Modelling Innovation Paths of European Firms Using Fuzzy Balanced Scorecard

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Abstract Because innovation processes are complex, uncertain and highly dimensional, modelling innovation paths is a very challenging task. As traditional regression models fail to address these issues, here we propose a novel approach for the modelling. The approach integrates Balanced Scorecard, a method used for strategic performance measurement, and fuzzy set qualitative comparative analysis. In addition to key performance indicators, strategic goals are taken into consideration in the modelling. We provide empirical evidence for the effectiveness of the approach on a large dataset of European firms. We show that several innovation pathways can be identified for these firms, depending on their strategic goals. These results may be of relevance for the decision making of innovative firms and other actors of innovation system.

Keywords Innovation · Performance measurement · Balanced scorecard · Fuzzy sets · Qualitative comparative analysis

1 Introduction

Business managers have been trying to increase the competitive advantage of both businesses and entire industrial sectors over the last 100 years. It was proved (by the developments of scientific knowledge, and also by the practice), that the firm's competitive advantage depends not only on the availability and the volume of capital. Nowadays, the competitiveness of a firm depends also on a number of other "soft"

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inputs such as knowledge, quality, creativity, learning ability, ability to cooperate and use different factors in the minimum time and cost savings. These factors are crucial to the ability of an enterprise to create innovative products and succeed in international (but often in national) markets. Therefore, the performance (or competitiveness) management of innovation activities is the topic of many studies [13]. Specifically, researchers and managers are interested in which of the factor in socio-economic environment has a significant positive effect on the innovation performance.

Scholars agree on the importance of organizational innovation for competitiveness. This form of innovation is perceived as prerequisite as well as facilitators and mainly also as immediate sources of competitive advantage in the business environment [8]. Hult et al. [18] stated that organizations' culture competitiveness is based on four factors—entrepreneurship, innovativeness, market orientation and organizational learning. Study of [29] confirmed that organizational culture, the environment embedded in corporate strategy has a positive impact on performance. Company strategy should be the result of strategic planning and application of various aggregated activities. Value chain is created, in whose conceptual structure it is possible to analyze the sources of competitive advantage [32].

Thanks to the rapid ability of the firms to introduce innovation and to high pressure to reduce costs, firms must increasingly assess their performance and be subject to benchmarking [9]. There is a growing need for continuous improvement. This principle must be an integral part of strategic management activities and it is also one of the parameters of multifaceted performance [33]. Managers' efforts to balance corporate strategies, the need for detailed knowledge of production inputs, and the precise knowledge of customer requirements have resulted in the use of the Balanced Scorecard (BSC) model. This familiar tool is helping to balance the firm strategy and define performance multifaceted indicators.

When we want to measure a multifaceted performance we need to use non-financial indicators which are not free of limitations. As [6] stated, some non-financial performance indicators may be difficult to measure accurately, efficiently, or in a timely fashion. According to Ittnerr and Larcker [19], other limitations are that they may be biased or ambiguous, easier to manipulate, measured in many ways that may change over time, time-consuming, and expensive. Because innovations most of the time track intangible assets, their measurement remains a challenge for most of the enterprises as well as academics [20]. To date, no rigorous model for innovation performance measurement has been found due to complexity and uncertainty present in innovation processes [14]. To overcome these problems, here we develop an integrated approach that combines strategic innovation performance assessment with qualitative comparative analysis. This approach enables finding innovation pathways within the BSC framework, thus connecting the performance criteria with corporate strategic priorities.

The remainder of this paper is structured as follows. In the next section, we present the theoretical background for BSC model and its use in the strategic management of innovation processes in companies. Section 3 provides the characteristics of the dataset and the research methodology. Section 4 presents the experimental results.

In Sect. 5, we discuss the results that were obtained and conclude the paper with suggestions for future research.

2 Theoretical Background

In a rapidly changing environment, enterprises must continuously innovate, develop new processes and deliver novel products or services to achieve and maintain a competitive advantage [36]. Hence nowadays, it is not about whether to innovate or not, but how to innovate successfully. In this context, innovation management itself is evolving and presents enterprises with tough challenges in performance measurement [7].

According to [10] most enterprises do not measure the benefits created by their innovation projects, many of them do not have internal structures to measure innovation and do not pay sufficient attention to the process of innovation management. This fact is confirmed by a number of surveys, for example The Boston Consulting Group's survey revealed that 74% of the executives believed that their company should track innovation as rigorously as core business operations, but only 43% of the companies actually measured innovation [2]. Dewangan and Godse [7] state that less than 41% of enterprises regard their Innovation Performance Measurement (IPM) systems as effective and a large majority of enterprises have felt the need to improve their IPM system. According to [21] the real issue is a lack of metrics and measurements which cause that companies measure too little, measure the wrong things or not measure innovation at all.

The main reason why a number of enterprises are still struggling with problems in this area is that measurement of innovation is intangible by nature. Innovations typically create much more intangible than tangible value, and intangible value cannot be measured using traditional financial methods [10]. Adams et al. [1] stress the absence of the frameworks for innovation management, measurement indicators as well as the relatively small number of empirical studies on measurement in practice. Still, we can find studies dealing with innovation performance measurement [15].

The measurement of innovation is also crucial issue for an academic research. As stated Adams et al. [1] unless constructs relating to the phenomenon are measurable using commonly accepted methods, there is a risk that different operationalization of the same effect will produce conflicting conclusions, and that theoretical advances become lost in the different terminologies.

In literature we can find three types of innovation performance models that are based on different methodologies including empirical ones like firms survey [30], case study [25] and theoretical approaches [38]. Recent frameworks used for innovation measurement are also diverse and often built with operations research tools such as Data Envelopment Analysis (DEA) or multi-criteria analysis tools such as Analytic Hierarchy Process (AHP) [28]. DEA is appropriate for innovation efficiency calculation and for benchmark [34, 35] and AHP for innovation portfolio management [24]. However, traditional models and frameworks for innovation measurement

are mainly oriented on past performance and stressing more control than process of innovation management.

Currently Balanced Scorecard is considered the most comprehensive model for the continuous improvement of the organization's performance. BSC can be used also to measure the performance of the innovation processes. The authors of the BSC concept itself state that the recent BSC provides a richer, more holistic view of the organization, and the model can be used with any selection of perspective appropriate to a particular exercise [17]. The fact that it can be adapted according to the needs of the organization in any of its areas, makes from BSC the most appropriate tool for introducing a complex system of measuring innovation performance [10, 15, 20].

In the context of innovation measurement a key improvement of BSC is the linkage of measurement to a strategy map; this tighter connection between the measurement system and the strategy map elevates the role of nonfinancial measures in strategy implementation and strategy evaluation [22]. Strategic alignment determines the value of intangible assets and strategy map is designed to help execute strategy and bring predictive qualities to key performance indicators [5]. Only by considering the cause-effect relationships, it is possible to switch from innovation performance measurement to innovation performance management.

One of the first authors that suggested BSC as an integrated performance measurement system for research and development were Kerssens-van Dronglene and Cook [23]. Later Bremser and Barsky [4] extended their work by integrating Stage-Gate approach to R&D management with the BSC to present a framework to show how firms can link resource commitments to these activities and strategic objectives. Gama et al. [10] proposed an Innovation Scorecard based on innovation metrics and the traditional BSC in order to measure the value added by innovation and tested the pilot in a large industrial company. Saunila and Ukko [37] introduce a conceptual framework of innovation capability measurement based on the literature review of performance measurement frameworks and assessment models. Ivanov and Avasilcăi [20] developed new model on the basis of detailed analysis of four most important performance measurement models (BSC, EFQM, Performance Prism and Malcolm Baldrige) that tries to emphasize the most important characteristics that have to be analyzed when innovation performance is measured. Zizlavsky [44] proposed an Innovation Scorecard based specifically on project management, BSC, input-process-output-outcomes model and Stage Gate approach. Above presented models and frameworks are theoretical or based on the analysis of one or few case studies and the results have not been verified on a large data set.

When using non-financial measures, we need to often deal with the data vagueness and ambiguity. The contemporary research reveals that the fuzzy set and the fuzzy logic theory are the appropriate theoretical background to solve this issue. Recently, many researchers have been developed and modified fuzzy linguistic approach in order to apply in diverse domains, some of them integrated fuzzy linguistic also in BSC structure [15, 27].

In one of the oldest works are BSC and Fuzzy logic combined into a methodology and a software tool that is able to help executives to optimize the strategic business processes [12]. Later on, several scholars integrates BSC with Fuzzy AHP to calculate

the relative weights for each performance measure [26, 39]. More recent studies propose approaches to analyze strategy map using BSC-FAHP to asses each aspects of strategy or impact of changes in the mission and vision of the organization [31, 40]. Interesting is also the approach of [3] that provide a first semantic fuzzy expert system for the BSC. Its knowledge base relies on an ontology and its inference system derives new knowledge from fuzzy rules.

However, none of them, to the best of our knowledge, utilized the advantages of fuzzy sets to model innovation paths within the BSC framework.

3 Research Methodology

In this section, we first introduce a BSC for evaluating firm innovation performance. Specifically, we adapted the model proposed in [13] that provides a set of indicators for each perspective of BSC. Our contribution is the inclusion of vision and strategy effect on all four BSC perspectives (Fig. 1). More precisely, five strategies were considered: (1) developing new markets; (2) reducing costs; (3) introducing or improving goods or services and their marketing; (4) increasing organization flexibility; and (5) building alliances with other firms and institutions. The causal effects in the BSC model also represent the theoretical framework for further detection of innovation paths.

The indicators used to evaluate firm innovation performance and their innovation strategies are presented in Table 1. Note that both quantitative and qualitative indicators were included and that these were fuzzified to [0, 1] interval for further qualitative comparative analysis. Note that the values are regularly distributed in the [0, 1] to make the fuzzification as objective as possible. The source of the data was
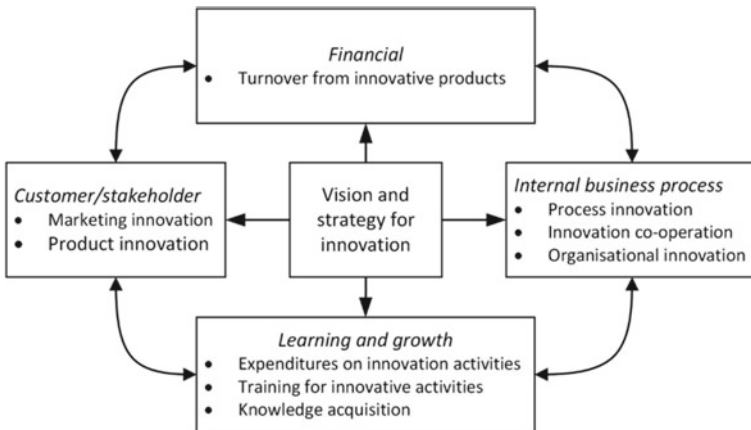

Fig. 1 BSC for evaluating firm innovation performance

Table 1 Indicators for BSC model

	Indicator	Description
l_1	Training for innovative activities	0 for no, 0.5 for medium and 1 for high intensity
l_2	Expenditure on innovation activities	Rescaled to [0, 1]
l_3	Knowledge acquisition	Importance of knowledge sources (0 for no importance, 0.25 for low, 0.5 for medium and 1 for high importance)
c_1	Product innovation	0 for none, 0.5 for product new to the firm and 1 for product newt to the market
c_2	Marketing innovation	0 for no marketing innovation, 0.25 for one type of marketing innovation, 0.5 for two of them, 0.75 for three of them, and 1 for the implementation of all types of marketing innovations
i_1	Process innovation	0 for no process innovation, 0.33 for one type of process innovation, 0.67 for two of them, and 1 for the implementation of all types of process innovations
i_2	Innovation co-operation	Diversity of cooperation partners: 0.14 for 1 partner, 0.29 for 2 partners, 0.43 for 3, 0.57 for 4, 0.71 for 5, 0.86 for 6, and 1 for 7 cooperation partners
i_3	Organizational innovation	0 for no organizational innovation, 0.33 for one type of organizational innovation, 0.67 for two of them, and 1 for the implementation of all types of organizational innovations
f_1	Turnover from innovative products	The share of turnover scaled to [0, 1]
s_1	Developing new markets	Importance of strategies: 0 for not relevant, 0.33 for low importance, 0.67 for medium importance and 1 for high importance
s_2	Reducing costs	
s_3	Introducing (improving) goods or services	
s_4	Increasing flexibility	
s_5	Building alliances	

the CIS (Community Innovation Survey) harmonized questionnaire, for details see the questionnaire available at: http://ec.europa.eu/eurostat/documents/.

The data used in this study come from the CIS survey for the period 2010–2012. To collect the data, CIS is based on the combination of exhaustive surveys and stratified random sampling of firms with at least ten employees. Overall, we were able to collect the data for 17,586 firms. The following countries were included in the dataset: Germany (5,777 firms), Portugal (3,341), Bulgaria (2,409), Hungary (1,182), Croatia (944), Romania (829), Estonia (771), Slovenia (733), Lithuania (653), Slovakia (560) and Cyprus (388). To impute missing data, median values of the respective industry was applied [28, 43].

As the data available at the Eurostat upon request, we report only their main characteristics here. Most firms in the dataset were SMEs (small and medium enterprises), introducing mostly product innovations out of the four innovation types. About half of the firms were innovative, with more than 20% turnover from innovative products. Suppliers were the most frequent cooperation partners. Regarding the innovation strategies, reducing costs was the most important one and increasing flexibility placed second. In contrast, building alliances and developing new markets were the least important strategies.

To model the innovation paths, we adopted the approach used in earlier studies for this task [11, 41] and used fuzzy set qualitative comparative analysis [42]. This method is suitable for modelling complex decision-making processes and detects also asymmetrical dependencies in the data [42]. This is done by examining all possible input-output combinations. Thus, necessary and sufficient conditions can be identified for each output. Those paths that are consistent with the data (with conditions covered by the output) and that cover sufficient data instances are stored in the solution. To calculate the fuzzy set membership of the path configuration, Gödel's t-norm was used for logical AND, this is the minimum operation was performed over the conditions. To obtain the consistency (cons) and coverage (cov) of the solutions, the following equations were used [42]:

$$cons(x_i \leq y_i) = \sum_{i=1}^{n} \min(x_i, y_i) / \sum_{i=1}^{n} x_i, \tag{1}$$

$$cov(x_i \leq y_i) = \sum_{i=1}^{n} \min(x_i, y_i) / \sum_{i=1}^{n} y_i. \tag{2}$$

4 Experimental Results

To perform the modelling of innovation paths, we used the freely available fsQCA software. For the sake of space, here we present only the most important path configuration, with the financial perspective f_1 as the output and the remaining perspectives and strategies as the input variables. Consistency cutoff was set to 0.5 to discard less consistent pathways.

The results of the modelling included 11 paths as follows:

Path 1: c_1 and $\sim c_2$ and $\sim l_1$ and $\sim l_3$ and $\sim i_1$ and $\sim i_2$ and $\sim i_3$ and s_1 and s_2 and s_3 and s_4 with cov $= 0.20$ and cons $= 0.51$,
Path 2: c_1 and $\sim c_2$ and $\sim l_1$ and $\sim i_1$ and $\sim i_2$ and $\sim i_3$ and s_1 and s_2 and s_3 and s_4 and s_5 with cov $= 0.15$ and cons $= 0.52$,
Path 3: c_1 and c_2 and l_1 and l_3 and i_1 and i_2 and i_3 and s_2 and s_3 and s_4 with cov $= 0.10$ and cons $= 0.57$,

Path 4: c_1 and c_2 and l_1 and l_3 and i_1 and i_3 and s_1 and s_2 and s_3 and s_4 and s_5 with cov = 0.10 and cons = 0.57,

Path 5: c_1 and ~c_2 and ~l_1 and ~l_2 and ~l_3 and ~i_1 and ~i_2 and ~i_3 and s_1 and s_2 and s_3 and ~s_5 with cov = 0.11 and cons = 0.50,

Path 6: ~c_2 and ~l_1 and ~l_2 and l_3 and ~i_1 and i_2 and ~i_3 and s_1 and s_2 and s_3 and s_4 and s_5 with cov = 0.09 and cons = 0.55,

Path 7: c_1 and c_2 and l_1 and l_2 and l_3 and i_1 and i_2 and i_3 and s_1 and s_2 and s_3 and s_4 with cov = 0.08 and cons = 0.64,

Path 8: c_1 and l_1 and l_2 and l_3 and i_1 and i_2 and i_3 and s_1 and s_2 and s_3 and s_4 and s_5 with cov = 0.09 and cons = 0.63,

Path 9: c_1 and c_2 and l_1 and l_2 and l_3 and i_2 and i_3 and s_1 and s_2 and s_3 and s_4 and s_5 with cov = 0.08 and cons = 0.64,

Path 10: c_1 and ~c_2 and ~l_1 and l_2 and ~l_3 and ~i_1 and ~i_2 and ~i_3 and ~s_1 and ~s_2 and ~s_3 and ~s_4 and ~s_5 with cov = 0.04 and cons = 0.57,

Path 11: c_1 and ~c_2 and l_1 and l_2 and l_3 and ~i_1 and i_2 and ~i_3 and s_1 and s_2 and s_3 and s_4 and s_5 with cov = 0.06 and cons = 0.62,

where cov denotes coverage, cons is consistency and ~ indicates negation operator ~$x = 1 - x$. For the complete solution of the model, we obtained the consistency of 0.52, which can considered sufficient relative to previous literature [26]. In addition, the solution had a high coverage of 0.39.

Path 1 and Path 5 state that high turnover from innovative products can be achieved by introducing product innovation only. However, those paths are not suitable for firms aiming to build strategic alliances. Overall, we can state that product innovation is a necessary condition to yield financial profit from innovation activities. As suggested by Path 2, this holds irrespective of the strategic goals. What is more interesting is the fact in Path 6 this condition is not met, and product innovation is replaced by knowledge acquisition and innovation co-operation by those firms. Firms following Path 3 introduced all the four types of innovations during the monitored period, which required both the innovation co-operation and training for innovative activities combined with knowledge acquisition. Path 4 represents a similar solution but for firms seeking for collaborative partners and new markets.

Interestingly, expenditure on innovation activities was not a necessary condition to achieve high share of turnover from innovative products in Paths 1–6, suggesting that these represent the configuration paths taken by SMEs. In contrast, the expenditure was present in Paths 7–11, which provided more consistent solutions. We can observe that high expenditure on a firm's innovation activities is often accompanied with intensive training and knowledge acquisition, this is a coordinated effort for learning and future growth. Also note that Path 10 suggests that the five strategies included in the data did not provide an exhaustive listing. Additional strategies can be considered, such as reducing consumption of raw materials or improving working conditions.

To further study the firms taking the identified path configurations, we investigated their countries of origin and industry classification. For the former, we classified the countries according to the EIS (European Innovation Scoreboard) categories into modest innovators, moderate innovators, strong innovators and innovation leaders.

Regarding the latter, we used the Eurostat definition of knowledge-intensive industries (i.e., those for which tertiary educated employees represent more than 33% of the industry employment). Based on these classifications, we found that Paths 1, 5 and 6 were taken by firms from less performing countries and knowledge-non-intensive industries. Paths 3, 4, 7 and 10 represent knowledge intensive industries from less performing countries. Finally, Paths 8, 9 and 11 were taken by firms from well performing countries and knowledge-intensive industries primarily.

5 Conclusion

In conclusion, we proposed a novel approach to modelling innovation paths that integrates innovation BSC with qualitative comparative analysis. We have outlined the BSC model, taking into account both the importance of firms' innovation strategies and the qualitative assessment of many innovation indicators. A large dataset of European firms was used to validate our approach. The findings of this study imply that strategic priorities are crucial for the selection of firms' innovation pathways. In addition, the results suggest that are eleven consistent innovation paths present in the dataset.

Prior research has indicated that expenditure on innovation activities is the most important determinants of innovation outcomes [16]. Indeed, we demonstrated that the expenditure is a necessary condition in highly innovative countries. However, the economic outcomes of innovation activity can also be achieved by introducing product innovation in less performing countries, when appropriate innovation strategy is taken. We believe that this research will serve as a base for future studies focused on individual countries and industries. The model proposed here may be applied to different CIS datasets without limitations. Moreover, the set of the BSC indicators, as well as the fuzzification procedure, may be adjusted to consider country/industry specifics. On the one hand, the variety of firms included in our dataset provided an extensive empirical support to our approach. On the other hand, more consistent results can be achieved in future studies when investigating a more specific sample of firms.

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