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R&D, productivity, and market value: An empirical study from high-technology firms

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ABSTRACT

Although prior research has addressed the influence of production activity and research and development (R&D) on productivity, it is not clear whether production and R&D affect the market value of a firm. This study proposes and verifies an R&D value chain framework to explore the relationship among productivity, R&D, and firm market values, as measured by Tobin's *q* theory. By doing so, we attempt to link new theoretical insights and empirical evidence on the effects of R&D efforts and basic production activities to the market valuations of high-technology firms. The value chain data envelopment analysis approach was proposed to estimate parallel-serial processes of basic operations and R&D efforts. This approach can be used to simultaneously estimate the profitability efficiency and marketability efficiency of high-technology firms. This area has rarely been studied, but it is particularly important for high-technology R&D policies and for further industrial development. Using the R&D value chain perspectives of model innovations and extensions proposed in several previous studies, we examined the appropriate levels of intermediate outputs. Production efficiency and R&D were combined to estimate the appropriate levels of intermediate outputs for high-technology firms. Based on the intermediate output analyses, we developed an R&D efforts decision matrix to explore and identify operational and R&D efficiency for high-technology firms. Our sample firms are displayed on a four-quadrant action grid that provides visual information on current short-term operational efficiency and decision making on long-term R&D strategic positions. The empirical findings from the R&D value chain model can provide information for policymakers and managers and suggest the adoption of various policies that place more emphasis on profitability and marketability strategies.

1. Introduction

Because R&D activities are critical to the profitability and competitive advantages of innovation, R&D activities have long-recognized, complex processes of innovation and value creation. R&D plays a crucial role because the high-technology industry is characterized by major changes in markets and technology that are coupled with rapid advances in innovation. In particular, high-technology firms face an intensely competitive and dynamic market environment. High-technology markets are characterized by short product life cycles and high production rates of new products that incorporate newer generations of technology [1]. In such markets, R&D efforts are the most critical driving force behind successful innovation. R&D is critical for survival in these environments. A firm's superior R&D capability not only leverages its strong capabilities in process and product innovation to dominate high-technology markets, but also leads to competitive advantages for the firm [1]. R&D innovation efforts are the most important activities of high-technology firms; that is, R&D investments are one of the most crucial elements to scientific and technological progress [2,3]. R&D efforts, including the acceleration of new product launches into the market and improvements in manufacturing capability, play a key role in helping firms maintain or increase their market competitiveness. For example, Lin et al. [4] argued that R&D is a major source of competitive advantage for firms in high-technology industries that are engaged in rapid knowledge generation because the changing markets and technologies, increased domestic and global competition, changing customer needs, rapid product obsolescence and the emergence of new markets necessitate a speedy R&D innovation process. In an extremely competitive environment, survival is based on the ability to rapidly deliver R&D efforts to generate innovation, upgrade technology, and increase the added value from markets and productivity, as recognized by recent reforms in

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the high-technology sector. R&D innovation activities have taken center stage in economic analyses of the high-technology industry [5]. Similarly, Bommer and Halajas [6] noted that high-technology firms are important generators of economic growth. R&D efforts can also help capture and maintain market share and improve firm profitability. Faced with a competitive environment, high-technology firms primarily aim to maintain their efficiency and R&D productivity to ensure their competitive advantages and survival.

Naturally, the R&D efforts are expected to have a profound influence on firm productivity. R&D innovation activities in technologically intensive sectors and throughout the economy have been the driving factor of Taiwan's strong economic growth because of the short life cycles of technological products, the dramatic shift in customer needs, and intense competition. Successful R&D efforts and production activities can contribute to the progress of innovation, particularly in a competitive high-technology environment. Prior studies have established the relationship between R&D expenditures and firm performance in high-technology industries. According to Lin et al. [4], R&D efforts may significantly affect firm performance in the pharmaceutical industry. Hu [7] examined the relationship between R&D expenditures and productivity in Chinese industries, particularly high-technology sectors, and highlighted the strong link between proprietary R&D and firm productivity. Ettlie [8] surveyed 600 durable goods firms from 20 countries and found that R&D intensity (i.e., R&D as a percentage of sales revenue) was significantly associated with improvements in a firm's market share. Griliches [9,10] highlighted the significant relationship between a firm's R&D expenditures and that firm's productivity. R&D efforts have the potential to provide competitive advantages that result in improved firm performance. All of the above studies attest that a firm's investment in R&D efforts may directly impact the firm's performance. More generally, prior studies have shown that firm-level R&D efforts drive innovation and improvements in productivity.

Unfortunately, the literature on R&D efforts does not satisfactorily explore how firms can link their basic production activities and marketability to create market value. This question is important because investments in R&D and production are costly. Expending resources without estimating their relative efficiency may lead to the misuse of resources. To address these questions, we developed an R&D value chain model that describes how R&D initiatives and production activities enable firms to build a base for profitability, which, in turn, contributes to the firm's marketability and market value. Particularly, we hypothesized that marketability mediates the relationship between profitability and market value. Although the existing R&D literature has addressed the direct impact of R&D investments on firm performance, the mediating role of marketability in the contribution of R&D investments to profitability has been ignored. Most importantly, no researchers have yet explored and linked R&D, productivity, and market value with formal theory and mathematical approaches. However, there are many sources of inefficiency that cannot be discovered using the data envelopment analysis (DEA) model because of what the model refers to as the "black box" [11,12], which is the source of inefficiency or other unexplained factors [12,13]. This black box exists primarily because some of the indicators (for example, the number of patents or sales volume) must be viewed as intermediate phase indicators rather than as final output indicators. The sales volume represents the portion of the market value that high-technology firms can use to obtain market returns. Similarly, the number of patents and research outcomes do not reflect the market valuation or productivity of a high-technology firm. To measure stock marketability, we can utilize additional indicators, such as market value, by performing a market-based analysis [14] and by determining the return on investment in a DEA analysis.

To overcome the traditional shortcomings of R&D indicators, we can better understand the actual market value of basic production activities and R&D efforts by utilizing the direct measurements of Tobin's q theory. The main problem is that the R&D expenditures and patents do not explain the market value of these R&D efforts in conventional productivity measurement studies. Accordingly, this study attempted to develop a measure of the profitability efficiency and marketability efficiency of the R&D value chain. We find that the R&D innovation effort and productivity growth literature still lacks robust empirical evidence regarding a strong link between R&D profitability and marketability at the firm level. Jacobides and Winter [15] and Jacobides [16] addressed how vertical disintegration can impact various productive capabilities and efficiency measurements along different parts of the value chain. Specifically, the productivity measurement of high-technology firms is multidimensional because their various sources of efficiency are part of their basic production activities and affect their R&D efforts and overall productivity. Thus, there is a need to explore and identify their various sources of various divisions in the undiscovered items on the efficiency, which provide a measure of the inefficiency of each high-technology firm. However, the traditional literature has not incorporated basic production efficiency and R&D efficiency into the analysis of high-technology firm performance. According to the literature, the general assumption is that the basic production input is only one measurement that leads to the standard efficiency measurement. More importantly, both basic production and R&D efforts are indispensable factors for measuring productivity because of the nature of the operations undertaken by high-technology firms.

Overall, this article makes three specific contributions. First, it is one of the first attempts to integrate the R&D, productivity, and market value perspectives to address the consequences of profitability efficiency and marketability efficiency at the firm level. Although each perspective has been intensively explored in the literature, a mechanism for integrating them has rarely been investigated. We analyzed the effects of these R&D innovation efforts and basic production activities on simultaneous productivity measures for Taiwanese firms that were active in high-technology industries. We also studied the efficiency of traditional production, which we term basic production, and the efficiency of R&D added value, which we term R&D productivity. Therefore, it was particularly important to explore the driving forces of market value, as they may offer insight into basic production behavior and R&D innovation activities. Second, we propose a vertical disintegration of the sector value chain that builds on Hagel and Singer's [17] original definition. By extending previous ideas, we propose a particular R&D value chain as a source means for firms to analyze the appropriate level of intermediate outputs and relative efficiency. In this process, we delve deeper into the black box of intermediate outputs by analyzing the efficiency of R&D innovation and basic production. Finally, we integrate a long-term perspective on R&D strategy [18] and short-term basic operational efficiency [18,19] by providing a more comprehensive conceptual analysis of the relationships between long-term R&D efforts and short-term operational efficiency. In doing so, we provide an R&D efforts decision matrix that shows how firms leverage their R&D efforts to build their strategic positions. We believe that the development of the R&D efforts decision matrix and the initial findings on the appropriate level of intermediate outcomes represent important methodological steps advancing the measurements and potential applications of outcome expectations for understanding and predicting R&D innovation activities in high-technology industries.

The remainder of the paper is organized as follows. Section 2 provides an overview of the previous theoretical and empirical literature discussing the relationship among R&D activities, patents, productivity, and firm performance. Section 3 presents a model