Ph. D. Dissertation in Economics

Effect of investment and financing decisions on R&D activities

August & 2012

Graduate School of Seoul National University
Technology Management, Economics, and Policy Program
Euy-Young Jung

Effect of investment and financing decisions on R&D activities

지도교수 이정동

이 논문을 경제학박사학위 논문으로 제출함

2012 년 8 월

서울대학교 대학원

협동과정 기술경영경제정책 전공

정의영

정의영의 경제학박사학위 논문을 인준함

2012 년 8 월

위 원 장 이 종 수 (인)

부위원장 이 정 동 (인)

위 원 이 현 정 (인)

위 원 황 석원 (인)

위 원 백 철 우 (인)

Abstract

Effect of investment and financing decisions on R&D activities

Euy-Young Jung
Technology Management, Economics and Policy Program
The Graduate School of Engineering
Seoul National University

This research explores how investment and financing decisions influence R&D activities. According to conventional investment theory, investment decisions represent which assets to buy or how much to invest, while financing decisions represent how to pay for them.

Although many studies of investment targets have been carried out, studies of investment amount are scarce because of measurement difficulties. Further, even though the optimal level of R&D investment (or saturation level in this study) was recently measured, the time lag between investment and performance was not considered. In addition to saturation level, critical mass, namely the minimum amount of effort necessary to increase returns on R&D investment, is another component of R&D investment decisions. However, again, the empirical measurement of the critical mass has thus far not been achieved.

With respect to R&D financing decisions, many studies have pointed out that highly leveraged firms tend to reduce R&D investment. However, recent studies have also explained that the relationship between debt and R&D investment can differ according to technological intensity or debt type. In particular, loan or relational debt is positively related to R&D investment and performance because loans unlike bonds are better suited to governing asset specificity, uncertainty, and appropriability of R&D investment. However, previous studies of the relationship between loans and R&D have not considered loan maturity, technological intensity, or business cycle, which also significantly influence this relationship.

Thus, this study first empirically measures the critical mass and saturation levels of R&D investment in small and medium-sized manufacturing enterprises, which are increasingly attracting the attention of scholars and policymakers because of their expanding role in advancing technological progress through R&D. Using cross-section threshold estimation, this study estimates two values, which differ in terms of R&D performance and technological intensity. When using patent applications as a proxy of performance, we find that there are critical mass levels for R&D intensity and expenditure in high-tech industries but not in low-tech industries. This is because critical mass can exist in high-tech industries because of high technological entry barriers and high uncertainty. In the case of profit performance, only a saturation level exists.

Second, this study investigates how loan ratio in terms of loan maturity, technological intensity, and business cycle influences R&D activity in small and medium-sized manufacturing enterprises. It finds that R&D intensity is positively correlated with the

long-term loan ratio and negatively with the short-term loan ratio. Further, an increase in the short-term loan ratio depresses R&D investment, especially in high-tech industries and during periods of economic downturn.

Third, this study suggests policies and strategies to enhance the performance and efficiency of R&D investment for small and medium-sized manufacturing enterprises. For high-tech firms below the critical mass, attaining critical mass by increasing R&D financing through long-term loan can be a good choice. In the long run, alternatives such as equity need to be considered.

In summary, this research shows how R&D investment decisions affect R&D performance by measuring the critical mass and saturation levels in small and medium-sized manufacturing firms as well as how financing decisions about capital structure influence R&D investment. Moreover, it suggests a composite decision to increase R&D performance and efficiency based on the results.

Keywords: R&D Investment, Small and medium sized enterprises, Technological intensity, Critical mass, Saturation level, Loan maturity

Student Number: 2008-30904

Contents

List of Tables

List of Figures

Chapter 1. Introduction

1.1 Research background

Innovation is the key element of the knowledge base, growth, productivity, and competitiveness of an economy (Lee, 2011), and R&D is the major source of innovation and technical change (Moncada-Paternò-Castello et al., 2010). Therefore, R&D investment is crucial for both firms and the government. Conventional investment theory suggests that R&D investment is based on two important decisions, namely which assets to buy or how much to invest (i.e., an investment decision) and how to pay for them (i.e., a financing decision).

Although research on R&D investment targets has been performed, previous studies of how much to invest are scarce because of the measurement complexity. In order to measure the degree of investment into R&D, two levels should be considered: the optimal level (or saturation level in this study) of R&D investment and the critical mass level. The former has long been a research subject and methods for its measurement exist theoretically (David et al., 2000; Howe and McFetridge, 1976). For example, Yeh et al. (2010) estimate the saturation level using a threshold regression model but they do not consider the time lag of R&D intensity.

By contrast, although the possibility of measuring the critical mass level has been mentioned in previous research (Grabowski and Mueller, 1978; Galbraith, 1993; Sterlacchini, 2008), few empirical papers have suggested concrete measurement approaches. Critical mass is recognized in the business and economics literature, where the terms “economies of scale,” “entry barrier,” “breakeven point,” “threshold effect,” or “the S-Curve” are more often used (Terpstra, 1983). It usually indicates that some minimum amount of effort or resources must be applied before any impact or output can be realized. Similarly, critical mass in R&D investment decisions indicates that a minimum amount of effort or resources is required in order to increase R&D performance rapidly from such an investment.

Estimated critical mass and saturation levels are important for guiding R&D investment policy for governments and corporate strategies for firms. Indeed, policymakers and managers use critical mass and saturation levels in order to plan R&D investment and thus enhance the efficiency of R&D resources. Specifically, they can calculate the deficient amount of R&D investment from the critical mass level and find additional financial sources.

With respect to R&D financing decisions, loans are the crucial source of external financing in many countries such as Japan, Germany and France (David et al., 2008). Furthermore, loans are an effective financing solution for small and medium-sized enterprises (SMEs), especially because most SMEs are owner-managed and owners often have strong incentives to issue external debt rather than external equity in order to retain ownership and control of their firms (Berger and Udell, 1998). In Korea, over 70% of external funding for SMEs is provided through loans, while governments also support R&D investment through loans. SMEs can borrow long-term loans for R&D investment directly from the government or from banks after receiving guarantees.

Despite the usefulness and importance of loan or relational debt, many previous studies have pointed out that a higher debt ratio reduces R&D investment (Balakrishnan and Fox, 1993; Bradley et al., 1984; Hall, 1992; Kochhar, 1996; Simerly and Li, 2000; Singh, 2005; Stiglitz and Weiss, 1981; Vincente-Lorente, 2001). The asset specificity, uncertainty, and appropriability of R&D investment all make lenders of debt reluctant to fund specific investments with poor collateral. In addition, highly leveraged firms are also reluctant to invest into R&D because the heavy pressure to repay existing loans can disrupt the continuity of R&D investment. This implies that the capital structure of a firm affects its R&D activity.

Few scholars that have considered debt heterogeneity or technological intensity have found a positive relation between loan ratio and R&D investment. According to David et al. (2008), relational debt provided through bank loans can positively influence R&D investment compared with transactional debt generated through a bond issue, as it provides a lender with the soft governance appropriate for a borrower to invest in R&D in contrast to the strict contractual constraints of transactional debt. Chiao (2002) points out that industrial characteristics, especially whether firms operate in science or non-science industries, affect investments in different ways. In other words, heterogeneous characteristics of debt and industry produce different results. However, this in-depth research is at an early stage, and many research areas remain largely untapped. In particular, analysis related to classifying firms into high-tech and low-tech (i.e., technological intensity), to loan maturity, which is an important factor for loan financing, and to the business cycle, which is deeply related to loan maturity, is necessary in future studies.

Finally, combined with the results provided by threshold estimation, managers and policymakers can establish appropriate strategies or policies for R&D investment and financing. Moreover, this study can contribute to existent research into R&D investment and financing by investigating how to measure critical mass and saturation levels and exploring how loan ratio in terms of technological intensity, loan maturity, and business cycle affects R&D activity.

1.2 Research objective

SMEs are increasingly attracting the attention of scholars and policymakers because of their crucial contributions to technological progress through R&D and innovation (Czarnitzki and Hottenrott, 2011). In Korea, the government makes an effort to support the R&D activities of SMEs. Thus, this study focuses on R&D activities of manufacturing SMEs.

First, it measures the critical mass and saturation levels of R&D investment using cross-section threshold estimation, which is used to guide decisions on how much to invest. It then separately analyzes high-tech and low-tech firms in terms of their R&D intensity, R&D human resources, R&D expenditure (as a proxy for R&D investment), and number of patent applications and gross profit ratio (as a proxy for R&D performance). Based on the results, implications to increase R&D performance and efficiency are suggested.

Second, this study investigates how loan ratio in terms of technological intensity, loan maturity, and business cycle affects R&D activity, which is related to financing decisions, namely how to pay. This study analyzes each relationship individually and then suggests an overarching framework for capital structure and R&D intensity.

Third, this study suggests policy and strategy to enhance the performance of R&D investment for manufacturing SMEs including analyzing the relationship between loan ratio and R&D intensity. The conceptual outline of this study is presented in Figure 1.

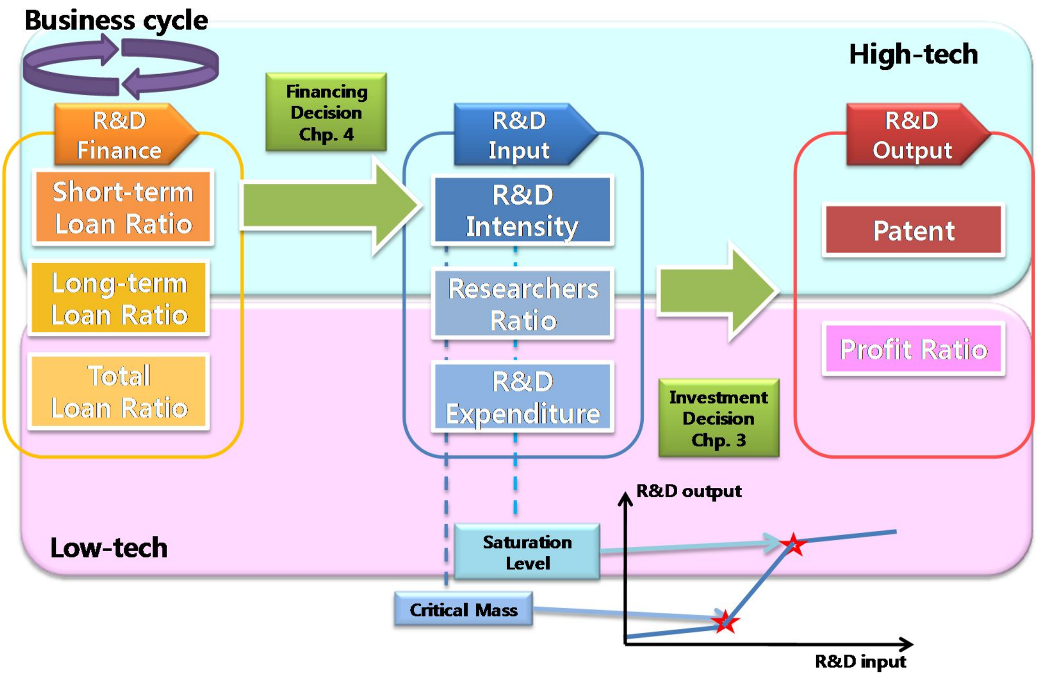

Figure 1. Conceptual outline of this study

1.3 Structure of the study

This study consists of five chapters. Chapter 2 reviews investment and financing decisions for R&D. Since the research area of R&D investment is extensive, issues on how much to invest and how to pay are in focus, and the relevant issues related to the empirical analysis are also reviewed. In Chapter 3, the critical mass and saturation levels are investigated using a cross-section threshold regression model. Based on the presented results, implications and limitations are then discussed. Chapter 4 presents the relationship between loan ratio (as a proxy for capital structure) and R&D intensity (as a proxy for R&D investment). Finally, the empirical results are summarized and policy and strategy to increase R&D investment performance are suggested in Chapter 5.

Chapter 2. Theoretical background

2.1 Review of R&D investment

2.1.1 R&D and innovation outcome

R&D is the main factor behind innovation and technical change (Moncada-Paternò-Castello et al., 2010). Many previous papers have found a relationship between R&D and innovation. For example, Mairesse and Mohnen (2004) assess the impact of R&D on innovation separately for high-tech and low-tech industries and find that R&D investment is positively correlated with process innovation, new product innovation (both new to the firm and new to the market), patent applications, and patent holdings.

The OECD defines R&D as creative work undertaken on a systematic basis in order to increase the stock of knowledge, including individual, cultural, and societal knowledge, and its use to devise new applications. According to Hall et al. (2009), R&D is classified into basic research, applied research, and development, depending on how close the research is to commercial application. In general, the closer it is, the larger is the size of investment. Similarly, a distinction can be made between R&D directed towards the invention of new methods of production ("process R&D") and that towards the creation of new and improved goods ("product R&D"). R&D can also be classified based on its funding source (i.e., private or public) or whether it is carried out by businesses or by other organizations such as universities and research institutes. In addition, based on the proportion of R&D devoted to research, it can be divided into scientific and technical fields. Furthermore, the industry can be labeled as high-tech and low-tech ("technological intensity") based on dividing R&D expenditure by value added and by production (Criscuolo and Martin, 2004).

2.1.2 Economic characteristics of R&D investment

Brealey et al. (2001) state that a company must (i) satisfy its customers in order to survive and prosper and (ii) produce and sell products and services at a profit. In order to produce, it needs many assets, such as a plant, equipment, offices, computers, and technology. Thus, the company has to decide (i) which assets to buy (or how much to buy) and (ii) how to pay for them. The former decision, termed the investment decision, relates to investing in assets such as a plant, equipment, and know-how, whereas the latter decision, termed the financing decision, is the choice of how to pay for such investments.

According to Hall and Lerner (2009), the primary output of R&D investment is the knowledge of how to create new goods and services; this knowledge is non-rival, which means that the firm does not monopolize its output. If knowledge cannot be kept secret, returns cannot be appropriated by the firm, and it will thus be reluctant to invest, leading to underinvestment in R&D. By contrast, the positive externalities derived from R&D include a social return that is higher than the private level (Griliches, 1991). Further, Romer (1986) uses endogenous macroeconomic growth models to suggest that one person’s use of knowledge does not diminish its utility to another person. These positive externalities justify policymakers’ interventions using intellectual property systems, government support of R&D, R&D tax incentives, and the encouragement of research partnerships (Hall and Lerner, 2009).

Hall and Lerner (2009) also claim that R&D has different characteristics compared with ordinary investment. First, the high proportion of wages and salaries for highly educated scientists and engineers create an intangible asset, namely the firm’s knowledge base, from which profits in future years will be generated. Thus, knowledge from R&D investment is tacit and embedded in the human capital of the firm’s employees.

Second, the high level of uncertainty associated with its output tends to be greatest at the beginning of a research program or project, which means that an optimal R&D investment strategy has an options-like character. This suggests that R&D projects that have low probabilities of great success in the future may be worth continuing even if they do not pass an expected rate of return test.

2.1.3 Research topics in R&D investment

The major issues about R&D investment, based on previous studies, are summarized in Figure 2. These issues can be concluded in two questions. First, what is the relation between R&D investment and performance? Second, how can we improve performance from R&D investment? The background of the first question is that innovation and R&D investment are expensive and thus a positive return is desirable in the future (Hall et al., 2009). Ultimately, these two questions are same: how can we improve performance from R&D investment?

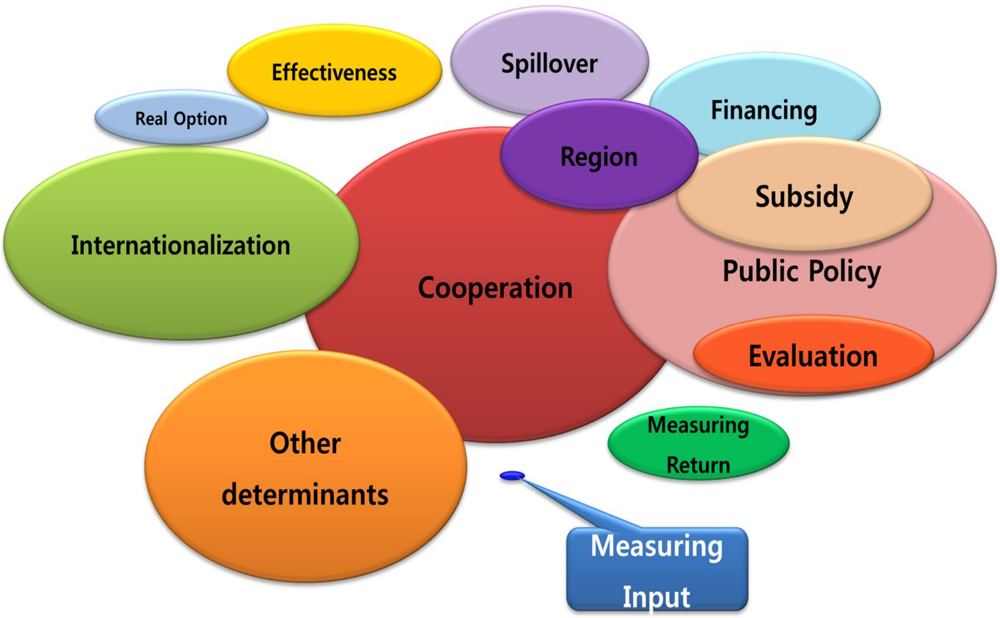

Figure 2. Research topics of R&D investment

According to Del Monte and Papagni (2003), there are three relationships between R&D investment and performance: positive, none, and negative. Table 1 shows that these relationships dependent on R&D investment and performance. Although the majority of papers show a positive relationship, the purpose of elucidating zero or negative relationships is to improve R&D investment in the future.

Table 1. Relation between R&D investment and performance

Author(year)	Sales growth rate	Employment growth rate	Productivity growth rate	Export/sales	Firm Survival	Financial variables
Nolan et al. (1980)	P[a]	P				
Rothwell(1979)				P		
OECD(1986)			P			
Hall(1987)	P					
Thwaites(1982)		P				
Singh(1994)	P					
Geroski(1995)	U[b]	U	U	P		
Cosh et al.(1996)		U		P	P	
Leo and Steiner(1995)		U				
Wakelin(1996)				P		
Geroski et al.(1997)	U					U
Ernst(2001)	P					
Griliches et al.(1991)						U
Lefebvre et al.(1998)	P			P		
Tether and Massini(1998)		P				
O'Mahony(1998)			P			
Roper(1997)				P		
Sherer(1965)	P					P
Austin(1993)						P

[a] Positive related; [b] Unrelated, Source: Del Monte and Papagni (2003)

The R&D paradox as the non-positive relationship between R&D investment and performance means that R&D performance does not increase in line with R&D investment. Ejermo et al. (2011) suggest three reasons for this paradox. The first is malfunctioning national innovation systems. The second is the natural consequence of diminishing returns on increasing R&D investment. The third is that these phenomena may co-exist. Meanwhile, Moncada-Paternò-Castello et al. (2010) find that the lower corporate R&D intensity in the EU is the result of sector specialization and the smaller population of R&D-investing firms within these sectors.

For the second question, many papers have discussed the determinants of better R&D performance following investment. Although there are several main agents for R&D investment, the representative one is firm, which can be subdivided into external and internal determinants. External determinants include policy (David et al., 2000), institutions including innovation systems (Moncada-Paternò-Castello et al., 2010; Ejermo et al., 2011), carbon emissions (Garrone and Grilli, 2010), privatization (Munari et al., 2002), technological intensity (Chiao, 2002; Carpenter and Peterson, 2002; Nunes et al., 2012), business cycle (Saint-Paul, 1993; Ouyang, 2011), and market structure (Griffiths and Webster, 2010; Hashmi and Van Biesebroeck, 2010). Internal determinants include firm size; ownership (Griffiths and Webster, 2010; Czarnitzki and Kraft, 2009; Munari et al., 2010; Ghosh et al., 2007); organizational structure (Christensen, 2002); location, which is related to regional innovation systems with spillover (Lee, 2009; Hewitt-Dundas and Roper, 2011) and the internalization of multinational firms (Guadalupe et al., 2010;

Negassi, 2004); and management strategy such as cooperation (De Marchi, 2012; Kloyer and Scholderer, 2012), which is a general issue in R&D investment.

However, although many issues are studied in R&D investment, most of them analyze qualitatively. Previous literatures including Dosi et al. (2006) indicate that the reason of R&D paradox in Europe is underinvestment, but they don't refer how much R&D investment is insufficient. On the other hand, R&D expenditure is increasing in developed and developing countries (Figure 3). However, increasing R&D expenditure which may be overinvestment, is not always the best policy (Hartmann et al., 2006). In order to determine underinvestment or overinvestment, measuring proper amount of R&D investment has to be preceded.

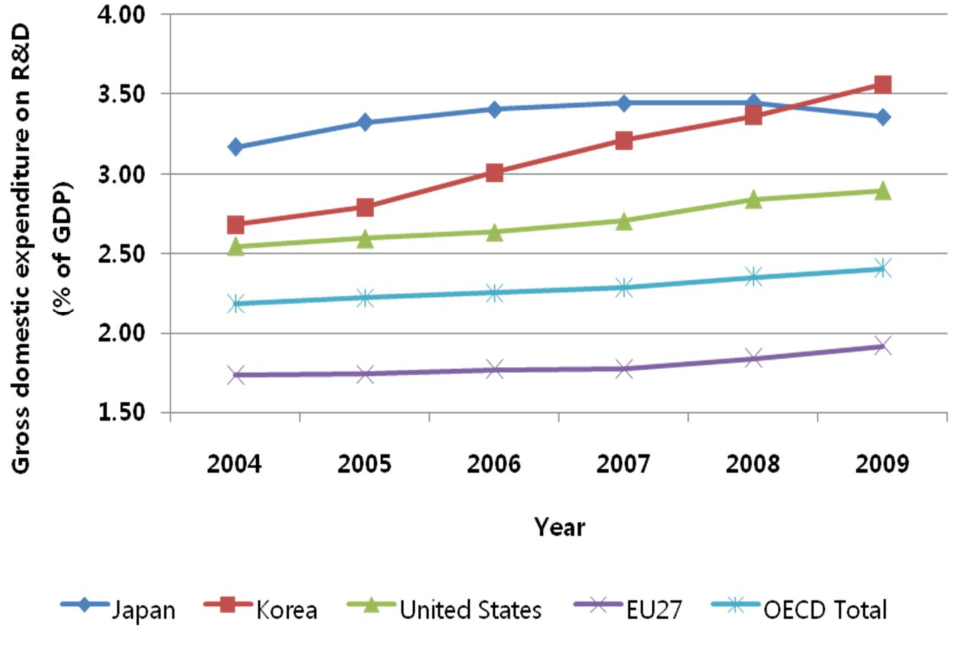

Figure 3. Trend of R&D expenditure, Source: OECD Science and Technology DB

In addition, many scholars have indicated that a higher debt ratio reduces R&D investment (Balakrishnan and Fox, 1993; Bradley et al., 1984; Hall, 1992; Kochhar, 1996; Simerly and Li, 2000; Singh and Faircloth, 2005; Stiglitz and Weiss, 1981; Vincente-Lorente, 2001), whereas others have argued for a positive relation between debt and R&D investment (Chaio, 2002; David et al., 2008; Wang and Thornhill, 2010). In-depth research about relationship between debt and R&D investment is at an early stage, and many researches have to perform.

2.2 Literature reviews

2.2.1 Relevant issues with empirical analysis

Important determinants for this research include public subsidies, technological intensity, and firm size. First, David et al.'s (2000) review suggests that several studies have found a complementarity between public and private R&D investments. Specifically, since a tax credit directly reduces the marginal cost of R&D, one would not expect to see "crowding out" effects on industrial R&D. Therefore, when firms expand their R&D activities through tax offsets against profits, they are likely to select projects that will generate greater profits in the short-term. Ultimately, projects that have high social rates of return and long-term projects may be less favored by the expansion of private funding. The direct funding of R&D programs by the government allows public R&D subsidies to be targeted towards projects that offer high marginal social rates of return. This funding can thus be concentrated in areas where there is a large gap between the social and the private rates of return. Such increased government funding for industrial R&D projects is thus likely to reduce firms' R&D investments.

By contrast, four reasons could stimulate complementary private R&D expenditures in the short run: (i) public R&D contracts increase the efficiency of the firm's R&D by lowering common costs or increasing absorptive capacity; (ii) they signal future demand; (iii) they may improve the chances of the firm's other projects succeeding; and (iv) they allow firms to overcome fixed R&D startup costs. In summary, both micro- and macro-level studies tend to show a complementarity between public and private R&D investments (David et al., 2000).

Moving onto technological intensity, Kamien and Schwartz (1974) refer to partial ignorance as technological uncertainty and market uncertainty. Moreover, Carpenter and Peterson (2002) suggest three reasons why high-tech investment is particularly likely to be affected by capital market imperfections. First, the returns on high-tech investments are highly uncertain because R&D projects have a low probability of financial success. Second, information asymmetries are likely to exist between firms and potential investors (i.e., insiders will have more information than outsiders about their projects). Third, R&D investment in high-tech firms has little value in the event of failure. Physical investment for R&D is likely to be firm-specific and have little collateral value.

Chiao (2002) finds that the high marginal costs of debt discourage firms in science-based industries compared with those in non-science-based industries from borrowing to finance R&D. Meanwhile, Czarnitzki and Hottenrott (2011) state that R&D projects can differ substantially in terms of the uncertainty of their returns, resource requirements, risk of failure, involvement of basic research, and the importance of secrecy and suggest that these properties may affect financing conditions. Nunes et al. (2012) find that many factors may contribute to R&D investment in high-tech SMEs compared with non-high-tech SMEs. These factors include: (i) the product's shorter life cycle and high cost of R&D investment diminish competition and create a need to diversify activities; (ii) continuous, rather than occasional, investment by high-tech SMEs may cultivate more efficient strategies for leading and managing corporate R&D projects; (iii) more highly qualified human resources may be a determinant of the more efficient management of R&D projects; (iv) greater absorptive capacity may promote the more effective use of good management practices in R&D projects; and (v) greater capacity to implement cooperation strategies with similar firms may allow firms to acquire experience benchmarks in R&D project management.

Concerning firm size, according to Czarnitzki and Hottenrott (2011), the role of SMEs is increasingly attracting the attention of scholars and policymakers because of their crucial contributions to technological progress through R&D and innovation. Hoffman et al. (1998) suggest that SMEs are more likely to involve product innovation than process innovation. Further, they are heavily focused on producing products for niche markets rather than mass markets, more frequently organized formally within larger SMEs, and tend to be more ad-hoc or project-driven in smaller SMEs. Nunes et al. (2012) present that SMEs face additional difficulties in managing R&D projects that require qualified human resources and efficient management of technology and information. Ortega-Argilés et al. (2009) comment that SMEs face financial constraints in R&D investment. Finally, Berger and Udell (1998) argue that the degree of informational opacity is a key feature that drives the financial growth cycle and that distinguishes small business finance from large business finance. Furthermore, they show where differently sized firms lie on a size/age/information continuum (see Figure 4).

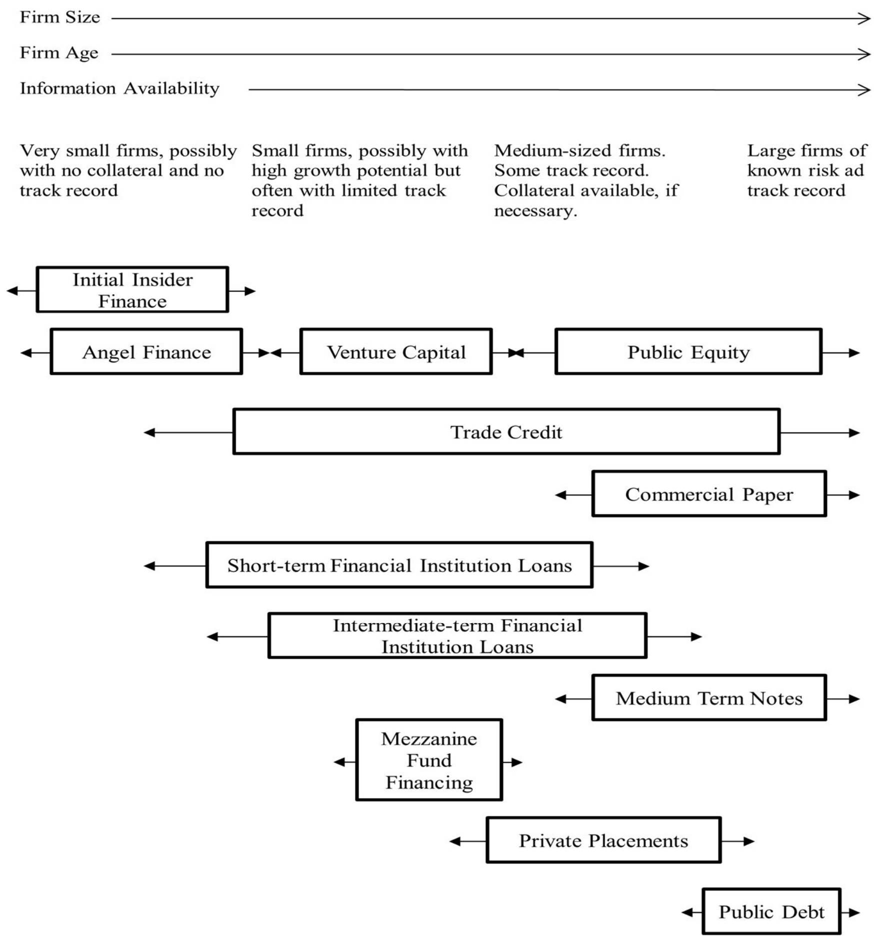

Figure 4. Firm continuum and sources of finance, Source: Berger and Udell (1998)

2.2.2 Thresholds of R&D investment

Although previous studies of R&D investment decisions that explore which R&D assets to buy are common, those that assess how much to invest are relatively scarce. The real option method is generally used in order to select R&D assets. By valuing real R&D options, firms can select R&D projects and buy R&D assets (Paxson, 2003). However, measuring the level of R&D investment is very complicated (Howe and McFetridge, 1976).

On measuring the level of R&D investment, two levels are main concerns. The one is the optimal level or saturation level of R&D investment and the other is the critical mass level. Previous studies have considered the saturation value of R&D resources (David et al., 2000; Howe and McFetridge, 1976). Howe and McFetridge (1976) propose a framework for R&D funding decisions based on firm-level investment behavior. Their equation of the framework can be viewed as a reduced form of the structure that describes the R&D decision-making process of a profit-maximizing firm. Investment in R&D can be assumed to proceed to the point at which the marginal rate of return (MRR) on R&D is equal to the marginal cost of funds (MCF):

$$MRR^{R} = f_1 (R, C_1)$$

$$MCF = f_2 (R, C_2)$$

where R is the R&D expenditure of the firm and C_1 and C_2 are vectors of the shift variables of the MRR and MCF schedules, respectively. Profit maximization implies that R&D investment proceeds to the point (R*) at which MRR^R = MCF (Figure 5).

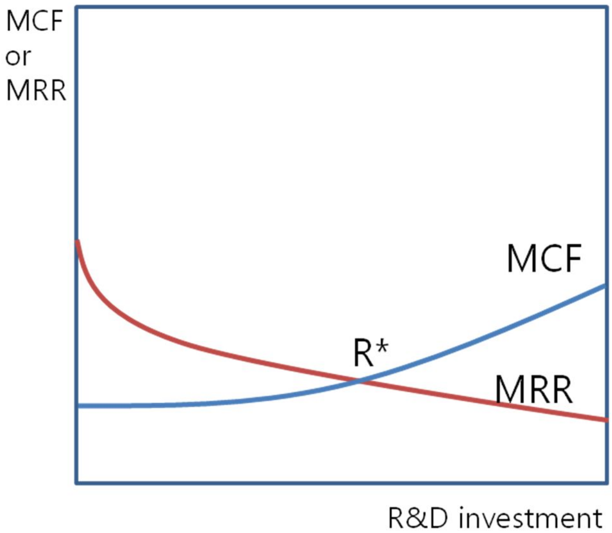

Figure 5. Relationship between MCF and MRR, Source: David et al. (2000)

According to David et al. (2000), the C1 variables reflect: (i) technological intensity, which governs the ease with which it is possible to generate innovations relevant to the firm's market area; (ii) demand status in the potential market area; and (iii) the institutional and other conditions that affect the appropriability of innovation benefits. Correspondingly, the C2 variables include: (i) technology policy, which affects the private cost of R&D projects such as the tax treatment of that class of investment, R&D subsidies, and the cost-sharing programs of government procurement agencies; (ii) the macroeconomic conditions and expectations that affect the internal cost of funds with the general state of price/earnings ratios in equity markets; (iii) the bond market conditions that affect the external cost of funds; and (iv) the availability and terms of venture capital finance, as influenced by institutional conditions such as the development of IPO markets and the tax treatment of capital gains.

Meanwhile, previous research has only discussed the existence of the critical mass level in R&D investment. For instance, Grabowski and Mueller (1978) mention that significant critical mass may be necessary for R&D projects to be carried out efficiently, while Galbraith (1993) argues that R&D is subject to minimum project sizes in order to generate useful results because of technical indivisibilities, while Sterlacchini (2008) insists that attaining the critical mass is crucial insofar as there are increasing returns from R&D.

2.2.3 External financing of R&D investment

Modigliani and Miller (1958) argue that a firm that chooses the optimal levels of investment should be indifferent to its capital structure and should face the same price for investment and R&D investment on the margin. However, their opinion is controversial and it might not hold for the following reasons: (i) the uncertainty related to incomplete markets may make a real options approach to the R&D investment decision more appropriate; (ii) the cost of capital may differ by source of funds for non-tax and tax reasons; and (iii) the cost of capital may differ across types of investments for both tax and other reasons (Hall and Lerner, 2009).

According to Hall (2002) and Hall and Lerner (2009), there might be a gap between the external and internal costs of capital because of asymmetric information between inventor/entrepreneur and investor, and moral hazard on the part of the inventor/entrepreneur arising from the separation of ownership and management.

The asymmetric information problem means that an inventor frequently has better information about the probability of success and the nature of the contemplated R&D investment compared with potential investors. Thus, the "lemons premium" (Akerlof, 1970) for R&D will be higher than that for ordinary investments, because investors have more difficulty distinguishing good projects from bad when projects are long-term (Leland and Pyle, 1977). According to Leland and Pyle (1977), two problems hamper firms that sell information directly to investors, namely the appropriability of returns by the firm and the credibility of selling information. It may thus be difficult or even impossible for potential users to distinguish between good and bad information. When the level of R&D expenditure is highly observable, the lemons problem is somewhat mitigated, but certainly not eliminated.

Reducing information asymmetry through fuller disclosure is partially effective because of the ease of the imitation of inventive ideas. Firms avoid revealing their innovative ideas to the market because of the associated heavy cost and lost competitive advantage. Therefore, firms and inventors face higher costs of external compared with internal capital for R&D because of the lemons premium.

With respect to asymmetric information, David et al. (2008) insist that because relational debt is private and does not require public information disclosure, this limits the appropriation of proprietary knowledge from R&D by competitors. From this point of view, debt heterogeneity can affect the relationship between debt and R&D investment in different ways.

Moral hazard in R&D investment frequently arises, since firms typically separate ownership and management. Moral hazard can arise in two cases. The first one is the tendency of managers to spend on activities that benefit them and the second is the reluctance of risk-averse managers to invest in uncertain R&D projects. Jensen and Meckling (1976) define agency costs as the sum of the monitoring expenditures incurred by the principal, the bonding expenditures incurred by the agent, and the residual loss. In their opinion, agency costs of the first type can be avoided by reducing the amount of free cash flow available to managers by leveraging. However, firms have to use higher-cost external funds in order to finance R&D. In the second scenario, if bankruptcy risk increases, both managers and potential bondholders may avoid highly uncertain projects that shareholders would like to undertake. The solution to this second type of agency cost would be to increase the long-term incentives faced by the manager. Although debt may be a useful tool for reducing agency costs in the firm, its effectiveness is limited because the knowledge generated by the R&D investment shows specificity and appropriability. Therefore, debtholders prefer to use physical assets to secure loans and are reluctant to lend for R&D investment. Indeed, Opler and Titman (1994) find that highly leveraged firms that engage in R&D suffer the most in economically distressed periods.

However, the moral hazard problem will be diminished for SMEs because the managers and owners are often the same. Furthermore, according to David et al. (2008), the low liquidation asset value of R&D investment is not a serious problem for relational lenders, as they can be forbearing and help the firm through liquidity problems, thus preserving the value of such investments. In particular, when the government guarantees the debt through an R&D investment support policy, it can be a trivial problem.

Chapter 3. The measurement of the threshold of R&D investment

3.1 Introduction

This research investigates two threshold values, the critical mass and saturation levels of R&D investment (Figure 6). The measurement of critical mass, which requires a minimum amount of effort or resources to increase R&D performance, and saturation level, which decreases the growth rate of R&D performance, can offer basic facts and implications about R&D policy and strategy.

Although threshold value is a subject of scholarly attention in many areas of social science research, there has been little focus on this field in R&D investment research. In particular, although the concept and importance of critical mass for R&D investment have been referred to in previous studies (Galbraith, 1993; Grabowski and Mueller, 1978; Sterlacchini, 2008), a concrete measure of critical mass is unchartered territory. Meanwhile, although Yeh et al. (2010) estimate the optimal level for R&D, which is similar with saturation level, they do not consider the time lag between investment and performance, which is a crucial factor for the analysis of R&D investment.

This study thus empirically measures the critical mass and saturation levels for R&D investment using the threshold estimation model proposed by Hansen (2000). I find that there are critical mass levels for R&D intensity and expenditure in high-tech industries when R&D performance is a number of patent, but not in low-tech industries because of their contrasting characteristics. Critical mass exists in high-tech industries because of the prevailing high technological entry barriers and high uncertainty. When R&D performance is a gross profit ratio, there are only saturation levels in both high-tech and low-tech industries because there are more considerations related to profit such as business cycle and marketing strategies. I thus show that the threshold values in R&D investment are different by technological intensity and R&D performance.

This chapter is organized as follows. Section 2 introduces the literatures regarding critical mass and saturation level. Section 3 suggests the empirical model consisting of econometric specifications and data description. Section 4 interprets the results, and the final section contains discussion and concluding remarks.

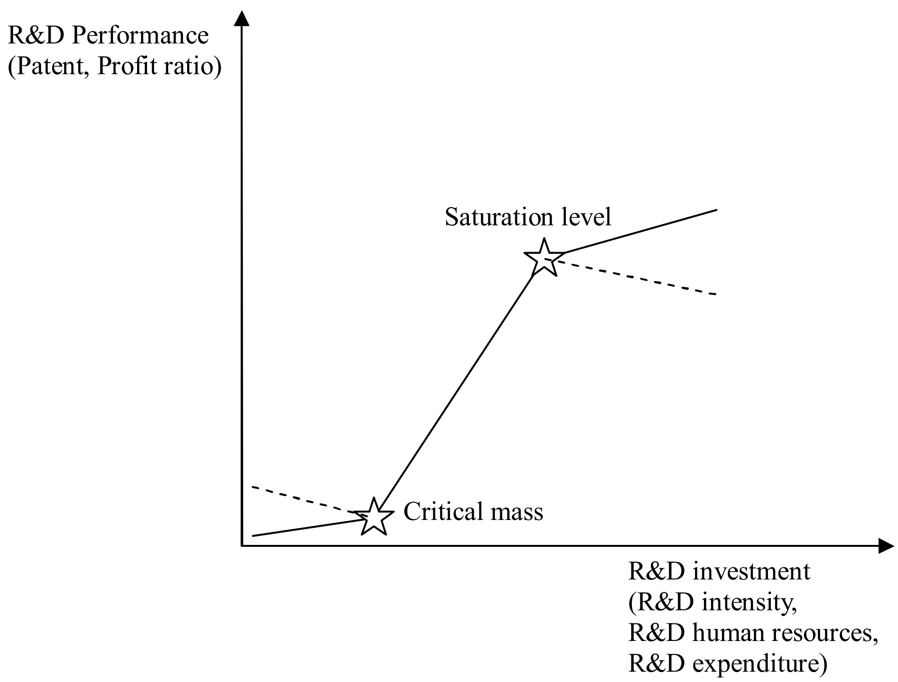

Figure 6. The concept of critical mass and saturation level

3.2 Literature reviews

3.2.1 Critical mass of R&D investment

In its original form, critical mass represents Heisenberg's informal estimate of the amount of uranium required (or threshold) for the atomic bomb (Logan, 1996). However, in the present context, it is also recognized in business and economics as a synonym for "economies of scale," "entry barrier," "breakeven point," "threshold effect" and "the S-Curve" (Terpstra, 1983). In social science, Rogers (2003) uses critical mass to describe the existence of a sufficient amount of adopters of an innovation in a social system such that the rate of adoption becomes self-sustaining and creates further growth. At this point, critical mass defines the point at which the early adopter stage becomes the early majority stage. In this regard, the analysis of the time to reach the critical mass is important, as this is related to the point of inflection in the relationship between the cumulative number of innovation adopters and time.

Meanwhile, although previous research has discussed the existence and the importance of critical mass in R&D investment, few papers have suggested a concrete measure. Grabowski and Mueller (1978) mention that significant critical mass may be necessary for R&D projects to be carried out efficiently, while Galbraith (1993) argues that a minimum level of R&D investment is necessary to generate useful results because of technical indivisibilities. Sterlacchini (2008) insists that attaining the critical mass is crucial insofar as there are increasing returns from R&D.

The reason that critical mass which is a synonym for “entry barrier” exists is technological entry barrier in knowledge and scale that may be represented by high expenditure (Orr, 1974). The technological entry barrier is different in technological intensities and it in high-tech industries is generally higher than that in low-tech industries (Marsili, 2002). The fiercer competition in high-tech industries (Agarwal, 1998) can increase the strength of entry barrier. Even though technological entry barrier doesn’t exist, critical mass can exist because of uncertainty in R&D investment. Because achieving a R&D performance to overcome uncertainty requires a high cost or critical mass. Therefore, as high-tech industries show a higher level of uncertainty (Hall and Lerner, 2009) and a higher technological entry barrier, critical mass level in low-tech industries may be lower than that in high-tech industries or not measurable because it is very low. Finally, the existence of critical mass can different in R&D performances. In particular, critical mass may not exist when R&D performance is profitability because entry barrier may not have a strong effect on profitability (Wu, 2009). Furthermore, profitability is also affected by business cycle and marketing strategy as well as R&D investment.

3.2.2 Saturation level of R&D investment

Although previous studies resources (David et al., 2000; Howe and McFetridge, 1976; Huang and Liu, 2005; Yeh et al., 2010) refer to the optimal value of R&D investment, these adopt various R&D performance indices to estimate the optimal level. Since R&D investment has a positive spillover effect, other elements of R&D performance will also increase in parallel even if investment in R&D exceeds the optimal level. Therefore, this study uses the term “saturation level” instead of optimal level.

Previous studies have considered the saturation value of R&D resources (David et al., 2000; Howe and McFetridge, 1976). Howe and McFetridge (1976) propose a framework for R&D funding decisions based on firm-level investment behavior. Their equation of the framework can be viewed as a reduced form of the structure that describes the R&D decision-making process of a profit-maximizing firm. Investment in R&D can be assumed to proceed to the point at which the MRR on R&D is equal to the MCF. Performance maximization implies that R&D investment proceeds to the point at which MRR = MCF.

Huang and Liu (2005) find that investment of innovation capital has a non-linear (inverted U-shaped) relationship with firm performance and estimate the saturation level using R&D investment squared term, while Yeh et al. (2010) estimates the saturation level of R&D intensity using the threshold regression model. However, Huang and Liu (2005) and Yeh et al. (2010) don’t consider the time lag that has the greatest impact on the relationship between R&D investment and performance.

3.3 Method and data

3.3.1 Method

Similar to the method used to assess innovation diffusion, threshold value can measured from the relationship between R&D performance and time. Hall (2005) analyzes the time when patenting explores in the US using a test for structural change of Zivot and Andrew (1992) and Andrew (1993). Rafferty (2008) elucidates the relationship between university R&D activities and the Bayh–Dole Act in the US using the same test as that adopted in Hall (2005). However, since this test for structural change is based on time-series analysis, it requires sufficient annual data. Therefore, data available over a short period are inappropriate for analysis. Further, because the method estimates the time at which R&D performance is rapidly changing, the point of structural change does not always mean the threshold value.

The second method is the threshold estimation described by Hansen (2000). Equations (1) and (2) can be formally treated as a special case of the threshold regression model:

$$y_i = \theta_1' x_i + e_i, q_i \leq \gamma \quad \cdots\cdots \text{Eq. (1)}$$
$$y_i = \theta_2' x_i + e_i, q_i > \gamma \quad \cdots\cdots \text{Eq. (2)}$$

where q_i is the threshold variable that is used to divide the sample into two groups and g is the threshold value. The random variable e_i is a regression error. Hansen's (2000) approach is to let $\delta_n = \theta_1 - \theta_2$ denote the threshold effect and let $\delta_n \to 0$ as $n \to \infty$. Further, he holds θ_1 fixed and makes θ_2 approach θ_1 as $n \to \infty$. This model allows the regression parameters to differ depending on the value of q_i. To rewrite the model in a single equation, let us define $I(q_i \le \gamma)$ where I() is the indicator function and set $x_i(\gamma) = x_i I(q_i \le \gamma)$. Thus, equations (1) and (2) now equal equation (3):

$$y_i = \theta_2^{'} x_i + \delta_n^{'} x_i(\gamma) + e_i \quad \cdots\cdots \text{Eq. (3)}$$

To express the model in matrix notation, we define the n*1 vectors Y and e by stacking the variables y_i and e_i, and the n*m matrices X and X_g by stacking the vectors $x_i^{'}$ and $x_i(\gamma)'$. Then, equation (3) can be written as:

$$Y = \theta X + \delta_n X_\gamma + e \quad \cdots\cdots \text{Eq. (4)}$$

The regression parameters are $(\theta, \delta_n, \gamma)$, and the natural estimator is least squares (LS) estimator.

Let

$$SE_n(\theta,\delta,\gamma) = (Y - X\theta - X_\gamma \delta)'(Y - X\theta - X_\gamma \delta) \quad \cdots\cdots \text{Eq. (5)}$$

be the function of the sum of squared errors. Then, by definition, the LS estimators

$\hat{\theta}, \hat{\delta}, \hat{\gamma}$ jointly minimize equation (5). For this minimization, g is assumed to be restricted to a bounded set $[\underline{\gamma}, \overline{\gamma}] = \Gamma$. The computationally easiest method to obtain the LS estimates is through concentration. Conditional on g, equation (6) is linear in j and δ_n, yielding the OLS estimators $\hat{\theta}(\gamma)$ and $\hat{\delta}(\gamma)$ by regression of Y on $X_\gamma^* = [X, X_\gamma]$. The concentrated sum of the squared errors function is $S_n(\gamma) = S_n(\hat{\theta}(\gamma), \hat{\delta}(\gamma), \gamma) = Y'Y - Y'X_\gamma^*(X_\gamma^*{}'X_\gamma^*)^{-1}X_\gamma^*{}'Y$, and $\hat{\gamma}$ is the value that minimizes $S_n(\gamma)$. $\hat{\gamma}$ can be defined as $\hat{\gamma} = \arg\min_{\gamma \in \Gamma_n} S_n(\gamma)$, where $\Gamma_n = \Gamma \cap \{q_1, \ldots, q_n\}$, which requires less than n function evaluations.

After estimating $\hat{\gamma}$, the slope coefficient j_1, j_2 can be estimated by OLS,

$$\hat{\theta}_1(\gamma) = (X_\gamma^*{}'X_\gamma^*)^{-1}X_\gamma^*{}'Y, q_i \le \hat{\gamma} \quad \cdots\cdots \text{Eq. (6)}$$
$$\hat{\theta}_2(\gamma) = (X_\gamma^*{}'X_\gamma^*)^{-1}X_\gamma^*{}'Y, q_i > \hat{\gamma} \quad \cdots\cdots \text{Eq. (7)}$$

The hypothesis of no threshold effect in (1) and (2) can be represented by the linear constraint

$$H_0: j_1 = j_2$$

Under H_0, the threshold g is not identified, and thus classical tests have non-standard distributions. To solve this problem, Hansen (1996) suggests a bootstrap method to simulate the asymptotic distribution. Under the null hypothesis of no threshold, the model is thus

$$y_i = \theta_1' x_i + e_i \quad \text{Eq. (8)}$$

Under homoskedasticity, the test of H_0 is based on the F-test, whereas under heteroskedasticity, the test of H_0 is based on the Lagrange Multiplier (LM) test. According to Hansen (1996), let $S_n(\gamma) = \frac{1}{\sqrt{n}} \sum_{i=1}^{n} x_i(\gamma)\tilde{e}_i(\gamma)$ [1] and $\{S(\gamma_1), S(\gamma_2), ..., S(\gamma_k)\}$ be the multivariate normal with mean zero and covariances $E(S(\gamma_j)S(\gamma_l))$. The null distribution has a chi-squared distribution and thus the test takes the form

$$T_n(\gamma) = S_n(\gamma)M_n(\gamma,\gamma)^{-1}R'(RM_n(\gamma,\gamma)^{-1}\hat{V}_n(\gamma)M_n(\gamma,\gamma)^{-1}R')^{-1}RM_n(\gamma,\gamma)^{-1}S_n(\gamma)' \quad \text{Eq. (9)}$$

where $\hat{V}_n(\gamma) = \frac{1}{n}\sum_{i=1}^{n} \tilde{s}_i(\gamma)\tilde{s}_i(\gamma)$, $s_i(\gamma) = x_i(\gamma)e_i$, $\tilde{s}_i(\gamma) = x_i(\gamma)\tilde{e}_i$ ($\tilde{e}_i$: e_i under H_0), R=(0Ip)', $M_n(\gamma,\gamma) = \frac{1}{n}\sum_{i=1}^{n} x_i(\gamma)'x_i(\gamma)$, $S_n(\gamma) = \frac{1}{\sqrt{n}}\sum_{i=1}^{n} x_i(\gamma)\tilde{e}_i$.

Hansen (1996) shows that p-values constructed from the bootstrap are asymptotically

[1] The Hansen test for parameter constancy statistics is based on the cumulative sums of $x_i e_i$ (Johnston and DiNardo, 1997).

valid.[2]

For j=1,…, J (repeat time), execute the following steps:

1) generate $\{v_{ij}\}_{i=1}^{n}$ iid N(0,1) random variables (using a random number generator)

2) set $S_n^j(\gamma) = \frac{1}{\sqrt{n}} \sum_{i=1}^{n} x_i(\gamma)\tilde{e}_i v_{ij}$ (under heteroskedasticity)

3) set $T_n^j(\gamma) = S_n^j(\gamma) M_n(\gamma,\gamma)^{-1} R'(RM_n(\gamma,\gamma)^{-1} \hat{V}_n(\gamma) M_n(\gamma,\gamma)^{-1} R')^{-1} RM_n(\gamma,\gamma)^{-1} S_n^j(\gamma)'$

4) $p = (1/J)\sum_{j=1}^{J} \{\max T_n^j(\gamma) \geq \max T_n(\gamma)\}$

Then, draw a sample of size n from the empirical distribution and use these errors to create a bootstrap sample under H_0. Repeat this procedure many times and calculate the percentage of draws for which the simulated statistic exceeds the actual. The null of no threshold effect is rejected if the p-value is smaller than the desired critical value.

[2] According to Johnston and DiNardo (1997, pp. 366–367), this procedure is similar to "residual resampling," which is the most common form of bootstrapping in time-series applications. For J, first draw a sample of size n with replacements from the set of rescaled residuals. Second, construct new dependent variables. Then, draw an adjusted residual randomly with replacements and add it to generate a new dependent variable.

3.3.2 Data

The R&D data used in this study were collected from the Survey of Research and Development in Korea (SRDK), which was first carried out in 1963. The purposes of the SRDK are to investigate annually R&D (in terms of human resources and expenditure) in Korea and to supply the basic data for national R&D policymaking and planning. These data are also used as OECD statistics on R&D activity. In addition, patent data were obtained from the Korea Institute of Patent Information. Financial data were mainly collected from Korea Enterprise Data and Korea Investors Service, which are leading corporate credit agencies in Korea.

To investigate the critical mass and saturation levels of R&D investment, this study focuses on SMEs in the manufacturing sector that have a two-digit code between 10 and 33 according to Korea's Standard Industrial Classification (SIC2) in 2007. After omitting outliers based on the dependent and independent variables, the final sample contained 2,748 SMEs.

The OECD classifies technology and industry into the following four categories: high technology, medium-high technology, medium-low technology, and low technology. This classification is based on technological intensity indicators, namely R&D expenditures divided by value added and R&D expenditures divided by production in OECD countries (Criscuolo and Martin, 2004). Based on the above-described OECD classification, the total sample was divided into two categories, high-tech industries (n = 2,226; represented by the high technology and medium-high technology categories and including the chemical, pharmaceuticals, medical, electronics, machinery, and motor vehicle industries) and low-tech industries (n = 522; medium-low technology and low technology). Table 2 shows the number of SMEs by SIC2.

Table 2. Number of SMEs by SIC2

	SIC2	N
High-tech (2,226)	20-Chemicals and chemical products	286
	21-Basic pharmaceutical products and pharmaceutical preparations	97
	26-Computer, electronic and network products	621
	27-Medical, precision, optical and watch products	263
	28-Electrical equipment	268
	29-Machinery and equipment	493
	30-Motor vehicles, trailers and semi-trailers	163
	31-Other transport equipment	35
Low-tech (522)	10-Food products	70
	11-Beverages	5
	12-Tobacco products	1
	13-Textiles	47
	14-Wearing apparel	13
	15-Leather and related products	9
	16-Wood and of products of wood and cork, except furniture	3
	17-Paper and paper products	7
	18-Printing and reproduction of recorded media	6
	19-Coke and refined petroleum products	12
	22-Rubber and plastics products	104
	23-Other non-metallic mineral products	53
	24-Basic metals	53
	25-Fabricated metal products, except machinery and equipment	117
	32-Furniture	6
	33-Other manufacturing	16

3.3.3 Variables

In the analysis, the number of patent applications (LNP) and gross profit ratio (GPR) were used as dependent variables. Even the successful completion of a scientific project such as a patent does not guarantee future profit (Ben-Zion, 1984). However, many papers have considered the generation of patents as the outcome of R&D, suggesting that applying patent statistics as a proxy of firm performance and R&D activities is relevant (Pavitt, 1985; Griliches, 1990; Kondo, 1999; Cohen et al., 2002; Iwasa and Odagiri, 2004; Beneito, 2006). Further, although previous papers have used return on assets or return on equity as proxies of R&D performance (Huang and Liu, 2005; Yeh et al., 2010), the ratio of gross profit to net sales to exclude the effect of depreciation and tax was used in this research.

The determinants of R&D performance in this study thus consist of the following five factors (see Table 3). As independent variables, there are three types of R&D investment, namely R&D intensity (RINT), R&D human resources (RHR), and R&D expenditure (REXP). RINT is calculated by dividing R&D expenditure by net sales (Balakrishnan and Fox, 1993; Hitt et al., 1991; Titman and Wessels, 1988; Wang and Thornhill, 2010). RHR is the ratio of researchers to employees, while REXP is the total R&D expenditure including government policy funds (i.e., the R&D total item in the SRDK). R&D investments are lagged by two years for patents and by three years for profit ratio, because previous research has assumed a time lag between R&D input and output (Hwang et al., 2009; Wang, 2007; Wang and Thornhill, 2010).[3] The control variables include firm size (SIZE), which is measured by the logarithm of total assets, firm age (AGE) from inception, and the debt ratio of liabilities to total assets (DEBTR). The average ratio of operating income to total assets (IND) for the sample SMEs is reflected in the industrial characteristics.

Tables 4 and 5 present the descriptive statistics for patents and profit ratio, respectively. R&D investment (i.e., RINT, RHR, and REXP) in high-tech industries is higher than that in low-tech industries, as is the total debt ratio. LNP and GPR as R&D performances in high-tech industries are higher than those in low-tech industries. Moreover, Tables 6 to 9 show that the bivariate correlations. DEBTR is negatively associated with LNP and GPR. SIZE and R&D investment are positively correlated with LNP, while SIZE and REXP are negatively correlated with GPR.

[3] In general, firms apply for patents after finishing the R&D process. More time is spent on making a profit from R&D (Hwang et al., 2009). Therefore, this study sets a different time lag for patents and profit ratio.

Table 3. Definition of variables

Variables		Definition
Patent	LNP	Log_{10}(number of patent application+ 1)
Profit ratio	GPR	Gross profit / Net sales
	RINT	R&D total expenditure / Net sales
	L2RINT	$RINT_{t-2}$
	L3RINT	$RINT_{t-3}$
	RHR	Researcher / Employee
R&D investment	L2RHR	RHR_{t-2}
	L3RHR	RHR_{t-3}
	REXP	Log_{10}(R&D total expenditure (Unit:1,000 KRW))
	L2REXP	$REXP_{t-2}$
	L3REXP	$REXP_{t-3}$
Firm size	SIZE	Log_{10} (Total assets[a])
Age	AGE	Establishment year – Year + 1
Debt ratio	DEBTR	Liabilities / Total assets
Industrial characteristics	IND	Average of (Operating profit / Total assets) in 2 digit SIC

[a] Adjusted by Producer Price Index(PPI)

Table 4. Descriptive statistics for patent

Variables	High-tech			Low-tech		
	N	Mean	S.D.	N	Mean	S.D.
LNP	1,195	0.279	0.346	318	0.212	0.312
DEBTR	1,195	0.529	0.221	318	0.535	0.217
SIZE	1,195	7.181	0.547	318	7.353	0.528
AGE	1,195	1.086	0.282	318	1.199	0.287
IND	1,195	0.041	0.017	318	0.047	0.013
L2RINT	1,112	0.055	0.053	309	0.030	0.038
L2RHR	1,195	0.205	0.182	318	0.113	0.124
L2REXP	1,195	5.685	0.461	318	5.530	0.447

Table 5. Descriptive statistics for profit ratio

Variables	High-tech			Low-tech		
	N	Mean	S.D.	N	Mean	S.D.
GPR	1,718	0.240	0.121	388	0.201	0.100
DEBTR	1,718	0.535	0.213	388	0.545	0.213
SIZE	1,718	7.003	0.535	388	7.147	0.532
AGE	1,718	1.081	0.226	388	1.171	0.238
IND	1,718	0.041	0.016	388	0.047	0.012
L3RINT	1,554	0.069	0.064	370	0.044	0.054
L3RHR	1,718	0.229	0.188	388	0.123	0.113
L3REXP	1,718	5.592	0.469	388	5.467	0.404

Table 6. Bivariate correlation coefficients for patent in high-tech firms[a]

High-tech	LNP	DEBTR	SIZE	AGE	IND	L2RINT	L2RHR
DEBTR	-0.08 (0.01)						
SIZE	0.13 (0.00)	-0.22 (0.00)					
AGE	-0.08 (0.00)	-0.16 (0.00)	0.50 (0.00)				
IND	-0.05 (0.10)	0.19 (0.00)	-0.03 (0.26)	0.10 (0.00)			
L2RINT	0.09 (0.00)	-0.02 (0.57)	-0.40 (0.00)	-0.34 (0.00)	-0.10 (0.00)		
L2RHR	0.07 (0.02)	-0.02 (0.42)	-0.51 (0.00)	-0.45 (0.00)	-0.21 (0.00)	0.55 (0.00)	
L2REXP	0.22 (0.00)	-0.27 (0.00)	0.61 (0.00)	0.27 (0.00)	-0.11 (0.00)	0.12 (0.00)	-0.09 (0.00)

[a] P-values are shown in parentheses.

Table 7. Bivariate correlation coefficients for patent in low-tech firms[a]

High-tech	LNP	DEBTR	SIZE	AGE	IND	L2RINT	L2RHR
DEBTR	-0.08 (0.17)						
SIZE	0.13 (0.00)	-0.28 (0.00)					
AGE	-0.03 (0.64)	-0.32 (0.00)	0.54 (0.00)				
IND	0.07 (0.23)	0.06 (0.29)	0.01 (0.87)	-0.04 (0.43)			
L2RINT	0.06 (0.31)	0.07 (0.21)	-0.46 (0.00)	-0.35 (0.00)	-0.09 (0.11)		
L2RHR	0.05 (0.36)	0.12 (0.03)	-0.50 (0.00)	-0.50 (0.00)	-0.04 (0.46)	0.52 (0.00)	
L2REXP	0.24 (0.00)	-0.18 (0.00)	0.54 (0.00)	0.26 (0.00)	0.06 (0.25)	0.11 (0.04)	-0.14 (0.01)

[a] P-values are shown in parentheses.

Table 8. Bivariate correlation coefficients for profit ratio in high-tech firms[a]

High-tech	GPR	DEBTR	SIZE	AGE	IND	L3RINT	L3RHR
DEBTR	-0.21 (0.00)						
SIZE	-0.27 (0.00)	-0.13 (0.00)					
AGE	-0.19 (0.00)	-0.14 (0.00)	0.43 (0.00)				
IND	-0.16 (0.10)	0.11 (0.00)	0.04 (0.12)	0.20 (0.00)			
L3RINT	0.37 (0.00)	0.02 (0.40)	-0.42 (0.00)	-0.37 (0.00)	-0.16 (0.00)		
L3RHR	0.32 (0.00)	-0.04 (0.14)	-0.48 (0.00)	-0.47 (0.00)	-0.29 (0.00)	0.54 (0.00)	
L3REXP	-0.05 (0.03)	-0.05 (0.03)	0.53 (0.00)	0.12 (0.00)	-0.12 (0.00)	0.18 (0.00)	-0.01 (0.58)

[a] P-values are shown in parentheses.

Table 9. Bivariate correlation coefficients for profit ratio in low-tech firms[a]

High-tech	GPR	DEBTR	SIZE	AGE	IND	L3RINT	L3RHR
DEBTR	-0.20 (0.00)						
SIZE	-0.30 (0.00)	-0.22 (0.00)					
AGE	-0.22 (0.00)	-0.27 (0.00)	0.49 (0.00)				
IND	-0.02 (0.67)	-0.06 (0.24)	0.05 (0.34)	0.00 (0.98)			
L3RINT	0.31 (0.00)	0.16 (0.00)	-0.53 (0.00)	-0.38 (0.00)	-0.01 (0.80)		
L3RHR	0.36 (0.00)	0.11 (0.03)	-0.53 (0.00)	-0.42 (0.00)	0.06 (0.22)	0.53 (0.00)	
L3REXP	-0.04 (0.49)	-0.07 (0.17)	0.38 (0.00)	0.14 (0.01)	0.08 (0.12)	0.13 (0.01)	-0.02 (0.72)

[a] P-values are shown in parentheses.

3.4 Results

Table 10 provides the results to the White test. This study uses the bootstrap method to approximate the LM test under heteroskedasticity and F-statistics under homoskedasticity. The White test shows that all errors in the models are heteroskedastic and thus this study employs the heteroskedasticity-consistent LM test to ascertain Hansen's (1996) threshold.

Table 10. White test (P-value)

	High-tech			Low-tech		
LNP	Model 1 (L2RINT)	Model 2 (L2RHR)	Model 3 (L2REXP)	Model 4 (L2RINT)	Model 5 (L2RHR)	Model 6 (L2REXP)
	0.000	0.000	0.000	0.001	0.001	0.000
GPR	Model 7 (L3RINT)	Model 8 (L3RHR)	Model 9 (L3REXP)	Model 10 (L3RINT)	Model 11 (L3RHR)	Model 12 (L3REXP)
	0.000	0.000	0.000	0.082	0.001	0.049

Tables 11 and 12 show the empirical results when R&D performance is defined as the number of patent applications by high-tech firms and low-tech firms, respectively. Tables 13 and 14 show the same empirical results when R&D performance is proxied by gross profit ratio. The p-values for the LM statistics are derived from repeating the bootstrap procedures 1,000 times for each of the bootstrap tests and the values are found to be significant except Models 2, 4, 11 and 12, which means that there are no threshold values.

Table 11. Empirical results for patent in high-tech firms[a]

Patent	Model 1 (L2RINT)				Model 2 (L2RHR)				Model 3 (L2REXP)			
Estimated threshold	0.014				-				5.477			
Critical mass/saturation level	Critical mass				-				Critical mass			
Variable	Below threshold		Over threshold		Below threshold		Over threshold		Below threshold		Over threshold	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
R&D investment	1.716	4.811	0.671***	0.251					-0.026	0.045	0.212***	0.049
SIZE	0.072*	0.043	0.218***	0.029					0.054*	0.032	0.047	0.032
DEBTR	0.164*	0.085	-0.107	0.054					-0.043	0.066	-0.056	0.058
AGE	-0.171**	0.078	-0.214***	0.046					-0.135***	0.055	-0.263***	0.053
IND	-0.133	1.297	0.661	0.734					-2.591***	0.999	1.016	0.777
Constant	-0.262	0.346	-1.046***	0.208					0.225	0.274	-0.996***	0.288
Observations	183		929						357		839	
R^2	0.05		0.08						0.05		0.07	
LM test for no threshold	37.45				14.71				25.06			
Bootstrap P-value	0.00				0.26				0.00			

[a] P-values for LM-statistics are from repeating the bootstrap procedures 1,000 times for each of the bootstrap tests. *** , ** and * indicate significance at the 1, 5 and 10% level, respectively.

Table 12. Empirical results for patent in low-tech firms[a]

Patent	Model 4 (L2RINT)				Model 5 (L2RHR)				Model 6 (L2REXP)			
Estimated threshold	-				0.061				6.216			
Critical mass/saturation level	-				Saturation level				Saturation level			
Variable	Below threshold		Over threshold		Below threshold		Over threshold		Below threshold		Over threshold	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
R&D investment					2.768**	1.365	0.105	0.164	0.084**	0.040	0.308	0.320
SIZE					0.150***	0.057	0.116***	0.047	0.036	0.035	-0.560	0.369
DEBTR					0.186*	0.103	-0.328***	0.122	-0.097	0.082	-0.297	0.329
AGE					-0.110	0.091	-0.053	0.100	-0.173***	0.062	2.040***	0.350
IND					1.156	1.720	1.967	1.603	0.974	1.174	-105.593***	35.415
Constant					-1.075***	0.458	-0.448	0.379	-0.320	0.251	6.024**	3.064
Observations					144		174		305		13	
R^2					0.08		0.09		0.04		0.69	
LM test for no threshold	15.58				22.27				18.19			
Bootstrap P-value	0.14				0.00				0.00			

[a] P-values for LM-statistics are from repeating the bootstrap procedures 1,000 times for each of the bootstrap tests. *** , ** and * indicate significance at the 1, 5 and 10% level, respectively.

Table 13. Empirical results for profit ratio in high-tech firms[a]

Profit ratio	Model 7 (L3RINT)				Model 8 (L3RHR)				Model 9 (L3REXP)			
Estimated threshold	0.047				0.088				5.587			
Critical mass/saturation level	Saturation level				Saturation level				-			
Variable	Below threshold		Over threshold		Below threshold		Over threshold		Below threshold		Over threshold	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
R&D investment	1.133***	0.283	0.409***	0.073	0.492**	0.235	0.083***	0.022	0.005	0.010	-0.021	0.016
SIZE	-0.037***	0.009	-0.020**	0.009	-0.027**	0.012	-0.044***	0.007	-0.093***	0.009	-0.053***	0.012
DEBTR	-0.102***	0.017	-0.171***	0.020	-0.116***	0.025	-0.125***	0.016	-0.088***	0.017	-0.172***	0.020
AGE	0.024	0.016	-0.021	0.022	0.067***	0.023	-0.055***	0.017	-0.028	0.018	-0.056***	0.020
IND	-0.643***	0.250	-0.445*	0.248	-1.314***	0.371	-0.121	0.203	-0.252	0.250	-0.969***	0.249
Constant	0.491***	0.068	0.493***	0.063	0.399***	0.087	0.667***	0.054	0.933***	0.072	0.936***	0.086
Observations	767		787		426		1292		843		875	
R^2	0.12		0.16		0.14		0.13		0.19		0.17	
LM test for no threshold	27.95				44.44				30.55			
Bootstrap P-value	0.00				0.00				0.00			

[a] P-values for LM-statistics are from repeating the bootstrap procedures 1,000 times for each of the bootstrap tests. *** , ** and * indicate significance at the 1, 5 and 10% level, respectively.

Table 14. Empirical results for profit ratio in low-tech firms[a]

Profit ratio	Model 10 (L3RINT)				Model 11 (L3RHR)				Model 12 (L3REXP)			
Estimated threshold	0.082				-				-			
Critical mass/saturation level	Saturation level				-				-			
Variable	Below threshold		Over threshold		Below threshold		Over threshold		Below threshold		Over threshold	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
R&D investment	1.548***	0.512	0.235	0.143								
SIZE	-0.009	0.013	-0.002	0.023								
DEBTR	-0.107***	0.026	-0.284***	0.039								
AGE	-0.061***	0.025	-0.034	0.043								
IND	-0.254	0.464	0.372	0.879								
Constant	0.360***	0.103	0.414**	0.184								
Observations	249		121									
R^2	0.15		0.28									
LM test for no threshold	25.02				9.31				14.95			
Bootstrap P-value	0.00				0.73				0.14			

[a] P-values for LM-statistics are from repeating the bootstrap procedures 1,000 times for each of the bootstrap tests. *** , ** and * indicate significance at the 1, 5 and 10% level, respectively.

Next, the coefficients of R&D investment are used in order to classify the threshold values into the critical mass and saturation levels. This study defines the critical mass as the coefficient of R&D investment when R&D investment is larger than the threshold value ("over threshold" group, O group) is significantly positive and the coefficient of R&D investment when R&D investment is smaller than the threshold value ("below threshold" group, B group) is insignificant. This definition suggests that R&D performance significantly increases as R&D investment rises when the amount of R&D investment is above the critical mass.

This study defines saturation level as follows. First, the significantly positive coefficient of R&D investment in the B group is bigger than the significant coefficient of R&D investment in the O group. This means that the growth rate of R&D performance decreases. Second, the coefficient of R&D investment in the B group is significantly positive, while that in the O group is not significant, which indicates that the growth rate of R&D performance has disappeared.

With respect to patent applications in high-tech firms, Models 1 and 3 show the critical mass exists. These models indicate that R&D performance clearly increases at the point which R&D intensity attains 1.4 % or R&D expenditure reaches approximately 300 million KRW[4](see Figure 7). In other words, if R&D intensity (or R&D expenditure) is below 1.4% (or 300 million KRW), R&D investment is ineffective. By contrast, in low-tech firms, there is no critical mass for R&D investment, and only the saturation levels in Models 5 and 6 exist. If the ratio of researchers to employees is over 6.1% or if R&D

---

[4] $10^{5.477}$ thousand KRW

expenditure is over 1.6 billion KRW[5], R&D investment can be inefficient.

In summary, when using patents as a proxy of R&D performance, there is a critical mass related to financial investment (i.e., R&D intensity and R&D expenditure) in high-tech industries, whereas there is no critical mass in low-tech industries. These results may come from the characteristic differences between high-tech and low-tech industries. Since the technological entry barriers and uncertainty in high-tech industries are higher than that in low-tech industries, higher costs must be incurred to achieve a R&D performance.

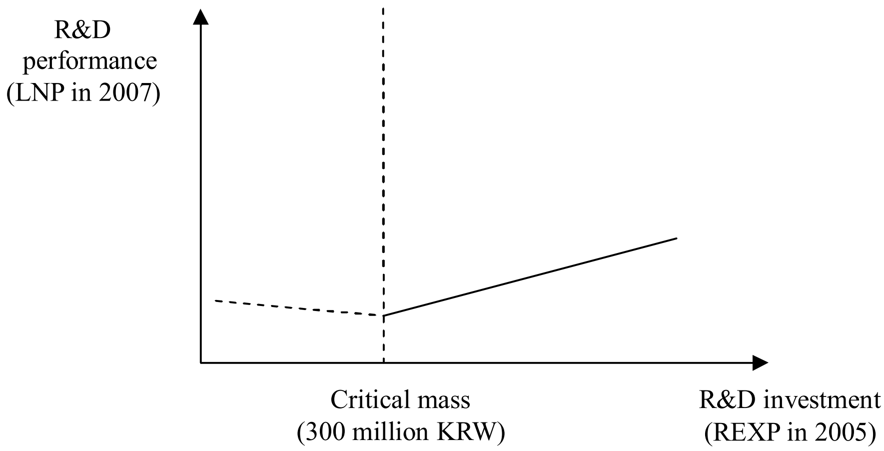

Figure 7. Critical mass for patent

In terms of gross profit ratio, only saturation levels are measured in Models 7, 8 and 10. For high-tech firms, if R&D intensity is over 4.7% (Figure 8) or the researchers to employees ratio is over 8.8%, growth rate of R&D performance decreases. With respect to low-tech firms, growth rate of R&D performance sustains until when R&D intensity

[5] $10^{6.216}$ thousand KRW

attains 8.2%. There may be two reasons that the critical mass is non-existent for both high-tech and low-tech firms. First, technological entry barrier may not have a strong effect on profitability. Second, there are more considerations related to profit such as business cycle and marketing strategies.

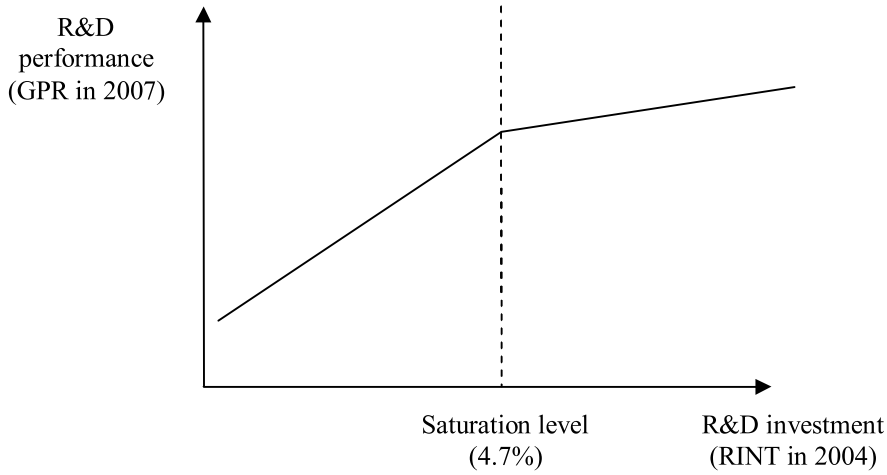

Figure 8. Saturation level for profit ratio

3.5 Discussion

This study empirically investigates the critical mass and saturation levels for R&D investment using threshold regression method. The results presented herein are shown to differ based upon R&D performance and technological intensity. In terms of patent applications, there are critical mass levels for R&D intensity and R&D expenditure in high-tech industries, but none in low-tech industries. Critical mass can exist in high-tech industries because of high technological entry barriers and high uncertainty. In the case of profit performance, however, only the saturation level exists, perhaps because technological entry barrier does not have a strong influence on profitability or because profitability is influenced by business cycle and marketing strategies.

Table 15 shows that the ratio is below threshold. Approximately 17% for R&D intensity and 30% for R&D expenditure of high-tech firms do not exceed the critical mass in terms of patent applications. If those high-tech firms that do not attain the critical mass increased their R&D investments to the level of the critical mass, they could accomplish much greater R&D performance. Therefore, relevant firms have to make a strategy to increase R&D investment. Since SMEs are likely to face difficulties in financing and managing R&D investment, the government needs to consider further how to support high-tech firms that are below the critical mass, particularly high-tech firms which are breaking new ground. Meanwhile, low-tech firms that exceed the saturation level must consider formulating R&D strategies that aim to increase efficiency through the rearrangement of resources. If the government supports the R&D activities of low-tech firms above the saturation level, it needs to contemplate the redistribution of public R&D funds in order to increase social R&D performance.

Table 15. Ratio below threshold for patent (%)[a]

High-tech Critical mass			Low-tech Saturation level		
Model 1 (L2RINT)	Model 2 (L2RHR)	Model 3 (L2REXP)	Model 4 (L2RINT)	Model 5 (L2RHR)	Model 6 (L2REXP)
16.5	-	29.8	-	45.3	95.9

[a] This ratio is equal to the number of SMEs for which R&D investment is below the threshold divided by all SMEs.

The extension of this research would be desirable, including considering more specific technological characteristics and allowing for cumulative R&D investment and other proxies of R&D performance such as sales growth and total factor productivity growth. Furthermore, comparison analysis using different time periods and countries would be interesting subjects for future research.

Chapter 4. The effect of capital structure on R&D investment

4.1 Introduction

Many studies (Balakrishnan and Fox, 1993; Bradley et al., 1984; Hall, 1992; Kochhar, 1996; Simerly and Li, 2000; Singh and Faircloth, 2005; Stiglitz and Weiss, 1981; Vincente-Lorente, 2001) have pointed out that a higher debt ratio causes firms to invest less in R&D. According to them, because R&D investment with high asset specificity, uncertainty, and appropriability offers poor collateral to assets, banks tend to be reluctant to lend to small firms preferring R&D investment. In addition, highly leveraged firms are supposed to invest less in R&D than in other physical assets because a heavier pressure from significant principal redemption within a year may make the firms financially inflexible and prevent them from sustaining R&D investment.

Nevertheless, a bank loan has been an important source of funds for firms to sustain their growth. Especially for small and medium enterprises (hereafter SMEs), it has served as a critical funding source (Berger and Udell, 1998; Meyer, 1998), accounting for over 90% of new external financial sources (David et al., 2008; Mayer, 1988). As a result, debt financing can also be an important source of R&D investment in the real world, especially in countries with a bank-oriented financial system such as Korea.

This study suggests that there must be no correlation between loan ratio and R&D

investment explaining the entire economy because a larger amount of long-term loans can encourage more R&D investment while a larger amount of short-term loans can depress R&D.

Based on this finding, this study uncovers two interesting results based on the stage of the business cycle as well as technological intensity. First, due to the different contributions of long-term and short-term loans to R&D investment, the relation between total loans and R&D investment reveals negative and positive direction in high-tech and low-tech industries respectively. In high-tech industries, R&D projects face more uncertainties and require a longer period from conceptualization to commercialization than in low-tech industries. Therefore, high-tech firms are more sensitive to short-term loan ratio in sustaining R&D investment even if the increase of long-term loans encourages R&D investment. Furthermore, because the negative effect of short-term loans on R&D investment is large enough to offset the positive one of long-term loans, total loans and R&D investment in high-tech industries show a negative relationship. On the other hand, because R&D projects in low-tech industries are usually based on a shorter payback period of investment; low-tech firms are relatively less sensitive to short-term loans. As a result, there are positive relationships between total loans and R&D investment in low-tech industries.

Second, the positive effect of long-term loans on R&D investment shows a counter-cyclical pattern while the negative effect of short-term loans shows a pro-cyclical pattern. This finding may be contrary to the generally accepted idea explaining the positive and negative relationship between loan ratio and R&D investment in times of economic upturn and downturn, respectively. In an upturn, the firms are less sensitive to the amount of short-term loans they hold because they can refinance maturity and extend loan maturities. However, an increase in long-term loans can contribute less to R&D investment because the firms prefer obtaining loans for investment in physical assets rather than in R&D, and they also prefer equity financing for funding R&D projects. On the other hand, in times of economic downturn, R&D investment is contracted to a larger extent by an increase in short-term loans because the firms are financially inflexible due to fewer opportunities to refinance or rollover and they are burdened with paying back existing loans. At the same time, they can be incentivized to invest more in R&D as long-terms loan increase because the firms focus on R&D investment to prepare for a coming upturn period.

This chaper is organized as follows. Section 2 reviews previous literature regarding the relation between loan ratio and R&D investment and suggests theoretical hypotheses. Section 3 describes the econometric models. Section 4 interprets the results, and the final section contains concluding remarks.

4. 2 Literature reviews

4.2.1 Relationship between R&D investment and debt

There have been two common notions regarding the financing for R&D. First, firms prefer internal sources for financing R&D projects because their higher asymmetric information and more principal-agent conflicts can cause higher costs of capital as compared to the financing of other physical assets (Hall, 1992; Hall and Lerner, 2009; Himmelberg and Petersen, 1994). Also, According to Giudici and Paleari (2000) and Oakey and Cooper (1991), self-generated profits are the main finance source for innovation in firms. Second, firms prefer equity financing to debt financing if they raise the funding for R&D externally since the project becomes sizable (Carpenter and Petersen, 2002).

In financing R&D externally, firms frequently observe that lenders tend to be reluctant to fund R&D investment as it is generally based on intangible assets that offer poor collateral to the lenders (Williamson, 1988). Even if they succeed in obtaining debts, firms experience difficulties in sustaining R&D investment due to the rigidity of debt contracts that impairs the financial flexibility of borrowing firms (O'Brien, 2003). In addition, debt financing has been considered inappropriate for mitigating the adverse selection of lenders and the moral hazard of borrowers because lenders are restrictive in accessing and reviewing detailed qualitative and subjective information on borrowers'

R&D projects (Hall, 1992; Stiglitz and Weiss, 1981). Based on these reasons, there is substantial empirical evidence of the negative association between debt ratio and R&D intensity (Balakrishnan and Fox, 1993; Bradley et al., 1984; Hall, 1992; Kochhar, 1996; Simerly and Li, 2000; Singh and Faircloth, 2005; Stiglitz and Weiss, 1981; Vincente-Lorente, 2001).

However, there are some studies criticizing the dichotomous conclusion that debt financing would be more inappropriate for R&D investment. First, debt financing can be useful for R&D investment in specific industries. For example, Chiao (2002) showed that debt is a useful resource to finance R&D investment in non-science-based industries while not in science-based industries because the latter usually faces higher risks, holds more R&D capital stocks, invests proportionately more in R&D, and consequently causes higher costs of debt than the former does. Second, relational debt financing can improve a firm's value until the debt ratio approaches a certain level. Only after passing the level does the high debt ratio start to increase hazards of bankruptcy of the firms and discourages them from investing in R&D. For example, Wang and Thornhill (2010) show an inverted U-shaped relation between relational debt ratio and R&D intensity. Finally, relational debt finance can be more appropriate than issuance of bonds for encouraging R&D investment because it reduces a lot of hazards and uncertainties in carrying out R&D by binding lenders and borrowers more closely (David et al., 2008). That is to say, banks can support firms of borrowers in retaining their R&D projects by softening the terms of debt contract such as refinancing or extending maturities and by providing additional business services such as letters of credit, check clearance, and cash management. Moreover, banks can monitor and guide the firms to prevent them from going the wrong way because banks have accumulated proprietary and subjective information on client firms for a long time and they sometimes obtain seats on their clients' boards of directors (Diamond, 1984; Diamond, 1991; Fama, 1985).

Since SMEs are usually owner-managed, the owner/managers often have strong incentives to issue external debt rather than external equity in order to keep ownership and control of their firms (Berger and Udell, 1998). In particular, the ratio of loan to external fund is very large for SMEs in Korea (Table 16).

Table 16. Ratio of external fund for SMEs in Korea (%)

Year	From Bank	From Government	From Non-bank financial institution	Equity	Corporate Bond	Bond	From Foreign financial institution
2003	73.2	19.4	3.4	0.5	0.5	2.1	0.9
2004	72.7	19.8	3.3	0.6	0.3	3.1	0.2
2005	72.2	22.7	2.8	0.0	0.3	1.3	0.8
2006	71.9	24.8	1.5	0.3	0.4	0.9	0.2
2007	74.3	21.7	2.1	0.0	0.4	1.2	0.2

Source: Small & Medium Business Administration database (http://stat2.smba.go.kr/dbsearch_re_01.jsp)

According to Canepa and Stoneman (2003), Giudici and Paleari (2000), and Oakey and Cooper (1991), self-generated profits are the main finance source for firms.[6] However, Canepa and Stoneman (2003) insist that bank finance makes an important role for innovation. Furthermore, Giudici and Paleari (2000) show that bank loan including

[6] In Korea, the ratio of self-generated funds in R&D investment is about 60% and it is increasing based on SRDK data

bank overdrafts and commercial credit are more frequently employed in the earlier-development stage (Table 17).

In addition, KfW (Kreditanstalt für Wiederaufbau) in Germany and ICO (Instituto de Crédito Oficial) in Spain offer long-term loans with maturity form four to fifteen years to SME for investing in R&D (NEFI, 2005). In Korea, public credit guarantee institutions such as Korea Technology Finance Corporation (KTFC) support banks to offer long-term loan to SMEs, encouraging them to invest in long-term R&D.

In sum, self-generated profits are the most important source for R&D investment generally. However, loan, especially long-term loan, is also crucial financing source for R&D investment. Furthermore, the influence of loan can be different upon technological intensity and business cycle.

Table 17. Importance of different sources of finance in the earlier-development stages[a]

Industry	Mechanics	Electronics	Information technology
Self-generated profits	77%	73%	82%
Entrepreneurs' personal savings	23%	18%	24%
Equity capital form existing shareholders	54%	27%	59%
New individual shareholders	23%	18%	6%
New corporate shareholders	0%	9%	6%
VCs or merchant banks	0%	9%	0%
Short-term credit	77%	45%	53%
Commercial credit	54%	45%	41%
Long-term credit	31%	27%	29%
Long-term facilitated credit	38%	45%	6%

[a] The percentages represent the number of firms who attributed the first two ranks in a three point scale, with higher score indicating a higher perceived importance of the corresponding source.
Source: Giudici and Paleari (2000)

4.2.2 Relationship between R&D investment and loan maturity

Usually, a firm takes a short-term loan with a maturity date within one year to cover any operating expenses. Simultaneously, it obtains long-term loans to expand production capacity, and pays it back after one year, usually within three or five years. All activities for R&D of a firm can be affected by combined effects between short-term and long-term loan.

However, most previous studies do not consider maturity as an important factor in deciding on the level of R&D investment. Although a few studies (Aivazian et al., 2005; Scherr and Hulburt, 2001) elucidate the relationship between debt maturity and investment, they do not focus on loan maturity and R&D investment.

Since R&D investment has higher uncertainties, more hazards, and requires longer payback period of investment from conceptualization to commercialization (Hall, 2002; Hall and Lerner, 2009); it must be more sensitive to loan maturity than ordinary investment. Consequently, long-term loans can at least contribute to R&D investment. Chiao (2002) showed the positive relation between long-term debt ratio and R&D investment. In addition, Brealey et al. (2001) advised that matching maturities of assets and liabilities is important. In other words, long-term financing with long-term loans can be beneficial for R&D as relatively long-lived assets.

A financially constrained condition of a firm from an increase in short-term loans could be a factor that negates the positive effect of long-term loans on R&D investment.

According to financial theory, there are positive as well as negative contributions of short-term loans to corporate investment. According to many studies (Barclay and Smith, 1995; Flannery, 1986; Kale and Noe, 1990; Myers, 1977), the capital structure of firms with more opportunity sets for growth holds more short-term loans or debts, and the firms with good credit rating prefer raising short-term loans. This is because the increase of short-term loans can signal to capital markets that the financial condition of the borrower is strong as well as flexible, and that the borrower is about to exercise one of its growth options. In addition, because short-term loans can be usually obtained at lower interest than long-term loans, they can ensure financial flexibility to the firm allowing it to invest in various investment options, including R&D investment.

On the other hand, the increase in short-term loans causes higher liquidity risks than long-term loans do because short-term loans require principal redemption within a year (Diamond, 1991). This financial distress can depress R&D investment as well as other physical investment, leading a firm to pay more attention to operating expenses. This depression would be serious in SMEs that are more cash-starved and more dependent on bank loans (García-Teruel and Martínez-Solano, 2007; Titman and Wessels, 1988).

Hypothesis 1a. A firm's R&D intensity is positively associated with long-term loan ratio.
Hypothesis 1b. A firm's R&D intensity is negatively associated with short-term loan ratio.

The combined effect of Hypothesis 1a and 1b can reveal a completely different relationship between total loan ratio and R&D intensity in high-tech and low-tech industries.

According to Agarwal (1998) and Carpenter and Petersen (2002), as compared to low-tech industries, the return on investment in high-tech industries is highly uncertain and only a few of the projects manage to breakeven. Moreover, there are many asymmetries of information because it is quite difficult for players other than banks to access and review R&D projects. In addition, the R&D investment in high-tech assets is based on low liquidation value because R&D expenditure is used to hire skilled workers such as scientists or engineers and purchase the facilities specific to the R&D project (Hall and Lerner, 2009). Additionally, because R&D projects in high-tech industries require a payback period of over three or five years, an increase in short-term loan ratio makes a firm financially inflexible and inhibits long-term investments such as R&D. As a result, the impact of liquidity risks on R&D investment must be higher in high-tech industries than in low-tech ones. The negative effect of short-term loans in high-tech firms may be large enough to offset the positive effect of long-term loans.

However, R&D projects in low-tech industries show less information asymmetry as compared to those in high-tech industries and frequently require a payback period of investment (Ettlie et al., 1993). Therefore, even if there is a negative relation between short-term loan ratio and R&D investment, it is not big enough to eliminate the positive effect of long-term loans on R&D investment.

Hypothesis 2a. R&D intensity of firms in high-tech industries is negatively associated with total loan ratio.

Hypothesis 2b. R&D intensity of firms in low-tech industries is positively associated with total loan ratio.

There are a few scholarly works focusing on the changes in R&D investment in times of economic upturn and downturn, which especially mention that R&D investments show a pro-cyclical pattern. For example, Aghion et al. (2008) find that R&D investment decreased during a downturn while it did not increase proportionally in an upturn. In addition, Bloom (2007) shows that higher uncertainties during downturns caused firms to depress R&D investment, especially firms with tight credit constraints.

The pattern of R&D investment can be explained according to the stage of business cycle in terms of short-term and long-term loan ratios: An increase in short-term loan ratio can depress R&D investment to a lesser extent during times of economic upturn because most of the firms can refinance maturity loans, extend loan maturities easily, and so on. At the same time, it is uncertain whether an increase in long-term loan ratio activates R&D investment to a larger extent because it leads to investment in the expansion of physical facilities, and not in R&D. Instead, R&D projects can be better funded from equity markets at relatively low cost without principal redemption in times of economic upturn. On the other hand, an increase in short-term loan ratio depresses R&D investment to a larger extent during times of economic downturn because the firms tend to keep them on their losses for principal redemption. However, the increase in long-term loan ratio can contribute more to R&D investment in spite of a downturn because it may be optimal for the firm to carry out new R&D projects for commercialization in upcoming times of economic upturn.

Eventually, due to mixed reactions of short-term and long-term loans to R&D investment at different stages of the business cycle, there is no clear consensus explaining the relation between total loans and R&D investment.

Hypothesis 3a. Relationship between long-term loan ratio and R&D intensity shows a counter-cyclical pattern.

Hypothesis 3b. Relationship between short-term loan ratio and R&D intensity shows a pro-cyclical pattern.

Table 18 summarizes the hypotheses in this study.

Table 18. Summary of hypotheses

	R&D intensity	R&D intensity by characteristics of industry		R&D intensity by stage of business cycle		
		High Tech	Low Tech	Upturn	Downturn	
Long-term loan ratio	Positive (H 1a)	Positive	Positive	Weak positive	Strong Positive	Counter-cyclical (H 3a)
Short-term loan ratio	Negative (H 1b)	Strong Negative	Weak Negative	Weak Negative	Weak Negative	Pro-cyclical (H 3b)
Total loan ratio	Inconclusive	Negative (H 2a)	Positive (H 2b)	Inconclusive	Inconclusive	

4.3 Method and data

4.3.1 Method

This study applied the random effect model for panel analysis. Because R&D intensity differs systematically by industries, the model should include industry dummies to control industrial effect on R&D investment. This study cannot select between the fixed or the random effect models based on the result of Hausman test because industry dummies are perfectly collinear with the constant variables if the fixed effect model is applied. In addition, it is known that a random sample is estimated by random effect model (Wooldridge, 2003). An alternative is the least squares dummy variable (LSDV) model, a fixed effect model to include dummy variables, that can be applied. However, there is a disadvantage of losing the properties of panel data in an LSDV model.

4.3.2 Data

Data are collected mainly from the Korea Enterprise Data (KED) and Korea Investors Service (KIS) that are leading corporate credit agencies in Korea. To show the relationship between loan ratio and R&D investment clearly, this study focused on unlisted SMEs in the manufacturing sector from 2003 until 2007. After deleting outliers based on R&D expenditure and total assets as well as firms without any R&D investment, our final sample consisted of 16,479 SMEs with 41,501 observations.

The definitions of high-tech and low-tech industries are based on the Organization for Economic Cooperation and Development (OECD) guideline. It classifies an industry into one of four categories: high technology, medium-high technology, medium-low technology, and low technology based on technological intensity indicators such as R&D expenditures divided by value added or sales by industries (Criscuolo and Martin, 2004). The OECD classification is reduced to two industries: high-tech industry[7] and low-tech industry[8]. As a result, the number of firms in high-tech (low-tech) industries is 10,144(6,335) with 27,057(14,444) observations.

The definitions of economic upturn and downturn are based on the growth rate of GDP and bank loans outstanding in Korea (Table 19). During the 2000s, the Korean economy has shown fluctuations. In spite of the collapse of the IT bubble in 2000, the Korean economy recovered at a fast pace during 2001 and 2002. However, the expansion of credit card companies caused serious defaulting on credit card debt and the domestic economy was in a depression until 2005. From 2006, the economy recovered as export markets expanded, especially due to the fast growth of the Asian and BRICS economies and this continued until the global crisis in 2008. This paper classifies the period between 2003 and 2005 as an economic downturn and the period between 2006 and 2007 as an upturn.

---

[7] Chemicals and chemical products; Basic pharmaceutical products and pharmaceutical preparations; Computer, electronic and network products; Medical, precision, optical and watch products; Electrical equipment; Machinery and equipment; Motor vehicles, trailers and semi-trailers; Other transport equipment

[8] Food products; Beverages; Tobacco products; Textiles; Wearing apparel; Leather and related products; Wood and of products of wood and cork except furniture; Paper and paper products; Printing and reproduction of recorded media; Coke and refined petroleum products; Rubber and plastics products; Other non-metallic mineral products; Basic metals; Fabricated metal products except machinery and equipment; Furniture; Other manufacturing

Table 19. Growth of GDP and bank loans in Korea (%)

	2002	2003	2004	2005	2006	2007	2008	2009
Growth of GDP	7.2	2.8	4.6	4.0	5.2	5.1	2.3	0.3
Growth of bank loan	24.8	14.1	1.7	6.6	14.5	24.6	20.1	2.9

Source : Bank of Korea (www.bok.or.kr)

4.3.3 Variables

The dependent variable R&D intensity (R&D) was calculated by dividing R&D expenditures by total sales. Numerous studies (Balakrishnan and Fox, 1993; Hitt et al., 1991; Titman and Wessels, 1988; Wang and Thornhill, 2010) have measured R&D intensity based on the above definition. In this study, six factors are assumed to affect R&D intensity. The first determinant is the size of firm (SIZE) measured by the logarithm value of total assets. The second is return on asset (ROA) as a proxy for free cash flow or internally reserved fund in the firm. To measure free cash flow or internally reserved fund, the statement of cash flow should be investigated. However, while credit rating agencies, the data source of this study, collect balance sheet and profit/loss statements of SMEs, the cash flow statements could only be collected from 10% of the sample SMEs.. Mainly, the relationship between cash flow and R&D investment has been known to be positive because of capital market imperfections (Hall, 1992; Himmelberg and Petersen, 1994). However, some studies (Fiegenbaum and Thomas, 1988; Hitt et al., 1991) suggest opposite evidence that there can be a negative relationship between them because corporate managers tend to take more risk-averse stance as their firms perform well. The third captures the growth of a firm (GROWTH), measured by the growth of total assets. In general, a fast-growing firm tends to invest actively in R&D investment (Balakrishnan and Fox, 1993; Ogawa, 2007; Titman and Wessels, 1988).The fourth and the fifth are industrial dummies based on the two-digit Standard Industrial Classification (SIC) and year dummies. Finally, the primary variables in this study are the loan ratios consisting of total loan ratio (TTLR), short-term loan ratio (STLR), and long-term loan ratio (LTLR). They are proxies for financial constraints of SMEs. Table 20 presents the definitions

Table 20. Definition of variables

Variables		Definition
R&D	R&D Intensity	R&D expenditure_{it}/Net Sales_{it}
SIZE	Firm size	Log_{10} (Total Assets^{a}_{it})
ROA	ROA	Net Income_{it}/Total Assets_{it}
GROWTH	Firm growth	(Total Assets^{a}_{it}/Total Assets^{a}_{it-1})-1
TTLR	Total loan ratio	(Long-term Loan_{it}+Short-termLoan^{b}_{it})/Total Assets_{it}
LTLR	Long-term loan ratio	Long-term Loan_{it}/ Total Assets_{it}
STLR	Short-term loan ratio	Short-term Loan^{b}_{it}/Total Assets_{it}

[a] Adjusted by GDP deflator
[b] Including 'Current portion of Long-term Loan' and Current portion of Long-term Loan-Foreign Currencies'

The model used in this study is as follows:

$$R\&D_{it} = \alpha + \beta_1 SIZE_{it} + \beta_2 ROA_{it} + \beta_3 GROWTH_{it} + \beta_4 LR_{it} + \sum_{j=1}^{n} \eta_j INDUSTRY_{ij} + \sum_{j=1}^{m} d_j YEAR_j + u_i + e_{it}$$

Here, LR_{it} means the loan ratio of firm i at year t consisting of total (TTLR), long-term (LTLR), or short-term loan ratio (STLR).

Table 21 shows the descriptive statistics pertaining to the main variables in the model and the bivariate correlations between them. As expected, the firms in high-tech industries show R&D intensity (5.3%) and growth rate (22.6%) higher than 3.0% and 17.3% of R&D-performing firms in low-tech industries, respectively. In addition, high-tech firms show the ratio of bank loans to total assets (36.7%) slightly lower than that of low-tech firms (41.5%). Especially, short-term loan accounts for approximately 50% of total loan in both high-tech and low-tech firms. This implies that the financial constraints from short-term loans influence the SMEs' decision of investment in R&D. In terms of the correlation between variables, total loan ratio and R&D intensity show positive correlation, although it is weakly significant with a value of 0.02.Long-term loan ratio and R&D intensity are positively correlated while short-term loan ratio and R&D intensity are negatively correlated in both high-tech and low-tech industries.

Table 22 describes the trend of R&D intensity and loan ratio over time. Remarkably, exceeding the short-term loan ratio, the long-term loan ratio increased sharply from 2006 that was treated as the beginning year of economic upturn in this study. During the same period, R&D intensity also increased from 4.3% in 2003 to 4.7% in 2006 and 4.8% in 2007. This implies that the correlation between long-term loan ratio and R&D intensity may be positive. On the other hand, short-term loan ratio reduced from 19.9% in 2003 to 18.9% during the economic downturn in 2005 and reversed to an increase to 19.7% during the economic upturn in 2007.

Table 21. Descriptive statistics[a].

	Variables	Mean	S.D.	1	2	3	4	5	6
Whole N=41,501	1. R&D	0.045	0.080						
	2. SIZE	6.680	0.496	-0.19					
	3. ROA	0.046	0.093	-0.14	-0.13				
	4. GROWTH	0.207	0.405	0.06	-0.05	0.18			
	5. TTLR	0.383	0.198	0.02	-0.10	-0.24	0.06		
	6. LTLR	0.188	0.185	0.07	-0.24	-0.05	0.13	0.58	
	7. STLR	0.195	0.175	-0.06	0.14	-0.22	-0.06	0.51	-0.40
High-tech N=27,057	1. R&D	0.053	0.088						
	2. SIZE	6.667	0.499	-0.18					
	3. ROA	0.046	0.102	-0.17	-0.13				
	4. GROWTH	0.226	0.426	0.04	-0.04	0.19			
	5. TTLR	0.367	0.196	0.02	-0.10	-0.23	0.06		
	6. LTLR	0.182	0.180	0.07	-0.23	-0.05	0.13	0.60	
	7. STLR	0.185	0.170	-0.05	0.12	-0.22	-0.06	0.52	-0.37
Low-tech N=14,444	1. R&D	0.030	0.060						
	2. SIZE	6.705	0.491	-0.23					
	3. ROA	0.045	0.073	-0.05	-0.15				
	4. GROWTH	0.173	0.359	0.08	-0.05	0.14			
	5. TTLR	0.415	0.196	0.07	-0.11	-0.28	0.10		
	6. LTLR	0.200	0.193	0.12	-0.26	-0.06	0.15	0.56	
	7. STLR	0.214	0.183	-0.06	0.16	-0.24	-0.06	0.48	-0.46

[a]All correlations with an absolute value greater than .02 are significant at $p < .01$

Table 22. Trend of R&D intensity and loan ratio (%).

Year	R&D	Total loan ratio (TTLR)	Long-term loan ratio (LTLR)	Short-term loan ratio (STLR)
2003	4.3	37.2	17.4	19.9
2004	4.2	37.5	17.6	20.0
2005	4.2	36.7	17.8	18.9
2006	4.7	38.6	19.4	19.1
2007	4.8	40.4	20.7	19.7
Total	4.5	38.3	18.8	19.5

Since R&D intensity is the ratio of R&D expenditure to net sales, relative growth rate difference between R&D expenditure and net sales can affect fluctuation of R&D intensity. In particular, since net sales tend to increase rapidly during economic upturn, R&D intensity seems to decrease. To confirm, the growth rate of R&D expenditure and net sales is calculated (Table 23). During economic upturn, the growth rate of R&D expenditure is larger than that of net sales.

Table 23. Growth rate of R&D expenditure and net sales

Year	High-tech				Low-tech			
	R&D expenditure		Net sales		R&D expenditure		Net sales	
	Mean[a]	Growth rate(%)	Mean	Growth rate(%)	Mean	Growth rate(%)	Mean	Growth rate(%)
2003	298	-	13,014	-	145	-	14,636	-
2004	313	5.0	13,177	1.3	143	-1.0	14,360	-1.9
2005	296	-5.5	11,835	-10.2	146	1.8	12,852	-10.5
2006	303	2.2	11,611	-1.9	165	12.8	12,489	-2.8
2007	322	6.5	11,778	1.4	184	11.9	12,902	3.3

[a] Adjusted by PPI, Unit: Millions KRW

4.4 Results

Table 24 provides the results of the three regression models about the effect of loan ratio on R&D intensity. First, the estimates of the variables SIZE, ROA, and GROWTH show the uniqueness of Korean SMEs regarding the determinants for R&D investment. The negative, negative, and positive estimates of SIZE, ROA, and GROWTH respectively, imply that large SMEs tend to invest less in R&D, and a profitable SME is risk-averse even if a fast growing SME invests more in R&D. That is to say, these findings imply that large and mature SMEs with stable profit tend to settle for the status quo (Fiegenbaum and Thomas, 1988; Hitt et al., 1991).

Model 1 in the first column shows that there is no clear relationship between total loan ratio and R&D intensity, unlike the generally accepted idea. This is because the effects of long-term and short-term loan ratios in opposite directions dilute the effect of total loan ratio. Model 2 and Model 3 in the second and third column suggest that there is a positive association between long-term loan ratio and R&D intensity while a negative association between short-term loan ratio and R&D intensity. Usually, because a firm takes on a long-term loan with a three-year grace period and a redemption period of five years or more, an increase in long-term loans encourages a firm to invest more in R&D even if R&D investment includes high uncertainties and risks and requires a long payback period of investment. The public credit guarantee institutions in Korea can especially contribute strongly to the positive correlation between long-term loans and R&D intensity by guaranteeing banks' loans to SMEs for three or five years. On the other hand, an increase in short-term loans causes high liquidity risks, and financially constrained SMEs consequently depress R&D investment. On comparing Model 3 with Model 2, the negative effect of short-term loans countervails the positive effect of long-term loans on R&D investment. As a result, Table 24 supports Hypothesis 1b as well as Hypothesis 1a.

Table 24. GLS random effects regression analysis of full samples [a,b]

Variable	Model 1 (Total)	Model 2 (Long-term)	Model 3 (Short-term)
SIZE	-0.030***	-0.029***	-0.029***
	(0.001)	(0.001)	(0.001)
ROA	-0.127***	-0.123***	-0.131***
	(0.004)	(0.004)	(0.004)
GROWTH	0.008***	0.007***	0.007***
	(0.001)	(0.001)	(0.001)
TTLR	-0.004		
	(0.002)		
LTLR		0.013***	
		(0.002)	
STLR			-0.019***
			(0.002)
CONSTANT	0.239***	0.228***	0.236***
	(0.014)	(0.014)	(0.013)
N	41,501	41,501	41,501
x2	3000	3027	3061

[a]The standard errors are shown in parentheses. The significance is shown for two-tailed t-tests at the 99% (***), 95% (**), and 90% (*) significance levels.
[b]Year dummies and 2-digit Standard Industrial Classification were included but not reported to save space.

In Table 25, the positive and negative effects of long-term and short-term loan ratios on R&D intensity generate different results of the total loans' effect on R&D intensity in high-tech and low-tech industries. In high-tech industries, long-term loans show positive relation with R&D investment in Model 4, and short-term loans show negative relation in Model 5. These findings are consistent with the results in Table 4. However, as the negative sensitivity (-0.024) of short-term loan ratio to R&D intensity is greater than the positive sensitivity (0.015) of long-term loan ratio, these results make the association between total loan ratio and R&D intensity positive in Model6. On the contrary, a different result is obtained in low-tech industries. In Model 7 and Model 8, the effects of long-term and short-term loans on R&D investment are positive and negative, respectively, similar with the result in high-tech industries. However, low-tech industries show that the positive sensitivity (0.012) of long-term loan ratio is greater than the negative sensitivity (-0.008) of short-term loan ratio to R&D intensity. As a result, their combined effect in terms of the total loan ratio on R&D intensity is positive in Model 9, showing a completely different pattern from the result of high-tech industries.

These results are based on different characteristics of R&D projects in high-tech and low-tech industries. Because the R&D projects in high-tech industries usually include higher uncertainties commercially as well as technically, and require longer payback period of investment compared to ones in low-tech industries, sustaining the investment in R&D projects for significant periods is an important factor in the success of projects. As a result, the loan portfolio with the increase in short-term loan ratio can cause financial distress to high-tech firms and depress their R&D investment. On the other hand, because R&D projects in low-tech industries are relatively less uncertain and are completed within one year, they can be less sensitive to the short-term loan ratio. Consequently, the positive effect of long-term loans must be more dominating than the negative effect of short-term loan ratio on R&D intensity in low-tech industries. Therefore, Table 25 supports Hypothesis 2b as well as Hypothesis 2a.

Table 26 presents the different patterns of the sensitivities of loan ratio to R&D intensity across times of economic upturn and downturn. First, according to Model 10 and Model 11, the increase in long-term loan ratio unexpectedly contributes more in R&D investment during a downturn period (0.020) than during an upturn period (0.004), showing a counter-cyclical pattern to support Hypothesis 3a. This is because the firms tend to focus on the investment in physical assets by obtaining long-term loans and invest in R&D projects by raising funds from equity markets in times of economic upturn. On the other hand, they strengthen R&D investment for upcoming upturn period because they cannot expand physical facilities in time of economic downturn. In terms of short-term loan ratio, Model 12 and Model 13 show that an increase in the short-term loan ratio depresses R&D investment to a larger extent in a downturn (-0.026) than in an upturn (-0.016), showing a pro-cyclical pattern to support Hypothesis 3b. In an upturn, because firms can refinance existing loans and extend loan maturity easily, an increase in short-term loans can have less impact on R&D investment. As a result, the relationship between total loan ratio and R&D intensity can be inconclusive during the time of economic downturn (Model 14) even if the negative relationship is shown during the time of economic upturn (Model 15) in contrast to the generally accepted idea.

Table 25. GLS random effects regression analysis of high-tech and low-tech firms [a,b].

Variable	Model 4 (High-tech Long-term)	Model 5 (High-tech Short-term)	Model 6 (High-tech Total)	Model 7 (Low-tech Long-term)	Model 8 (Low-tech Short-term)	Model 9 (Low-tech Total)
SIZE	-0.029***	-0.029***	-0.030***	-0.027***	-0.028***	-0.028***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
ROA	-0.137***	-0.147***	-0.143***	-0.061***	-0.068***	-0.061***
	(0.005)	(0.005)	(0.005)	(0.006)	(0.007)	(0.007)
GROWTH	0.006***	0.007***	0.007***	0.008***	0.009***	0.009***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
LTLR	0.015***			0.012***		
	(0.003)			(0.003)		
STLR		-0.024***			-0.008**	
		(0.003)			(0.003)	
TTLR			-0.006**			0.005***
			(0.003)			(0.003)
CONSTANT	0.232***	0.241***	0.245***	0.215***	0.223***	0.220***
	(0.010)	(0.010)	(0.010)	(0.013)	(0.013)	(0.013)
N	27,057	27,057	27,057	14,444	14,444	14,444
x2	1811	1846	1797	666	656	652

[a]The standard errors are shown in parentheses. The significance is shown for two-tailed t-tests at the 99% (***), 95% (**), and 90% (*) significance levels.
[b]Year dummies and 2-digit Standard Industrial Classification were included but not reported to save space.

Table 26. GLS random effects regression analysis of long-term and short-term loan ratio during times of economic upturn ('06-'07) and downturn('03-'05)[a,b].

Variable	Model 10 ('03-'05)	Model 11 ('06-'07)	Model 12 ('03-'05)	Model 13 ('06-'07)	Model 14 ('03-'05)	Model 15 ('06-'07)
SIZE	-0.029***	-0.031***	-0.030***	-0.031***	-0.031***	-0.032***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
ROA	-0.136***	-0.117***	-0.148***	-0.124***	-0.143***	-0.124***
	(0.006)	(0.005)	(0.006)	(0.006)	(0.006)	(0.006)
GROWTH	0.010***	0.007***	0.010***	0.007***	0.011***	0.008***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
LTLR	0.020***	0.004*				
	(0.004)	(0.003)				
STLR			-0.026***	-0.016***		
			(0.004)	(0.003)		
TTLR					-0.005	-0.010***
					(0.003)	(0.003)
CONSTANT	0.215***	0.263***	0.230***	0.265***	0.234***	0.273***
	(0.017)	(0.018)	(0.017)	(0.017)	(0.017)	(0.017)
N	20755	20746	20755	20746	20755	20746
x2	1875	1790	1904	1816	1843	1801

[a]The standard errors are shown in parentheses. The significance is shown for two-tailed t-tests at the 99% (***), 95% (**), and 90% (*) significance levels.
[b]Year dummies and 2-digit Standard Industrial Classification were included but not reported to save space.

4.5 Discussion

Loans have been denigrated as inappropriate instruments for financing R&D projects because of their rigid contracts that cause financial inflexibility. However, this study shows that the relation between loan ratio and R&D intensity depends on loan maturity. That is to say, R&D intensity is positively correlated with long-term loan ratio and negatively with short-term loan ratio.

According to the results, an increase in the short-term loan ratio depresses R&D investment more, especially in the high-tech industry and during times of economic upturn. This result implies that it must be important for firms to manage the maturities of loans in their portfolio in order to sustain R&D investment for any projects at any time.

Long-term loans are especially found to play a vital role in increasing investments to R&D projects even during times of economic downturn, thereby showing a counter-cyclical pattern. This finding implies that the supply of long-term loans can sustain R&D investment regardless of the stage of the business cycle. In this circumstance, a government can play an important role to encourage private financial institutions to offer more long-term loans to firms, especially SMEs in bank-oriented countries.

This study is unique as it sheds light on the positive role of bank loans for R&D investment. Further investigation including more evidence from many countries can support this positive relation between bank loans and R&D investment.

Chapter 5. Conclusion

5.1 Summary

5.1.1 Critical mass and saturation level of R&D investment

In terms of patent applications, there are critical mass levels for R&D intensity and R&D expenditure in high-tech firms, while there are saturation levels for the researchers to employees ratio and R&D expenditure in low-tech firms. In high-tech industries, critical mass can exist because of high technological entry barrier and high uncertainty. In the case of profit performance, however, only the saturation level exists, as profit is affected by various factors such as marketing as well as R&D.

Approximately 17–30% of firms in high-tech industries do not exceed the critical mass with regard to patent applications. If those high-tech firms below the critical mass increased their R&D investments to the level of the critical mass, they could achieve greater R&D performance. The government and relevant firms thus need to find solutions to increase their R&D investments and improve performance. By contrast, low-tech firms that are above the saturation level should consider formulating R&D strategies that aim to increase efficiency through the rearrangement of R&D resources. If the government supports the R&D activities of low-tech firms above the saturation level, it needs to contemplate the redistribution of public R&D funds for in order to increase social R&D performance.

5.1.2 Relationship between R&D investment and capital structure

Loans have been denigrated as inappropriate instruments for financing R&D projects because of their rigid contracts that cause financial inflexibility. However, this study suggests that there must be no correlation between loan ratio and R&D investment explaining the entire economy because a larger amount of long-term loans can encourage more R&D investment while a larger amount of short-term loans can depress R&D.

Based on this finding, this study uncovers draws two interesting results conclusions based on the stage of the business cycle as well as on technological intensity. First, since the contributions of provided by long-term and short-term loans to R&D investment is different, the relation between total loans and R&D investment reveals shows a negative and a positive direction in high-tech and low-tech industries, respectively. Second, the positive effect of long-term loans on R&D investment shows a counter-cyclical pattern, while whereas the negative effect of short-term loans shows a pro-cyclical pattern.

This result implies that it must be important for firms to manage the maturities of loans in their portfolios in order to sustain R&D investment for any projects at any over time. Long-term loans are especially found to play a vital role in increasing investments to R&D projects investment, even during times period of economic downturn, thereby showing a counter-cyclical pattern. This finding further implies suggests that the supply of long-term loans can sustain R&D investment regardless of the stage of the business cycle.

5.2 Policy implications

Table 27 defines the group based on the critical mass of RINT and REXP in high-tech industries. A value of zero means that their RINT or REXP values are below the level of the critical mass. The R&D intensity and R&D expenditure of those firms in Group IV are above the critical value, whereas Group I is the black list because both intensity and expenditure are below the critical mass. Table 28 shows the mean value by group in 2005.

Table 27. Group definition

		L2RINT	
		0	1
L2REXP	0	I	III
	1	II	IV

Table 28. Mean values by group in 2005

2005	I	II	III	IV
DEBTR	0.572	0.508	0.603	0.506
CLR[a]	0.424	0.409	0.409	0.363
NCLR[b]	0.153	0.099	0.194	0.143
GOVR[c]	0.033	0.036	0.113	0.121
Self-REXP[d]	5.014	5.757	5.122	5.840
Gov-REXP[e]	0.268	1.008	1.361	2.172
RINT	0.007	0.009	0.071	0.062
REXP	5.046	5.776	5.191	5.926
DSR1[f]	0.068	0.223	1.000	1.000
DSR2[g]	0.000	0.968	0.013	0.909

[a] CLR: Current liabilities / Total assets, ; [b] NCLR: Non-current liabilities / Total assets; [c] GOVR: R&D expenditure from government / Total R&D expenditure; [d] Self-REXP: Log_{10}(Self R&D expenditure +1); [e]Gov-REXP: Log_{10}(R&D expenditure from government +1); [f]DSR1(Dummy): 1 if Self R&D expenditure/ Net sales > Critical mass (0.0143); [g] DSR2 (Dummy): 1 if Self-REXP > Critical mass (5.477)

Firms in Group I are found to have relatively high debt ratios. In particular, their current liabilities ratio including short-term loans is the highest among the four groups. Moreover, RINT and REXP are the lowest, consistent with the results presented in Chapter 4. The percentage of self R&D intensity above the critical mass is only 6.8% (DSR1) of firms in Group I, while this percentage is zero in self R&D expenditure (DSR2). However, the R&D intensity and R&D expenditure of firms in Group IV that have lower debt ratios and current liabilities ratios exceed the critical mass. In other words, most of these firms can manage R&D investment by their own efforts.

Nevertheless, government support and expenditure in Group IV is the highest among the four groups. Unfortunately, government support for firms in Group I (i.e., those most in need) is the lowest.

Therefore, high-tech firms in Group I need further support from the government as well as innovative firm strategies. When managers or policymakers plan for additional R&D investment, long-term loan financing can be a good choice, as long-term loan ratio has a significantly positive relationship with R&D intensity based on the presented results.

Equity financing may not be attractive because the equity market in Korea is not currently buoyant. However, in the long run equity financing would be helpful. The Korea Finance Corporation, established in 2009, establishes SME and venture investment funds through contributions, with fund managers making investments in individual companies according to the purpose of each fund. Since the number of these funds is increasing, equity financing would provide further invigoration. Many governments around the world support SMEs through equity funding. According to Hall and Lerner (2009), US Small Business Investment Company and Small Business Innovation Research programs disburse venture funding. In Germany, over 800 federal and state government financing programs have been established, while the UK has created programs to allocate funds to high-tech SMEs.

5.3 Contributions and limitations

This research measures the critical mass and saturation levels of R&D investment. Based on the presented results, firms and the government can formulate a plan to increase R&D performance and efficiency. Further, this study shows that the relation between loan ratio and R&D intensity depends on loan maturity, technological intensity, and business cycle. This finding sheds light on the positive role of bank loans for R&D investment.

Combined information on how much to invest and on how to pay is useful for making accurate R&D investment and financing decisions. Adding these combined results to information on which asset to buy would make the result even more influential.

The following points should be considered in further studies: the econometric improvement of threshold regression in order to make estimates using fewer observations; analysis using other financing sources such as equity, government funds, and bonds; comparison analysis among nations; and an extension to other industries such as services and software. In particular, analysis in the software industry would be interesting. Arora et al. (2010) find that the change in the IT industry, one of manufacturing industries, is systematic, substantial, and increasingly dependent on the software industry. Therefore, analysis in Korea software industry, especially mobile software industry such as Apple App store which is becoming even more crucial, is very helpful for Korean IT firms which have recently emerged as a strong player in the IT industry.

Bibliography

Aerts, K., & Schmidt, T. (2008). Two for the price of one? Additionality effects of R&D subsidies a comparison between Flanders and Germany. *Research Policy, 37*, 806-822.

Agarwal, R. (1998). Small firm survival and technological activity. *Small Business Economics, 11*, 215-224.

Aggarwal, A. (2000). Deregulation, technology imports and in-house R&D efforts: An analysis of the Indian experience. *Research Policy, 29*, 1081-1093.

Aghion, P., Angeletos, G., Banerjee, A., & Manova, K. (2005). Volatility and growth: Credit constraints and productivity-enhancing investment. *NBER Working Paper No. 11349*.

Aghion, P., Askenazy, P., Berman, N., Cette, G., & Eymard, L. (2008). Credit constraints and the cyclicality of R&D investment: Evidence from France. *Banque de France Working Paper No. 198*.

Aivazian, V. A., Ge, Y., & Qiu, J. (2005). Debt maturity structure and firm investment. *Financial Management, 34*(4), 107-119.

Akerlof, G. A. (1970). The market for "Lemons": Quality uncertainty and the market mechanism. *The Quarterly Journal of Economics, 84*(3), 488-500.

Alonso-Borrego, C., & Forcadell, F. J. (2010). Related diversification and R&D intensity dynamics. *Research Policy, 39*, 537-548.

Andersson, M., Baltzopoulos, A., & Lööf, H. (2012). R&D strategies and entrepreneurial spawning. *Research Policy, 41*, 54-68.

Añón-Higón, D. (2007). The impact of R&D spillovers on UK manufacturing TFP: A dynamic panel approach. *Research Policy*, 36, 964-979.

Arora, A., Branstetter, L. G., & Drev, M. (2010). Going soft: How the rise of software based innovation led to the decline of Japan's It industry and the resurgence of Silicon Valley. *NBER Working Paper No. 16156.*

Artés, J. (2009). Long-run versus short-run decisions: R&D and market structure in Spanish firms. *Research Policy, 38*, 120-132.

Åstebro, T., & Serrano, C. J. (2011). Business partners, financing, and the commercialization of inventions. *NBER Working Paper No. 17181.*

Athukorala, P., & Kohpaiboon, A. (2010). Globalization of R&D by US-based multinational enterprises. *Research Policy, 39*, 1335-1347.

Autio, E., Kanninen, S., & Gustafsson, R. (2008). First- and second-order additionality and learning outcomes in collaborative R&D programs. *Research Policy, 37*, 59-76.

Azagra-Caro, J., Archontakis, F., Gutiérrez-Gracia, A., & Fernández-de-Lucio, I. (2006). Faculty support for the objectives of university–industry relations versus degree of R&D cooperation: The importance of regional absorptive capacity. *Research Policy, 35*, 37-55.

Bönte, W. (2004). Spillovers from publicly financed business R&D: Some empirical evidence from Germany. *Research Policy, 33*, 1635-1655.

Bah, R., & Dumontier, P. (2001). R&D intensity and corporate financial policy: Some international evidence. *Journal of Business Finance & Accounting, 28*(5-6), 671-

692.

Balakrishnan, S., & Fox, I. (1993). Asset specificity, firm heterogeneity and capital structure. *Strategic Management Journal 14*, 3-16.

Ballesteros, J. A., & Rico, A. M. (2001). Public financing of cooperative R&D projects in Spain: The Concerted Projects under the National R&D Plan. *Research Policy, 30*, 625-641.

Barclay, M. J., & Smith Jr., C. W. (1995). The maturity structure of corporate debt. *The Journal of Finance, 50*, 609-631.

Barry, F. (2005). FDI, transfer pricing and the measurement of R&D intensity. *Research Policy, 34*, 673-681.

Bas, C. L., & Sierra, C. (2002). 'Location versus home country advantages' in R&D activities: Some further results on multinationals' locational strategies. *Research Policy, 31*, 589-609.

Bayona, C., García-Marco, T., & Huerta, E. (2001). Firms' motivations for cooperative R&D: An empirical analysis of Spanish firms. *Research Policy, 30*, 1289-1307.

Becker, M. C., & Lillemark, M. (2006). Marketing/R&D integration in the pharmaceutical industry. *Research Policy, 35*, 105-120.

Becker, W., & Dietz, J. (2004). R&D cooperation and innovation activities of firms—evidence for the German manufacturing industry. *Research Policy, 33*, 209-223.

Belderbos, R., Carree, M., & Lokshin, B. (2004). Cooperative R&D and firm performance. *Research Policy, 33*, 1477-1492.

Ben-Zion, U. (1984). The R&D and investment decision and its relationship to the firm's market value: Some preliminary esults. In Z. Griliches (Ed.), *R & D, Patents, and Productivity*. Chicago: University of Chicago Press.

Beneito, P. (2006). The innovative performance of in-house and contracted R&D in terms of patents and utility models. *Research Policy, 35*, 502-517.

Bergek, A., & Bruzelius, M. (2010). Are patents with multiple inventors from different countries a good indicator of international R&D collaboration? The case of ABB. *Research Policy, 39*, 1321-1334.

Berger, A. N., & Udell, G. F. (1998). The economics of small business finance: The roles of private equity and debt markets in the financial growth cycle. *Journal of Banking & Finance 22*, 613-673.

Bertrand, O. (2009). Effects of foreign acquisitions on R&D activity: Evidence from firm-level data for France. *Research Policy, 38*, 1021-1031.

Bizan, O. (2003). The determinants of success of R&D projects: Evidence from American–Israeli research alliances. *Research Policy, 32*, 1619-1640.

Blanes, J. V., & Busom, I. (2004). Who participates in R&D subsidy programs? The case of Spanish manufacturing firms. *Research Policy, 33*, 1459-1476.

Blass, A., & Yosha, O. (2003). Financing R&D in mature companies: An empirical analysis. *Economics of Innovation and New Technology, 12*(5), 425-447.

Blonigen, B. A., & Kolpin, V. (2002). Technology, agglomeration, and regional competition for investment. *NBER Working Paper No. 8862*.

Bloom, N. (2007). Uncertainty and the Dynamics of R&D. *NBER Working Paper No. 12841*.

Bowns, S., Bradley, I., Knee, P., Williams, F., & Williams, G. (2003). Measuring the economic benefits from R&D: Improvements in the MMI model of the United Kingdom National Measurement System. *Research Policy, 32*, 991-1002.

Bradley, M., Jarrell, G. A., & Kim, E. H. (1984). On the existence of an optimal capital structure: Theory and evidence. *The Journal of Finance 39*, 857-880.

Brealey, R. A., Myers, S. C., & Marcus, A. J. (2001). *Fundamentals of corporate finance, Third edtion*. Boston: The McGraw-Hill Companies.

Breznitz, D. (2007). Industrial R&D as a national policy: Horizontal technology policies and industry-state co-evolution in the growth of the Israeli software industry. *Research Policy, 36*, 1465-1482.

Breznitz, D., & Zehavi, A. (2010). The limits of capital: Transcending the public financer–private producer split in industrial R&D. *Research Policy, 39*, 301-312.

Busom, I., & Fernández-Ribas, A. (2008). The impact of firm participation in R&D programmes on R&D partnerships. *Research Policy, 37*, 240-257.

Cabrer-Borrás, B., & Serrano-Domingo, G. (2007). Innovation and R&D spillover effects in Spanish regions: A spatial approach. *Research Policy, 36*, 1357-1371.

Calia, R. C., Guerrini, F. M., & Moura, G. L. (2007). Innovation networks: From technological development to business model reconfiguration. *Technovation, 27*, 426-432.

Canepa, A., & Stoneman, P. (2003). Financial constraints on innovation a European cross country study. In M. Waterson (Ed.), *Competition, Monopoly, and Corporate Governance: Essays in Honour of Keith Cowling*. Northampton: Edward Elgar

Publishing.

Cappelen, A., Raknerud, A., & Rybalka, M. (2012). The effects of R&D tax credits on patenting and innovations. *Research Policy, 41*, 334-345.

Carpenter, R. E., & Petersen, B. C. (2002). Capital Market Imperfections, High-Tech Investment, and New Equity Financing. *The Economic Journal, 112*(477), F54-F72.

Carreira, C., & Silva, F. (2011). No deep pockets: Some stylized empirical results on firms' financial constraints. *Journal of Economic Surveys, 24*(4), 731-753.

Cassiman, B., Colomboc, M. G., Garrone, P., & Veugelers, R. (2005). The impact of M&A on the R&D process: An empirical analysis of the role of technological- and market-relatedness. *Research Policy, 34*, 195-220.

Chan, L. K. C., Lakonishok, J., & Sougiannis, T. (1999). The stock market valuation of research and development expenditures. *NBER Working Paper No. 7223*.

Chataway, J., Tait, J., & Wield, D. (2004). Understanding company R&D strategies in agro-biotechnology: Trajectories and blind spots. *Research Policy, 33*, 1041-1057.

Chen, S. (2004). Taiwanese IT firms' offshore R&D in China and the connection with the global innovation network. *Research Policy, 33*, 337-349.

Chiao, C. (2002). Relationship between debt, R&D and physical investment, evidence from US firm-level data. *Applied Financial Economics, 12*(2), 105-121.

Choi, J. Y., Lee, J. H., & Sohn, S. Y. (2009). Impact analysis for national R&D funding in science and technology using quantification method II. *Research Policy, 38*, 1534-1544.

Christensen, J. F. (2002). Incongruities as a source of organizational renewal in corporate management of R&D. *Research Policy, 31*, 1317-1332.

Claryssea, B., M. Wrightc, & Mustare, P. (2009). Behavioural additionality of R&D subsidies: A learning perspective. *Research Policy, 38*, 1517-1533.

Coe, T. C., & Helpman, E. (1995). International R & D spillovers. *European Economic Review, 39*, 859-887.

Cohen, W. M., Goto, A., Nagata, A., Nelson, R. R., & Walsh, J. P. (2002). R&D spillovers, patents and the incentives to innovate in Japan and the United States. *Research Policy, 31*, 1349-1367.

Criscuolo, C., & Martin, R. (2004). An emerging knowledge-based economy in China?: Indicators from OECD databases. *OECD Science, Technology and Industry Working Papers 2004/04*.

Criscuolo, P. (2005). On the road again: Researcher mobility inside the R&D network. *Research Policy, 34*, 1350-1365.

Cuervo-Cazurra, A., & Un, C. A. (2007). Regional economic integration and R&D investment. *Research Policy, 36*, 227-246.

Czarnitzki, D., & Hottenrott, H. (2011). R&D investment and financing constraints of small and medium-sized firms. *Small Business Economics, 36*, 65-83.

Czarnitzki, D., & Kraft, K. (2009). Capital control, debt financing and innovative activity. *Journal of Economic Behavior & Organization, 71*(2), 372-383.

David, P., O'Brien, J. P., & Yoshikawa, T. (2008). The implications of debt heterogeneity for R&D investment and firm performance. *Academy of Management Journalc*

51, 165-181.

David, P. A., & Hall, B. H. (2000). Heart of darkness: Modeling public–private funding interactions inside the R&D black box. *Research Policy, 29*, 1165-1183.

David, P. A., Hall, B. H., & Toole, A. A. (2000). Is public R&D a complement or substitute for private R&D? A review of the econometric evidence. *Research Policy, 29*, 497-529.

De Marchi, V. (2012). Environmental innovation and R&D cooperation: Empirical evidence from Spanish manufacturing firms. *Research Policy, 41*, 614-623.

Del Canto, J. G., & González, I. S. (1999). A resource-based analysis of the factors determining a firm's R&D activities. *Research Policy, 28*, 891-905.

Del Monte, A., & Papagni, E. (2003). R&D and the growth of firms: Empirical analysis of a panel of Italian firms. *Research Policy, 32*, 1003-1014.

Desmet, K., Kujal, P., & Lobo, F. (2004). Implementing R&D policies: An analysis of Spain's pharmaceutical research program. *Research Policy, 33*, 1493-1507.

Diamond, D. W. (1984). Financial intermediation and delegated monitoring. *Review of Economic Studies, 51*, 393-414.

Diamond, D. W. (1991). Debt maturity structure and liquidity risk. *The Quarterly Journal of Economics, 106*(3), 709-737.

Dosi, G., Llerena, P., & Labini, M. S. (2006). The relationships between science, technologies and their industrial exploitation: An illustration through the myths and realities of the so-called 'European Paradox'. *Research Policy, 35*, 1450-1464.

Ejermo, O., Kander, A., & Henning, M. S. (2011). The R&D-growth paradox arises in fast-growing sectors. *Research Policy, 40*, 664-672.

Ettlie, J. E., Dreher, C., Kovacs, G. L., & Trygg, L. (1993). Cross-national comparisons of product development in manufacturing. *The Journal of High Technology Management Research, 4*(2), 139-155.

Fama, E. F. (1985). What's different about banks? *Journal of Monetary Economics, 15*, 29-39.

Feldman, M. P., & Kelley, M. R. (2006). The ex ante assessment of knowledge spillovers: Government R&D policy, economic incentives and private firm behavior. *Research Policy, 35*, 1509-1521.

Fiegenbaum, A., & Thomas, H. (1988). Attitudes toward risk and the risk-return paradox: Prospect theory explanations. *Academy of Management Journal, 31*, 85-106.

Flannery, M. J. (1986). Asymmetric information and risky debt maturity choice. *The Journal of Finance, 41*(1), 19-37.

Fontana, R., Geuna, A., & Matt, M. (2006). Factors affecting university–industry R&D projects: The importance of searching, screening and signalling. *Research Policy, 35*, 309-323.

Fors, G., & Svensson, R. (2002). R&D and foreign sales in Swedish multinationals: A simultaneous relationship? *Research Policy, 31*, 95-107.

Fraumeni, B. M., & Okubo, S. (2005). R&D in the national income and product accounts: A first look at its effect on GDP. In C. Corrado, J. Haltiwanger & D. Sichel (Eds.), *Measuring capital in the new economy*: University of Chicago Press.

Freel, M. S. (2003). Sectoral patterns of small firm innovation, networking and proximity.

Research Policy, 32, 751-770.

Fritsch, M., & Franke, G. (2004). Innovation, regional knowledge spillovers and R&D cooperation. *Research Policy, 33*, 245-255.

Fritsch, M., & Lukas, R. (2001). Who cooperates on R&D? *Research Policy, 30*, 297-312.

Galasso, A., & Simcoe, T. S. (2010). CEO overconfidence and innovation. *NBER Working Paper No. 16041*.

Galbraith, J. K. (1993). *American capitalism. The concept of countervailing power.* New Brunswick: Transaction Publishers.

Gans, J. S., & Stern, S. (2000). When does funding research by smaller firms bear fruit evidence from the SBIR program. *NBER Working Paper No. 7877*.

García-Teruel, P. J., & Martínez-Solano, P. (2007). Short-term debt in Spanish SMEs. *International Small Business Journal, 25*, 579-602.

Garrone, P., & Grilli, L. (2010). Is there a relation ship between public expenditures in energy R&D and carbon emissions per GDP? An empirical investigation. *Energy policy, 38*, 5600-5613.

Ghosh, A., Moon, D., & Tandon, K. (2007). CEO ownereship and discretionary investment. *Journal of Business Finance & Accounting, 34*(5 & 6), 819-839.

Giebe, T., T. Grebe, & Wolfstetter, E. (2006). How to allocate R&D (and other) subsidies: An experimentally tested policy recommendation. *Research Policy, 35*, 1261-1272.

Giudici, G., & Paleari, S. (2000). The provision of finance to innovation: A survey conducted among Italian technology-based small firms. *Small Business*

Economics, 14, 37-53.

González, X., & Pazó, C. (2008). Do public subsidies stimulate private R&D spending? *Research Policy, 37*, 371-389.

Goto, A., & Suzuki, K. (1989). R&D capital, rate of return on R&D investment and spillover of R&D in Japanese manufacturing industries. *The Review of Economics and Statistics, 71*(4), 555-564.

Grabowski, H. G., & Mueller, D. C. (1978). Industrial research and development, intangible capital stocks, and firm profit rates. *The Bell Journal of Economics, 9*(2), 328-343.

Griffiths, W., & Webster, E. (2010). What governs firm-level R&D: Internal or external factors? *Technovation, 30*, 471-481.

Griliches, Z. (1990). Patents statistics as economic indicators: A survey. *Journal of Economic Literature, 28*(4), 1661-1707.

Griliches, Z. (1991). The search for R&D spillovers. *NBER Working Paper No. 3768*.

Guadalupe, M., Kuzmina, O., & Thomas, C. (2010). Innovation and foreign ownership. *NBER Working Paper No. 16573*.

Hagedoorn, J. (2002). Inter-firm R&D partnerships: An overview of major trends and patterns since 1960. *Research Policy, 31*, 477-492.

Hall, B. H. (1992). Investment and research and development at the firm level: Does the source of financing matter? *NBER Working Paper No. 4096*.

Hall, B. H. (2002). The financing of research and development. *NBER Working Paper No. 8773*.

Hall, B. H. (2005). Exploring the patent explosion. *Journal of Technology Transfer, 30*(1-2), 35-48.

Hall, B. H. (2007). Measuring the returns to R&D: The depreciation problem. *NBER Working Paper No. 13473*.

Hall, B. H., & Lerner, J. (2009). The financing of R&D and innovation. *NBER Working Paper No. 15325*.

Hall, B. H., Lotti, F., & Mairesse, J. (2008). Innovation and productivity in SMEs: Empirical evidence for Italy. *NBER Working Paper No. 14594*.

Hall, B. H., & Maffioli, A. (2008). Evaluating the impact of technology development funds in emerging economies: Evidence from Latin America. *NBER Working Paper No. 13835*.

Hall, B. H., Mairesse, J., & Mohnen, P. (2009). Measuring the returns to R&D. *NBER Working Paper No. 15622*.

Hall, B. H., & Oriani, R. (2004). Does the market value R&D investment by European firms? Evidence from a panel of manufacturing firms in France, Germany, and Italy. *NBER Working Paper No. 10408*.

Hanaki, N., Nakajima, R., & Ogura, Y. (2010). The dynamics of R&D network in the IT industry. *Research Policy, 39*, 386-399.

Hansen, B. E. (1996). When a nuisance parameter is not identified under the null hypothesis. *Econometrica, 64*(2), 413-430.

Harris, R., Li, Q. C., & Trainor, M. (2009). Is a higher rate of R&D tax credit a panacea for low levels of R&D in disadvantaged regions? *Research Policy, 38*, 192-205.

Harrison, R., Jaumandreu, J., Mairesse, J., & Peters, B. (2008). Does innovation stimulate employment? A firm-level analysis using comparable micro-data from four European countries. *NBER Working Paper No. 14216*.

Hartmann, G. C., Myers, M. B., & Rosenbloom, R. S. (2006). Planning your firm's R&D investment. *Research Technology Management, 49*(2), 25-36.

Hartmann, M., & Hassan, A. (2006). Application of real options analysis for pharmaceutical R&D project valuation—Empirical results from a survey. *Research Policy, 35*, 343-354.

Hashai, N., & Almor, T. (2008). R&D intensity, value appropriation and integration patterns within organizational boundaries. *Research Policy, 37*, 1022-1034.

Hashmi, A. R., & Biesebroeck, J. V. (2010). Market structure and innovation: A dynamic analysis of the global automobile industry. *NBER Working Paper No. 1595*.

Hayashi, T. (2003). Effect of R&D programmes on the formation of university–industry–government networks: Comparative analysis of Japanese R&D programmes. *Research Policy, 32*, 1421-1442.

Hegde, D., & Hicks, D. (2008). The maturation of global corporate R&D: Evidence from the activity of U.S. foreign subsidiaries. *Research Policy, 37*, 390-406.

Heijs, J. (2003). Freerider behaviour and the public finance of R&D activities in enterprises: The case of the Spanish low interest credits for R&D. *Research Policy, 32*, 445-461.

Helm, R., & Kloyer, M. (2004). Controlling contractual exchange risks in R&D interfirm cooperation: An empirical study. *Research Policy, 33*, 1103-1122.

Hewitt-Dundas, N., & Roper, S. (2011). Creating advantage in peripheral regions the role of publicly funded R&D centres. *Research Policy, 40*, 832-841.

Higón, D. A., & Antolín, M. M. (2012). Multinationality, foreignness and institutional distance in the relation between R&D and productivity. *Research Policy, 41*, 592-601.

Himmelberg, C. P., & Petersen, B. C. (1994). R&D and internal finance: A panel study of small firms in high-tech industries. *The Review of Economics and Statistics, 76*(1), 38-51.

Hitt, M. A., Hoskisson, R. E., Ireland, R. D., & Harrison, J. S. (1991). Effects of acquisitions on R&D inputs and outputs. *Academy of Management Journal, 34*(3), 693-706.

Hoffman, K., Parejo, M., Bessant, J., & Perren, L. (1998). Small firms, R&D, technology and innovation in the UK: A literature review. *Technovation, 18*(1), 39-55.

Howe, J. D., & McFetridge, D. G. (1976). The determinants of R&D expenditures. *The Canadian Journal of Economics, 9*(1), 57-71.

Huang, C. J., & Liu, C. J. (2005). Exploration for the relationship between innovation, IT and performance. *Journal of Intellectural Capital, 6*(2), 237-252.

Hwang, S., An, D., Choi, S., Kwon, S., Cheon, D., Kim, A., & Park, J. (2009). Efficiency of national R&D investment (in Korean): STEPI.

Ito, B., & Wakasugi, R. (2007). What factors determine the mode of overseas R&D by multinationals? Empirical evidence. *Research Policy, 36*, 1275-1287.

Iwasa, T., & Odagiri, H. (2004). Overseas R&D, knowledge sourcing, and patenting: An empirical study of Japanese R&D investment in the US. *Research Policy, 33*, 807-828.

Jamasb, T., & Pollitt, M. (2008). Liberalisation and R&D in network industries: The case of the electricity industry. *Research Policy, 37*, 995-1008.

Jensen, M. C., & Meckling, W. H. (1976). Theory of the firm: Managerial behavior, agency costs and ownership structure. *Journal of Financial Economics, 3*, 305-360.

Johnston, J., & DiNardo, J. (1997). *Econometric methods, 4th ed.* Singapore: The McGraw-Hill Companies.

Kale, J. R., & Noe, T. H. (1990). Risky debt maturity choice in a sequential game equilibrium. *Journal of Financial Research, 13*(2), 155-165.

Kamien, M. I., & Schwartz, N. L. (1974). Risky R&D with rivalry. In S. V. Berg (Ed.), *Annals of economic and social measurement* (Vol. 3): National Bureau of Economic Research.

Kearns, A., & Ruane, F. (2001). The tangible contribution of R&D-spending foreign-owned plants to a host region: A plant level study of the Irish manufacturing sector (1980-1996). *Research Policy, 30*, 227-244.

Kloyer, M., & Scholderer, J. (2012). Effective incomplete contracts and milestones in market-distant R&D collaboration. *Research Policy, 41*, 346-357.

Kochhar, R. (1996). Explaining firm capital structure: The role of agency theory vs transaction cost economics. *Strategic Management Journal, 17*, 713-728.

Kondo, M. (1999). R&D dynamics of creating patents in the Japanese industry. *Research*

Policy, 28, 587-600.

Kumar, N., & Aggarwal, A. (2005). Liberalization, outward orientation and in-house R&D activity of multinational and local firms: A quantitative exploration for Indian manufacturing. *Research Policy, 34*, 441-460.

Kurokawa, S., Iwata, S., & Roberts, E. B. (2007). Global R&D activities of Japanese MNCs in the US: A triangulation approach. *Research Policy*, 3-36.

Lach, S. (2000). Do R&D subsidies stimulate or displace private R&D? Evidence from Israel. *NBER Working Paper No. 7943*.

Lang, G. (2009). Measuring the returns of R&D-An empirical study of the German manufacturing sector over 45 years. *Research Policy, 38*, 1438-1445.

Lee, C. (2009a). Competition favors the prepared firm: Firms' R&D responses to competitive market pressure. *Research Policy, 38*, 861-870.

Lee, C. (2009b). Do firms in clusters invest in R&D more intensively? Theory and evidence from multi-country data. *Research Policy, 38*, 1159-1171.

Lee, C., & Sung, T. (2005). Schumpeter's legacy: A new perspective on the relationship between firm size and R&D. *Research Policy, 34*, 914-931.

Lee, J. (2011). *Engineering technology and policy*. Seoul: Jiho.

Lehrer, M., & Asakawa, K. (2004). Rethinking the public sector: idiosyncrasies of biotechnology commercialization as motors of national R&D reform in Germany and Japan. *Research Policy, 33*, 921-938.

Leland, H. E., & Pyle, D. H. (1977). Informational asymmetries, financial structure, and financial intermediation. *The Journal of Finance, 32*(2), 371-387.

Lerner, J., Sørensen, M., & Strömberg, P. (2008). Private Equity and Long-Run Investment: The Case of Innovation. *NBER Working Paper No. 14623*.

Lhuillery, S., & Pfister, E. (2009). R&D cooperation and failures in innovation projects empirical evidence from French CIS data. *Research Policy, 38*, 45-57.

List, J. A., & Haigh, M. S. (2010). Investment under uncertainty: Testing the options model with professional traders. *NBER Working Paper No. 16038*.

Lychagin, S., Pinkse, J., Slade, M. E., & Reenen, J. V. (2010). Spillovers in space: Does geography matter? *NBER Working Paper No. 16188*.

M'Chirgui, Z. (2009). Dynamics of R&D networked relationships and mergers and acquisitions in the smart card field. *Research Policy, 38*, 1453-1467.

Møen, J. (2007). R&D spillovers from subsidized firms that fail: Tracing knowledge by following employees across firms. *Research Policy, 36*, 1443-1464.

Müller, E., & Zimmermann, V. (2009). The importance of equity finance for R&D activity. *Small Business Economics, 33*, 303-318.

Mairesse, J., & Mohnen, P. (2004). The importance of R&D for innovation: A reassessment using French survey data. *NBER Working Paper No. 10897*.

Marsili, O. (2002). Technological regimes and sources of entrepreneurship. *Small Business Economics, 19*, 217-231.

Mathews, J. A. (2002). The origins and dynamics of Taiwan's R&D consortia. *Research Policy, 31*, 633-651.

Mayer, C. (1988). New issues in corporate finance. *European Economic Review, 32*, 1167-1189.

McNamara, P., & Baden-Fuller, C. (2007). Shareholder returns and the exploration–exploitation dilemma: R&D announcements by biotechnology firms. *Research Policy, 36*, 548-565.

Meuleman, M., & Maeseneire, W. D. (2012). Do R&D subsidies affect SMEs'access to external financing? *Research Policy, 41*, 580-591.

Meyer, L. H. (1998). The present and future roles of banks in small business finance. *Journal of Banking & Finance, 22*, 1109-1116.

Miltersen, K. R., & Schwartz, E. S. (2004). R&D investments with competitive interactions. *NBER Working Paper No. 10258*.

Miotti, L., & Sachwald, F. (2003). Co-operative R&D: why and with whom? An integrated framework of analysis. *Research Policy, 32*, 1481-1499.

Modigliani, F., & Miller, M. H. (1958). The cost of capital, corporation finance and the theory of investment. *The American Economic Review, 48*, 261-297.

Mol, M. J. (2005). Does being R&D intensive still discourage outsourcing? Evidence from Dutch manufacturing. *Research Policy, 34*, 571-582.

Moncada-Paternò-Catstello, P., Ciupagea, C., Smith, K., Tübke, A., & Tubbs, M. (2010). Does Europe perform too little corporate R&D? A comparison of EU and non-EU corporate R&D performance. *Research Policy, 39*, 523-536.

Mora-Valentin, E. M., Montoro-Sanchez, A., & Guerras-Martin, L. A. (2004). Determining factors in the success of R&D cooperative agreements between firms and research organizations. *Research Policy, 33*, 17-40.

Mudambi, R., & Swift, T. (2011). Proactive R&D management and firm growth: A punctuated equilibrium model. *Research Policy, 40*, 429-440.

Munari, F., Oriani, R., & Sobrero, M. (2010). The effects of owner identity and external governance systems on R&D investments: A study of Western European firms. *Research Policy, 39*, 1093-1104.

Munari, F., Roberts, E. B., & Sobrero, M. (2002). Privatization processes and the redefinition of corporate R&D boundaries. *Research Policy, 31*, 31-53.

Myers, S. C. (1977). Determinants of corporate borrowing. *Journal of Financial Economics, 5*, 147-175.

Narula, R. (2002). Innovation systems and 'inertia' in R&D location: Norwegian firms and the role of systemic lock-in *Research Policy, 31*, 795-816.

Narula, R., & Satangelo, G. D. (2009). Location, collocation and R&D alliances in the European ICT industry. *Research Policy, 38*, 393-403.

NEFI. (2005). Financing innovation and research investments for SMEs: Challenges and promotional approaches: Network of European Financial Institutions.

Negassi, S. (2004). R&D co-operation and innovation a microeconometric study on French firms. *Research Policy, 33*, 365-384.

Nunes, P. M., Serraqueiro, Z., & Leitão, J. (2012). Is there a linear relationship between R&D intensity and growth? Empirical evidence of non-high-tech vs. high-tech SMEs. *Research Policy, 41*, 36-53.

O'Brien, J. P. (2003). The capital structure implications of pursuing a strategy of innovation. *Strategic Management Journal, 24*(5), 415-431.

O'Mahony, M., & Vecchi, M. (2009). R&D, knowledge spillovers and company productivity performance. *Research Policy, 38*, 35-44.

Oakey, R. P., & Cooper, S. Y. (1991). The relationship between product technology and innovation performance in high technology small firms. *Technovation, 11*(2), 79-92.

Ogawa, K. (2007). Debt, R&D investment and technological progress: A panel study of Japanese manufacturing firms' behavior during the 1990s. *Journal of the Japanese and International Economies, 21*, 403-423.

Okamuro, H. (2007). Determinants of successful R&D cooperation in Japanese small businesses: The impact of organizational and contractual characteristics. *Research Policy, 36*, 1529-1544.

Okamuro, H., Kato, M., & Honjo, Y. (2011). Determinants of R&D cooperation in Japanese start-ups. *Research Policy, 40*, 728-738.

Opler, T. C., & Titman, S. (1994). Financial distress and corporate performance. *The Journal of Finance, 49*(3), 1015-1040.

Orr, D. (1974). The Determinants of entry: A study of the Canadian manufacturing industries. *Review of Economics and Statistics, 56*, 58-66.

Ortega-Argilés, R., Vivarelli, M., & Voigt, P. (2009). R&D in SMEs:A paradox? *Small Business Economics, 33*, 3-11.

Ouyang, M. (2011). On the Cyclicality of R&D. *The Review of Economics and Statistics, 93*(2), 542-553.

Özçelik, E., & Taymaz, E. (2008). R&D support programs in developing countries: The Turkish experience. *Research Policy, 37*, 258-275.

Pavitt, K. (1985). Patent statistics as indicators of innovative activities: Possibilities and problems. *Scientometrics, 7*, 77-99.

Paxson, D. A. (2003). *Real R&D Options*. Oxford: Blackwell Publishers.

Popp, D., & Newell, R. G. (2009). Where does energy R&D come from? Examining crowding out from environmentally-friendly R&D. *NBER Working Paper No. 15423*.

Rafferty, M. (2008). The Bayh–Dole Act and university research and development. *Research Policy, 37*, 29-40.

Rammer, C., Czarnitzki, D., & Spielkamp, A. (2009). Innovation success of non-R&D-performers: Substituting technology by management in SMEs. *Small Business Economics, 33*, 35-58.

Rogers, E. M. (2003). *Diffusion of Innovations, 5th Ed.* New York: Free Press.

Roijakkers, N., & Hagedoorn, J. (2006). Inter-firm R&D partnering in pharmaceutical biotechnology since 1975: Trends, patterns, and networks. *Research Policy, 35*, 431-446.

Romer, P. M. (1986). Increasing returns and long run growth. *Journal of Political Economy, 94*(5), 1002-1037.

Roper, S., Hewitt-Dundas, N., & Love, J. H. (2004). An ex ante evaluation framework for the regional benefits of publicly supported R&D projects. *Research Policy, 33*, 487-509.

Saint-Paul, G. (1993). Productivity growth and the structure of the business cycle. *European Economic Review, 37*, 861-890.

Sakakibara, M., & Cho, D. (2002). Cooperative R&D in Japan and Korea: A comparison of industrial policy. *Research Policy, 31*, 673-692.

Santamaría, L., Barge-Gil, A., & Modrego, A. (2010). Public selection and financing of R&D cooperative projects: Credit versus subsidy funding. *Research Policy, 39*, 549-563.

Scherr, F. C., & Hulburt, H. M. (2001). The debt maturity structure of small firms. *Financial Management, 30*(1), 85-111.

Schwartz, E. S. (2003). Patents and R&D as real options. *NBER Working Paper No. 10114*.

Shimizutani, S., & Todo, Y. (2008). What determines overseas R&D activities? The case of Japanese multinational firms. *Research Policy, 37*, 530-544.

Simerly, R. L., & Li, M. F. (2000). Environmental dynamism, capital structure and performance: A theoretical integration and empirical test. *Strategic Management Journal, 21*, 31-49.

Singh, J. (2008). Distributed R&D, cross regional knowledge integration and quality of innovative output. *Research Policy, 37*, 77-96.

Singh, M., & Faircloth, S. (2005). The impact of corporate debt on long term investment and firm performance. *Applied Economics, 37*, 875-883.

Socorro, M. P. (2009). R&D investment as a signal in corporate takeovers. *Managerial and Decision Economics, 30*, 335-350.

Song, J., Asakawa, K., & Chu, Y. (2011). What determines knowledge sourcing from host locations of overseas R&D operations?: A study of global R&D activities of

Japanese multinationals. *Research Policy, 40*, 380-390.

Sterlacchini, A. (1999). Do innovative activities matter to small firms in non-R&D-intensive industries? An application to export performance. *Research Policy, 28*, 819-832.

Sterlacchini, A. (2008). R&D, higher education and regional growth: Uneven linkages among European regions. *Research Policy, 37*, 1096-1107.

Stiglitz, J. E., & Weiss, A. (1981). Credit rationing in markets with imperfect information. *The American Economic Review, 71*, 393-410.

Svensoon, R. (2007). Commercialization of patents and external financing during the R&D phase. *Research Policy, 36*, 1052-1069.

Tadesse, S. (2002). Financial architecture and economic performance: International evidence. *Journal of Financial Intermediation, 11*, 429-454.

Takalo, T., & Tanayama, T. (2010). Adverse selection and financing of innovation: Is there a need for R&D subsidies? *Journal of Technology Transfer, 35*, 16-41.

Teixeira, A., & Fortuna, N. (2010). Human capital, R&D, trade, and long-run productivity. Testing the technological absorption hypothesis for the Portuguese economy, 1960-2001. *Research Policy, 39*, 335-350.

Terpstra, V. (1983). Critical Mass and International Marketing Strategy. *Journal of the Academy of Marketing Science, 11*(3), 269-282.

Titman, S., & Wessels, R. (1998). The determinants of capital structure choice. *The Journal of Finance, 43*, 1-19.

Tomiura, E. (2007). Effects of R&D and networking on the export decision of Japanese firms. *Research Policy, 2007*, 758-767.

Tsai, K., & Wang, J. (2005). Does R&D performance decline with firm size?—A re-examination in terms of elasticity. *Research Policy, 34*, 966-976.

Tsai, Y., Lin, J. Y., & Kurekova, L. (2009). Innovative R&D and optimal investment under uncertainty in high-tech industries: An implication for emerging economies. *Research Policy, 38*, 1388-1395.

Un, C. A., & Cuervo-Cazurra, A. (2008). Do subsidiaries of foreign MNEs invest more in R&D than domestic firms? *Research Policy, 37*, 1812-1828.

van Beers, C., Berghäll, E., & Poot, T. (2008). R&D internationalization, R&D collaboration and public knowledge institutions in small economies: Evidence from Finland and the Netherlands. *Research Policy, 37*, 294-308.

van Bekkum, S., Pennings, E., & Smit, H. (2009). A real options perspective on R&D portfolio diversification. *Research Policy, 38*, 1150-1158.

Varsakelis, N. C. (2001). The impact of patent protection, economy openness and national culture on R&D investment: A cross-country empirical investigation. *Research Policy, 30*, 1059-1068.

Vincente-Lorente, J. D. (2001). Specificity and opacity as resource-based determinants of capital structure. *Strategic Management Journal 22*, 157-177.

von Zedtwitz, M., & Gassmann, O. (2002). Market versus technology drive in R&D internationalization: Four different patterns of managing research and development. *Research Policy, 2002*, 569-588.

Wang, E. C. (2007). R&D efficiency and economic performance: A cross-country analysis using the stochastic frontier approach. *Journal of Policy Modeling, 29*, 345-360.

Wang, E. C. (2010). Determinants of R&D investment: The Extreme-Bounds-Analysis approach applied to 26 OECD countries. *Research Policy, 39*, 103-116.

Wang, E. C., & Huang, W. (2007). Relative efficiency of R&D activities: A cross-country study accounting for environmental factors in the DEA approach. *Research Policy, 36*, 260-273.

Wang, T., & Thornhill, S. (2010). R&D investment and financing choices: A comprehensive perspective. *Research Policy, 39*, 1148-1159.

Wen, J., & Kobayashi, S. (2001). Exploring collaborative R&D network: Some new evidence in Japan. *Research Policy, 30*, 1309-1319.

West, J., & Iansiti, M. (2003). Experience, experimentation, and the accumulation of knowledge: The evolution of R&D in the semiconductor industry. *Research Policy, 32*, 809-825.

Williamson, O. E. (1988). Corporate finance and corporate governance. *The Journal of Finance, 43*, 567-591.

Wolff, G. B., & Reinthaler, V. (2008). The effectiveness of subsidies revisited: Accounting for wage and employment effects in business R&D. *Research Policy, 37*, 1403-1412.

Wooldridge, J. M. (2003). *Introductory econometrics*. South-Western: Mason.

Wu, H. (2009). Entry barriers and markup ratios: Evidence from OECD countries. *Applied Economics Letters, 16*, 125-130.

Yasuda, T. (2005). Firm growth, size, age and behavior in Japanese manufacturing. *Small Business Economics, 24*, 1-15.

Yeh, M., Chu, H., Sher, P., & Chiu, Y. (2010). R&D intensity, firm performance and the identification of the threshold: Fresh evidence from the panel threshold regression model. *Applied Economics, 42*(3), 389-401.

Zhang, J., Baden-Fuller, C., & Mangematin, V. (2007). Technological knowledge base, R&D organization structure and alliance formation: Evidence from the biopharmaceutical industry. *Research Policy, 36*, 512-528.

Zivot, E., & Andrews, D. W. K. (2002). Further evidence on the Great Crash, the Oil-Price Shock, and the unit-root hypothesis. *Journal of Business & Economic Statistics, 10*(3), 25-44.

Abstract (Korean)

본 연구의 목적은 연구 개발 투자와 금융에 대한 결정이 연구 개발 활동에 미치는 영향을 밝히는 것이다. 기존 투자 이론에 따르면, 어떤 자산을 살 것인지 혹은 얼마만큼 투자할 것인지를 결정하는 투자 결정과 그 자산의 대금을 어떻게 지불할 것인지를 결정하는 금융 결정이 기업 투자에 있어 중요한 두 가지 결정 사항이다.

연구 개발 투자 결정과 관련해서, 투자 대상에 대해서는 많은 연구가 진행되었지만, 적정 투자량에 대한 연구는 측정의 어려움으로 인해 거의 이뤄지지 않았다. 최근 연구 개발 투자의 최적 수준에 관한 연구들이 이뤄졌지만, 투자와 성과간의 시차에 대한 고려가 이뤄지지 않았다. 연구 개발의 투자의 최적 수준 (혹은 포화점) 뿐만 아니라 연구 개발 성과 증가를 위해 필요한 최소한의 투자량을 의미하는 임계점도 연구 개발 투자 결정에 있어 중요한 고려사항이다. 그러나 많은 학자들이 임계점의 존재와 중요성에 대해 언급하였음에도 불구하고 임계점의 측정은 이뤄지지 않았다.

연구 개발 금융 결정과 관련해서, 많은 연구들이 부채 비율이 높은 회사들은 연구 개발 투자를 줄이는 경향이 있다고 지적하였다. 그러나 최근 연구들에 따르면, 부채와 연구 개발 투자의 관계는 기술 집중도 혹은 부채의 종류에 따라 달라질 수 있다. 특히 채권과 달리 대출은 연구 개발 투자의 자산 특이성, 불확실성, 전유성을 잘 통제할 수 있기 때문에, 대출과 연구 개발 투자는

정(正)의 관련성을 갖게 된다. 그러나 대출과 연구 개발의 관계를 다룬 기존의 연구들은 관계에 중요한 영향을 미칠 수 있는 대출 만기, 기술 집중도, 경기(景氣)를 고려하지 않았다.

따라서 본 연구에서는 첫째, 학자와 정책 입안자들의 관심이 날로 높아지고 있는 중소 제조업체 연구 개발 투자의 임계점과 포화점을 실증적으로 측정하였다. 횡단면 한계 추정법을 이용하여 두 가지 값을 추정하였으며, 추정된 결과는 연구 개발 성과와 기술 집중도에 따라 다르게 나타난다. 특허 성과와 관련해서, 하이테크 산업에서는 연구개발 집약도와 연구개발 지출에 있어 임계점이 측정되었으나, 로테크 산업에서는 임계점이 측정되지 않았다. 그 이유는 로테크 산업 대비 하이테크 산업의 높은 불확실성, 기술 진입장벽 때문인 것으로 보인다. 이익 성과 관련해서, 하이테크 산업과 로테크 산업 모두에서 포화점 만이 측정되었다.

둘째, 대출 만기, 기술 집중도, 경기상황을 고려하여 중소제조업체의 대출 비율이 연구개발 활동에 미치는 영향을 조사하였다. 분석 결과에 따르면, 연구개발 집약도는 각각 장기 대출 비율과는 정(正)의 관계를, 단기 대출 비율과는 부(負)의 관계를 갖는다. 또한 경기 하강기에 그리고 하이테크 기업들이 단기 대출 비율 증가 시 연구 개발 투자를 더 줄이는 경향을 보인다.

셋째, 앞서 분석한 결과들을 토대로 중소기업 연구 개발 투자의 성과와 효율성을 높일 수 있는 정책과 전략을 제안하였다. 임계점보다 적은 양을 투자하는 하이테크 기업들에게, 장기 대출을 통해 확보된 자금으로 연구 개발 투

자를 늘려 임계점에 도달하는 방법은 좋은 선택이 될 수 있다. 장기적으로는 자본 투자도 좋은 대안이 될 수 있다.

정리하면, 본 연구는 연구 개발 투자의 임계점과 포화점 측정을 통해 중소기업의 연구 개발 투자 결정이 연구 개발 성과에 미치는 영향과 대출 비율과 연구개발 집약도 사이의 관계 분석을 통해 자본 구조에 대한 결정이 연구 개발 투자에 미치는 영향을 보여주었다. 그리고 이를 바탕으로 연구 개발 투자의 성과와 효율성을 높일 수 있는 복합적인 결정 방안을 제시하였다.

주요어 : 연구 개발 투자, 중소기업, 기술 집중도, 임계점, 포화점, 대출 만기
학 번 : 2008-30904