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Mining the R&D innovation performance processes for high-tech firms based on rough set theory

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ABSTRACT

The research and development (R&D) innovation of firms continues to be viewed as an important source of competitive advantage to academics and practitioners. To explore and extract the R&D innovation decision rules, it is important to understand how the R&D innovation rule-base works. However, many studies have not yet adequately induced and extracted the decision rule of R&D innovation and performance based on the characteristics and components of the original data rather than on post-determination models. The analysis of this study is grounded in the taxonomy of induction-related activities using a rough set theory approach or rule-based decision-making technique to infer R&D innovation decision rules and models linking R&D innovation to sales growth. The rules developed using rough set theory can be directly translated into a path-dependent flow network to infer decision paths and parameters. The flow network graph and cause-and-effect relationship of decision rules are heavily exploited in R&D innovation characteristics. In addition, an empirical case of R&D innovation performance will be illustrated to show that the rough sets model and the flow network graph are useful and efficient tools for building R&D innovation decision rules and providing predictions. We will then illustrate that integrating the flow network graph with rough set theory can fully reflect the characteristics of R&D innovation, and, through the established model, we can obtain a more reasonable result than with artificial influence.

1. Introduction

Research and development (R&D) innovation activity is recognized by its concern with multiple indicators displaying complex structures, uncertainty with many interlocking manufacturing and technological processes, and, consequently, a set of innovation behaviors. Therefore, R&D innovation activity is an important source of competitiveness in many industries. This is particularly true in high-technology industries,[1] characterized by short product life cycles, high uncertainty, and intense competition among new products for market share (Qian and Li, 2003). In spite of this increasing importance, many high-technology firms have begun to invest heavily in R&D innovation activities to develop novel and innovative products that can help to capture and maintain market share and improve future firm profitability. The R&D effort is a very complex structure with multiple factors to explore to advance R&D resource allocation strategies and translate them into innovations. In response to international competitive pressure, high-technology firm survival and competitive advantage rely upon R&D ability, and hence, innovation in extremely competitive environments (Duysters and Hagedoorn, 2000; Wan et al., 2005). This innovativeness can help capture and maintain market share for improving firm profitability (Wang et al., 2008). There is no doubt about the importance of R&D efforts to high-technology firms as the foundation of their survival. In high-technology industries, where the pace of technical change is speedy, firms place a greater emphasis on R&D efforts toward their products, processes, and technology to overcome technological hurdles and distinguish their offerings from those of competing firms (Thornhill, 2006). R&D efforts can also indicate the innovative competences affecting the performance of firms, particularly in high-technology industries

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[1] In this study, the high-technology industries include electronics, computers, integrated circuits, semiconductors, and telecommunications without covering pharmaceutical firms. In the pharmaceutical industry, as a strongly science-based sector, some of important characteristics such as the long development lead time of drugs and long product life cycles may lead to a difference evaluation results and conclusions. For these reason, the pharmaceutical firms are excluded in our samples.

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(Henderson and Cockburn, 1994; Duystersc and Hagedoorn, 2001; Hagedoon and Cloodt, 2003). For these reasons, R&D activity is considered by high-technology firms an important part of maintaining competitiveness and driving profitability.

Many studies rely on empirical studies to analyze R&D innovation activities according to different formal functions, such as the use of the neoclassical production technology function (Griffith et al., 2004), the Cobb–Douglas production function (Tsai and Wang, 2004; Guellec, and Van Pottelsberghe de la Potterie, 2004), panel random effect regressions (Del Monte and Papagni, 2003), OLS regressions (Thornhill, 2006; Coombs and Bierly, 2006), the relev method (Coccia, 2001), and the real options approach (Willigers and Hansen, 2008; Wu and Yen, 2007). Although some of these traditional statistical methods lead to models with a satisfactory ability to analyze R&D innovation activities, they often include a priori assumptions on the data. The advantage that such rough set theory (RST) can be considered applicable here is that it does not rely on other parameters or prior model assumptions. This does not mean that RST does not have any model assumptions. The essence of the RST idea can simply be described by its classes of indiscernible relationships (see Section 3.2). More specifically, RST effectively derives a set of decision rules based on the observed behavior (Beynon and Driffield, 2005). As a result, in this study, we apply RST to mining the decision rule for R&D and innovation to the firm and industry levels. We focus on two firm-level measures of R&D innovation and performance-generating R&D and their innovation decision rules, then examine the causal relationship between R&D innovation activities and, consequently, firm performance. To construct the R&D innovation decision of high-technology firms, we employed the appropriate RST approach, using characteristics and components found to be associated with the R&D innovation decisions and put them forward as inducing decision variables. Empirical analyses of high-technology firms' R&D and innovation decisions are relatively scarce in the existing literature. Therefore, this study is the first attempt to explore the link between R&D innovation and performance decisions of high-technology firms' initial data, or rather any predetermination formal function assumptions.

As can be seen, the R&D innovations of firms have been studied quite extensively for a long period of time. Conventional R&D innovation and performance relationship studies were based on the existing information to build functions or relationship models as a foundation of the measurement decision. Most studies, however, have not appropriately approached how to apply these relationships to traditional production functions, or economic models, before employing these functions, which may not reflect the real relationships in such models. The major problem with most studies measuring R&D innovation and performance is that they rely on predetermined or fitting model measurements (Pawlak, 1991; Pawlak et al., 1995; Pawlak, 1997). This is especially true when researchers adopt a production function or an economic model to measure R&D innovation and performance. Under such a situation, the rule extraction technique is relatively better for inducing a large number of influential attributes and data from irregular, disorderly, and imprecise data, or, more specifically, for discovering relationships in the data. The rules developed by RST are directly translated into the path-dependent flow network graph (Ford and Fulkerson, 1962; Pawlak, 2002; 2004; 2005; Ou Yang et al., 2008) to infer the decision path and parameters between R&D innovation and performance at the firm level in high-technology industries. The use of RST for inducing R&D innovation and performance decisions was advanced as a simple and available way to construct the R&D innovation and performance decisions of high-technology firms. As mentioned previously, this will be the first study to use RST to induce and explore the relationship between R&D innovation and performance in the high-technology industry. The major objective of this study, therefore, is to better understand the possible rules of specific R&D innovation and performance, by using multiple indicators related to latent variables conditional on the inherent characteristics of the original data. We believe this will provide greater insight for making R&D innovation decisions.

The rest of this article is organized as follows. In Section 2, an overview of the previous relevant work in the domain of R&D innovation is introduced. In Section 3, an RST for inducing the rule of R&D innovation and sale growth ratio is presented. Based on this approach, we define R&D innovation variables, apply their regulation to overall high-technology firm success, and make the link between R&D innovation and percentage sale growth. Next, we design and develop a flow network dependent on the RST decision rule created in Section 4. Finally, conclusions and remarks are proposed in Section 5.

2. Review of prior studies on R&D efforts

To begin our exploration for creating relationships between R&D efforts measures, we first need to explain the literature on the characteristics of R&D innovation and performance to construct some reference points and rules. Naturally, R&D efforts can accelerate the accumulation of knowledge and technological strength. It can also help determine a firm's performance. In the current literature, there exist many studies proposing various methods for establishing and identifying the relationships between R&D innovations and firm performance. Earlier empirical studies have examined associating R&D expenditures strongly with sales growth (Morbey and Reithner, 1990), profit and productivity (Baumol and Wolff, 1983; Dosi, 1988; Morbey and Reithner, 1990). In light of this logic, Franko (1989) argued that R&D investments were positively related to long-term performance. Ettlie (1998) examined the effect of R&D intensity on manufacturing performance. He found that R&D intensity has significantly contributed to the increasing market share and improvements in manufacturing agility. Wakelin (2001) applied the Cobb–Douglas function to estimate United Kingdom (UK) manufacturing firms' R&D expenditures, finding these expenditures to have a significant positive impact on productivity growth. Brown and Gobeli (1992) applied the results of a case study to develop a system for measuring R&D productivity. They developed a conceptual model and determined the top 10 qualitative and quantitative indicators of R&D productivity measurements. In line with this is the conclusion by Werner and Souder (1997) that R&D performance evaluation is an integrated measurement system in which qualitative and quantitative metrics may be combined and used simultaneously. Dressler et al. (1999) suggested that the cost-saving ratio was an appropriate approach used to measure R&D performance. In addition to the papers mentioned previously, a few other empirical findings suggested that R&D has a positive impact on a firm's performance (Ito and Pucik, 1993; Long and Ravenscraft, 1993; Lee and Shin, 1995). In summary, a majority of the literature has empirically demonstrated the significant impact of R&D innovation activities on the performance of firms; however, these studies did not examine whether the original data as appropriate for the exploration and connections between R&D innovation and performance in the empirical model. So far, evidence permitting inference from the existing information is quite limited.

Firms are concerned about R&D resources deployment and productivity because investing in R&D efforts has become an important innovation source for their production activities and strategic decisions. Several economic studies have attempted to