is concerned with the question 'does the firm have right portfolio of resources for technological innovation?'; 'What is done' is concerned with the question 'does the firm carry out the right effort to achieve the success of technological innovation'; and the 'What happens' is concerned with the question 'does the firm achieve the target of technological innovation'. Therefore, the paper is conceiving the measurement of innovation performance as a construct with three different dimensions: innovation availability ('what is input', input performance indicators), innovation efficiency ('what is done', process performance indicators) and innovation effect ('what happens', output performance indicators). These three elements are closely linked to one another.

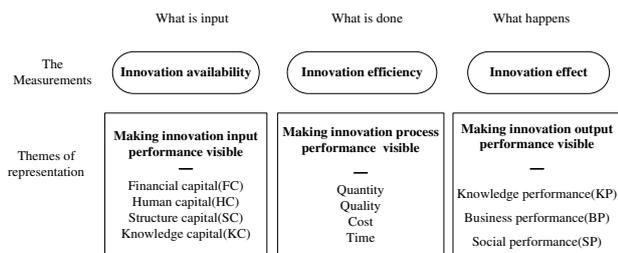


Fig.1 KPI framework for technological innovation performance audit

The purpose of developing the KPI framework for technological innovation performance audit is to make the performance indicators much more clear and visible. The critical input resources can be classified into two categories: financial capital (FC), intellectual capital which includes human capital (HC), structure capital (SC), and Knowledge capital (KC). The four aspects of quantity, quality, cost and time are used to scale the performance of innovation efficiency. Finally, three levels of knowledge

performance (KP), business performance (BP) and social performance (SP) are taken into consideration while measuring the output performance of firm's technological innovation. The 26 indicators are listed in Table 1. The key performance indicators referred commonly in related literature are summed up in Table 2. The symbol "*" stands for the use of the given indicator in the reference.

No.	Indicators
Innovation availability (Input performance indicators)	
1	FC-R&D expenditure (R&D intensity)
2	FC-Technical improvement expenditure (Acquisition of new machinery and equipment related to innovations)
3	HC-R&D staff (Percentage of researchers to overall employees)
4	SC-External support (Intensity of collaboration with other firms or R&D centers)
5	KC-Current knowledge owned (Patent intensity)
Innovation efficiency (Process performance indicators)	
6	Quantity- Number of new products or redesigns
7	Quantity - Number of patents
8	Quantity - Number of licenses
9	Quality- Success rate of R&D projects
10	Quality-% on-time delivery of specification to manufacturing
11	Cost - Average cost of R&D projects
12	Cost - R&D/technology acquisition cost per new product or redesign
13	Time-Average development time of R&D projects
14	Time- Average Total Time-to-market (from concept through to launch)
Innovation value (Output performance indicators)	
15	KP-The ratio of new technology applied in new products
16	KP- The ratio of new technology applied in new production process
17	KP-The potential value of patents and licenses
18	KP-The position of firm's technology comparing with competitor
19	BP-New sales ratio (Percentage sales by new products)
20	BP-Cost saving ratio(Percentage cost saving by new technology)
21	BP-Percentage profit due to R&D
22	BP-Market share gained due to R&D
23	BP-R&D productivity(Expected or realized IRR/ROI of R&D expenditures)
24	SP-Reduced unit labour costs
25	SP-Reduced consumption of materials and energy
26	SP-Reduced environmental impacts

III. RESEARCH METHOD

A. Research design

Table 2. Key performance Indicators referred to literature

Literature	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
OECD (2005)[14]	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Chiesa et al.(1996 a)[2]							*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Chiesa et al.(1996 b)[15]							*	*					*	*				*					*			
Dressler et al. (1998)[16]																			*							
Dressler et al. (1999)[17]																				*						
Drongelen et al. (1999)[18]							*	*					*	*				*	*	*	*	*	*			
Coccia(2001)[19]								*	*																	
Feeny et al. (2003)[20]	*					*	*	*																		
Hagedoorn et al. (2003)[10]	*					*	*																			
Bremser et al. (2004)[21]						*	*		*	*			*	*				*		*			*			
Lin et al. (2005)[22]	*				*	*	*	*					*	*	*	*	*									
Cho et al. (2005)[23]									*	*			*	*												
Alegre et al. (2006)[24]									*		*		*	*				*	*	*	*	*	*			
Ahn et al. (2006)[12]															*	*		*	*	*	*	*	*			
Chiesa et al. (2007)[9]					*	*	*	*	*	*	*	*	*	*				*	*	*	*	*	*			

With respect to the framework above, there are some questions: Are the indicators important for the firm's technological innovation? Are the indicators easy to be measured in firms? Could it be carried out as a performance management system of firm's technological innovation?

Three steps are implemented to check the validity of KPI system for technological innovation performance audit. Firstly, based on this framework, a survey on technological innovation performance audit at firm's level was conducted on line. Followed by is the statistical analysis involved two stages which would be explained below. Finally, in-depth interviews by E-mail and telephone are carried out to validate the survey findings.

The questionnaire was designed based on a combination of 7-point Likert-type scale questions and open questions. A final version was built up on the basis of the feedback received from a selected number of doctoral students in management (Europe, USA, Switzerland, Lebanon and China) who are interested in technology and innovation management (TIM) as a test sample for the questionnaire.

The main contents of the questionnaire could be divided into three parts. The first part seeks to understand the background of the firm which the recipient worked. The second part attempts to identify the technological innovation performance measurement with three levels of input resource availability, innovation process efficiency and innovation output effect, and three dimensions of 'Importance', 'Measurability' and 'Performance' are taken into account on each indicator. 'Importance' is to see whether the indicators are important for the firm, 'Measurability' is used to observe if the indicators are easy to be measured, and 'Performance' is applied to audit the firm's performance in terms of the indicators by comparing with the its main competitors. The third part seeks to appreciate the success in goal attainment of firm's technological innovation with three dimensions of knowledge, business and corporate social responsibility.

B. Sample and data collection

This survey is only administered to executives and R&D managers, who are experienced with technological innovation activities in firms. Data collection may be the most difficult part of setting up this model for the recipients because business rarely wills to share their commercial data with others. Nevertheless, we have received 53 responses on line by sending the links to our investigation list, with only 21 responses being strictly accordant to the requirements of the research. The effective sample is strictly limited to the firms placing importance on R&D activities, of which R&D intensity (the ratio between R&D expenditure and turnover) were beyond 5%.

C. Analysis

The task of data analysis is carried out into three stages in our research:

Stage 1: Reliability analysis: to test the reliability of the measurement scales of KPI system.

Stage 2: To test the validity of the technological innovation's KPI system, the mean scores and standard deviations of indicator scale are examined with the dimensions of 'importance' and 'measurability', which also aims to verify whether the indicators can be adopted by firms.

Stage 3: With auditing the technological innovation performance of firms in which the respondents work, the specific gap between the good performance firm and the poor performance one can be found. Furthermore, suggestions for the development of firm's technological innovation would be provided in this research.

IV RESULTS

A. Reliability analysis

The measurement scales of KPI system is tested by the statistical software SPSS17.0. As shown in Table 3, all of the Cronbach's Alpha values are higher than 0.70. According to the typical research, reliability coefficients of 0.70 or higher are considered adequate (Nunnally, 1978)[25]. These results suggest that the measurement scales of KPI system have good reliable properties.

Table 3 Reliability statistics

Scales	Cronbach's Alpha	N of Items
Total	.951	81
KPI's importance	.779	26
KPI's measurability	.923	26
KPI's Performance	.889	26
Outcome	.812	3

B. The validity of KPI system

The mean and standard deviation of the dimensions of 'Importance' and 'Measurability' for each indicator are shown in Tab. 4. As represented by the descriptive data, there is no indicator whose mean score is below 4 on both dimensions of 'Importance' and 'Measurability'. Therefore, each indicator is important and easy to be measured in firms ground on the opinions of recipients in the mass. According to the scatter diagram of KPI with the dimensions of 'Importance' and 'Measurability' shown in Fig.2, 16 indicators are dropped into the first quadrant with their value of X-coordinate and Y-coordinate being greater than 5, which means that these indicators are important for firm's technological innovation and are easy to be measured in firms; 8 indicators are dropped into the fourth quadrant with their value of X-coordinate being greater than 5 and the value of Y-coordinate being less than 5, which indicates that these important indicators are not very easy to be measured in firms; and 2 indicators are dropped into the second quadrant with their value of X-coordinate being less than 5 and the value of Y-coordinate being greater than 5, which shows that these indicators could be measured easily in firms while they are not the ones of the most important performance indicators for the firms.

It is described by the analysis of data in Table 4 that the most important indicators have a mean value exceeding 6. Among the item of ‘innovation availability’, the indicators of ‘FC-R&D expenditure’ and ‘FC-Technical improvement expenditure’ are the most important ones; from the perspective of ‘innovation efficiency’, ‘Quantity- Number of new products or redesigns’, ‘Quality- Success rate of R&D projects’ and ‘Average Total Time-to-market’ are the most important indicators; and for the dimension of ‘innovation effect’, ‘KP-The position of firm’s technology comparing with competitor’, ‘BP-New sales ratio’, ‘BP-Cost saving ratio’ and ‘BP-Market share gained due to R&D’ are the most important indicators for the firms.

Table 4 The importance and measurability of KPI

Dimensions	St.	Indicators Number								
		1	2	3	4	5	6	7	8	9
Importance	Mean	6.05	6.17	5.44	5.42	5.75	6.28	5.63	4.82	6.21
	St.d	0.78	0.71	1.25	1.22	0.68	0.83	1.36	1.42	0.98
Measurability	Mean	6.26	5.39	6.33	5.37	5.50	6.28	6.13	5.65	6.00
	St.d	0.73	1.42	0.77	1.54	1.41	0.83	0.89	1.06	1.05

Dimensions	St.	Indicators Number								
		10	11	12	13	14	15	16	17	18
Importance	Mean	5.53	4.74	5.41	5.78	6.05	5.17	5.12	5.63	6.00
	St.d	1.25	1.63	1.00	1.40	1.18	1.47	1.22	1.02	0.97
Measurability	Mean	5.40	5.42	4.82	5.74	5.95	4.94	4.94	4.44	4.78
	St.d	1.35	1.30	1.33	1.19	1.18	1.30	1.20	1.63	1.73

Dimensions	St.	Indicators Number							
		19	20	21	22	23	24	25	26
Importance	Mean	6.00	6.22	5.72	6.06	5.75	5.25	5.56	5.53
	St.d	1.00	1.00	1.41	0.87	1.00	1.53	1.03	1.23
Measurability	Mean	6.41	5.78	4.83	4.72	4.81	5.31	5.56	5.06
	St.d	0.71	1.22	1.82	1.71	1.38	1.54	1.21	1.14

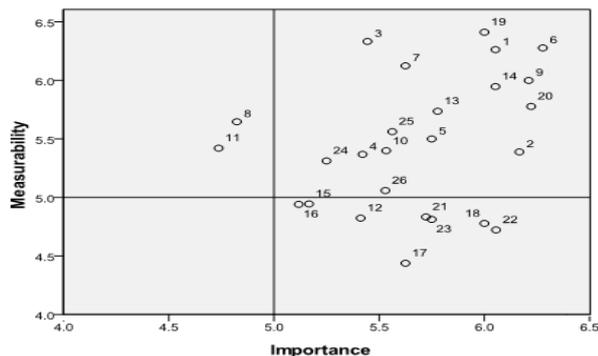


Fig.2 The scatter diagram of KPI with two dimensions of ‘Importance’ and ‘Measurability’

C. In-depth performance audit for four Hi-tech firms

In order to test the practicability of the KPI system, four information technology (IT) firms were chosen as a case study of an in-depth performance audit, which are adequately representative of the firms we interviewed. While two of them achieve an excellent performance, the other two have a bad performance in technological

innovation. Because all detailed information obtained by the investigation should be kept strictly confidential and the findings should not identify any individual or company, the names of all firms are omitted in the research. The background of the four firms which is obtained by database and in-depth interviews is listed in table 4 showed as below, and the performance of the four firms in terms of all indicators is shown in Fig.3 and Fig.4.

As shown in Fig.3, both firm 1 and firm 2 had a good performance in technological innovation, however, their performance in 26 indicators are obviously different. The performance of Firm 2 is much more balanced in all KPI than that of firm 1, while the performance of firm 1 with the indicators of R&D efficiency is much more outstanding. According to our in-depth investigation, we can find that the innovation strategy of firm 1 and firm 2 are quite different, which has something to do with their technological innovation performance. As the former being a medium-sized firm wants to be a technology leader in its industry, the latter being a large-sized firm wants to keep the dominant position in its industry.

Table 5 The background of four representative firms

Firm	Industry	Firm size
Firm 1	IT accessories	Medium-size
Firm 2	Mobile communication	Large-size
Firm 3	IT materials	Medium-size
Firm 4	IT equipment	Large-size

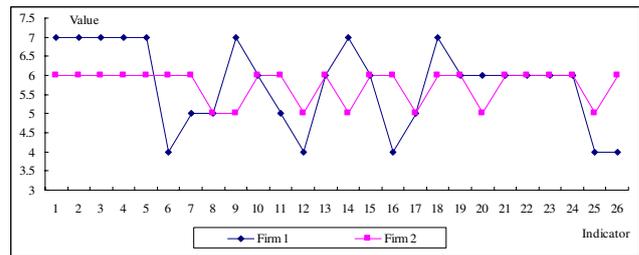


Fig.3 Technological innovation performance of firm 1&2

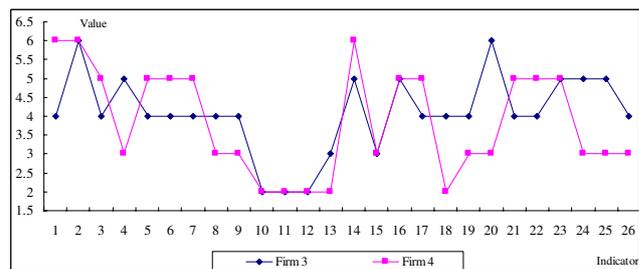


Fig.4 Technological innovation performance of firm 3&4

Fig.4 illustrates that low innovation efficiency leads to poor performance directly with respect to firm 3 and firm 4. Furthermore, being lack of input in R&D staff and expenditure results in low innovation efficiency for firm3, being short of external support leads to low innovation efficiency for firm 4. Thus, it can be found that the in-depth performance audit by the KPI of technological innovation in this research can provide much useful information for the firms. In other words, this case study proved that the KPI system is valid to some extent.

V CONCLUSION

Kerssens-van et al. (1999) suggested that performance measurement of technological innovation is more than choosing a set of metrics, which is a part of the broader concept of performance control influencing the capacity of the metrics to achieve its objective [18]. Moreover, it should be effective for the firms to diagnose innovative activity for supporting resource allocation, motivating personnel, enhancing communication and coordination and learning, reducing R&D risks, and improving innovation performance [9].

This research aims at taking a step further in developing a methodology framework of key performance indicator system, which is regarded as the core performance measurement system of innovation. With retrospect to the important literature, the KPI of the innovation performance audit is identified with three dimensions of ‘innovation availability’, ‘innovation efficiency’ and ‘innovation effect’. The first dimension emphasizes the importance of intellectual capital; the second one put forward the four properties of innovation efficiency which includes quantity, quality, cost and time; the last one deems the importance of knowledge performance, and additionally recommend to take the business performance and the social performance into consideration. Based on the investigation and related data analysis, the KPI system is proved to be effective as a whole, most indicators of which are verified to be important and could easily to be measured in firms.

Generally speaking, this research has built a valid framework for technological innovation performance audit. However, the KPI system is still need to be improved so that it could be much more easily and conveniently to be measured. Further investigations are needed to put the performance audit system into practice in different industries.

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