Is There a Case for an Augmented Tobin's Q Model of R&D Investment? Investigating the Role of Market Structure, Knowledge Spillovers and Corporate Governance Quality

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DECLARATION

I certify that the work contained in this thesis, or any part of it, has not been accepted in substance for any previous degree awarded to me, and is not concurrently being submitted for any degree other than that of Doctor of Philosophy being studied at the University of Greenwich. I also declare that this work is the result of my own investigations, except where otherwise identified by references and that the contents are not the outcome of any form of research misconduct.

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ABSTRACT

The determinants of R&D investment at firm-level have been a topic of interest for economists for a long time. However, our knowledge of the firm's R&D investment behaviour remains somewhat fragmented. In this thesis, I postulate the idea of an augmented Tobin's Q model, in which several different but not mutually exclusive theories can be considered together in explaining the R&D investment decision-making process at firm-level.

The first contribution of this thesis is to bring back to the literature on firm investment in general and R&D investment in particular the Tobin's Q theory, or more precisely, the role of market returns adjusted for replacement cost of capital and its implications for expectations formation. To do this, I propose using the one-period-ahead growth rate of Tobin's average Q instead of average Q itself as a measure of expected profitability and investment opportunities. Second, I argue that this measure can only reflect one part the information set that managers take into account in forming their investment decisions. Hence, the model is augmented and tested empirically with three other factors: product-market competition, the level of R&D spillovers and corporate governance quality, all of which I demonstrate to have a significantly effect on desired R&D investment at firm-level in the literature.

Taking the system generalised method of moments estimator to a rich data set of 3,718 manufacturing firms from 15 OECD countries over the 2005-2013 period, the thesis reports several findings. First, the one-period-ahead growth rate of Tobin's average Q, which corresponds to one-period-ahead market rate of return weighted with one-period-ahead change in replacement cost of capital, has a positive and significant effect on firm R&D investment. However, it cannot explain the rate of R&D investment fully – in contrast to the neoclassical theory that predicts the investment opportunity reflected by Tobin's marginal Q can be the sole determinant of R&D or physical capital investment. In my results, while the positive effect of the one-period-ahead growth rate of Tobin's average Q remains a significant determinant of R&D investment, I also find: (i) an inverted-U shape relationship between product-market competition and R&D investment; (ii) significant effects of both intra- and inter-industry spillovers that indicate both knowledge externalities and 'market-stealing' effects, depending on the level at which the spillover pools are constructed; and (iii) some mixed effects of governance quality on R&D investment.

The last contribution of this research relates to observed source of heterogeneity in the relationship between the one-period-ahead growth rate of Tobin's average Q and R&D investment. I find that the effect of the one-period-ahead growth rate of Tobin's average Q is stronger when the firms are either small or medium-sized, but it is weaker and insignificant when the firm's R&D intensity level is lower than the average R&D intensity in its two-digit SIC industry over the 2005-2013 period of investigation.

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CHAPTER 1: INTRODUCTION

1.1. The importance of R&D investment for innovation and growth

The importance of new technologies and innovations for competitiveness and growth is a truism among managers, policy makers, and researchers. According to Porter (1990), innovation, continuous improvement and change are the three cornerstones of global competitiveness. In today's competitive market environment, firm managers are increasingly concerned with the need to be first, fast, and on-time in delivery of the new products or innovative processes (Wong, 2002). The UK government strongly believes that unless firms invest in innovation and find ways to incorporate innovation into the delivery of front line services, future performance will remain inefficient and ineffective (Brown, 2010). In fact, the most recent UK Innovation Index published by Nesta estimated that between 2000 and 2008, innovation accounted for 51 per cent of labour productivity growth (UK Department for Business Innovation & Skills, 2014, p. 25).

Even though innovations have the potential to transform organisations and industries, they are also fraught with risk. Some innovations are worth little or even nothing, although some of them are extremely valuable and bring strong market power to the innovators (Marshall and Ojiako, 2010; Bosworth and Jobome, 1999; Greve, 2003). Risk is a central component of innovation, as emphasised in Hurst (1982, p.86): "An innovation is a hypothesis, whose truth cannot be established with certainty". Hence, even though the importance of innovation is recognised, fostering innovation is still a complex policy and practice issue. It is also a complex issue in terms of theoretical and empirical modelling as we are still far from agreement on models or theories on factors that determine firm incentives to innovate and whether these factors work in tandem or at cross purposes (Ugur, 2013). As indicated by Souitaris (1999, p.288): "Despite the substantial research effort, it is not very clear what the relevant variables themselves are, nor what impact they have on innovation".

Given the importance of innovation for productivity and growth, much attention has focused on research and development (hereafter R&D) investment as a separate input in addition to conventional inputs such as physical capital and labour (Griliches, 1979). R&D consists of creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society to devise new applications (Frascati Manual, 2002, p.30). Given the knowledge dimension, returns to R&D investment may be non-excludable and subject to time lags, with potentially significant differences between private and social rate of returns. These characteristics differentiate R&D investment from other inputs such as physical capital. Hence, it has been a significant area of research informed by ‘endogenous growth models’ (e.g. Romer, 1986, 1990; Grossman and Helpman, 1991), where R&D (or knowledge) capital is regarded as a key factor that allows regions and countries to attain higher levels of income and growth (Trajtenberg, 1990; Bilbao-Osorio and Rodriguez-Poze, 2004; Akcali and Sismanoglu, 2015). Similar findings have been reported at micro-level (Wakelin, 2001; Wang, 2010; Koellinger, 2008; Wenzel et al., 2009).

Recently, several OECD countries have adopted the idea of R&D capitalisation. Instead of the traditional practice that treats R&D investment as ‘expenditure’, it is now considered as investment in knowledge (R&D) capital. R&D capital is formed when a producer invests in a project that ‘increases the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications’ (Frascati Manual, 2002; Wenzel et al., 2009). The reason for that change is that the treatment of R&D as expenditures did not reflect the true nature of R&D, its products of which can be used over multiple periods in different sectors or industries. R&D, codified in a written report or patent, can also be sold and is therefore an asset to its owner (Ker, 2014).

There are already some studies that analyse the empirical case for R&D capitalisation. For example, using the data set of 520 UK firms from 1990-1999, Oswald and Zarowin (2007) find that capitalisation enables management to better communicate information about the success of projects and their probable future benefits. Similarly, R&D capitalisation helps mitigate the information asymmetry problem and improve market liquidity for R&D-intensive firms (Boone and Raman, 2001). In addition, Prencipe et al. (2008) investigate the R&D cost capitalisation to the family firms in Italy, and confirm that the R&D capitalisation protect the family firms’ reputation in its long-term relationship with the lenders.

Nonetheless, it is also the case that R&D investment entails long-term horizons; and a high degree of uncertainty in terms of securing successful innovations and converting the latter into new products and services in the market (Mansfield et al., 1977). Several studies have shown that the market valuation of R&D investments is volatile over time (Hall, 1993a, 1993b); and across countries (Jaffe, 1986; Cockburn and Griliches, 1988; Grandi et al., 2009).

Therefore, the need for investigating the determinants of R&D investment is evident at all levels - from the national, regional and micro levels. Nevertheless, the literature on innovation in general and R&D in particular is still characterized by an evident lack of consensus on the factors that influence the firm's R&D investment decisions and the extent to which there is scope for developing a unified framework for modelling and estimation.

1.2. Existing models of R&D investment: A fragmented research landscape

Despite the apparent consensus on the importance of R&D investment for firm performance in general, our knowledge of the firm R&D investment behaviour remains somewhat fragmented. True, a large number of studies have investigated the determinants of R&D investment, paying attention to the roles of market competition (Schumpeter, 1942; Arrow, 1962; Aghion et al., 2005); corporate governance dimensions (see Belloc (2012) for a review); and firm characteristics such as cash flow, leverage, etc. (Hall, 2002; Ughetto, 2008; Lewis and Tan, 2016). These studies draw on different theories to justify their models. For instance, some studies adopt a Schumpeterian perspective on the relationship between product-market competition and R&D investment. In this perspective, the driver of firm investment in R&D is the prospect of monopoly rents that increase both the firm's profitability and its ability to finance R&D investment through own funds. On the contrary, Arrow (1962) confronts Schumpeterian idea by arguing that a monopoly shielded against competition has less incentive to innovate because it can earn positive profits with or without innovation; while a firm in a perfectly competitive market does not earn positive profits unless it innovates and its innovation is protected by exclusive intellectual property rights.

Besides, several studies concentrate on the relationship between R&D investment and corporate governance (hereafter CG). This stream of work draws on the so-called 'agency theory', which predicts a negative relationship between the firm's R&D effort and agency costs (Jensen and Meckling, 1976; Shleifer and Summers, 1988). However, findings have been varied and often conflicting (Belloc, 2012). The reason is that, in a world of imperfect contracts, the effect of CG provisions on agency costs (i.e., the extent to which a CG provision aligns the interests of the shareholders and managers) is uncertain. Another source of ambiguity is whether market structure and the CG provisions are complements or substitutes in their disciplining effects on managers.

Thirdly, despite the neoclassical insights about knowledge externalities (Arrow, 1962; 1996), and a wealth of evidence on the positive relationship between R&D spillovers and productivity (for the reviews, see Ugur et al., 2016a; Hall et al., 2010), there has been little attempt at investigating whether or not the firm's R&D investment decisions are influenced by incomplete appropriability of the R&D investment.[1] This is in contrast to the extant literature that investigates the extent to which public support to R&D investment (direct subsidies and/or tax credits) can ameliorate the negative effects of spillovers on firm incentives to invest in R&D activities.

Finally, there has been both theoretical and empirical work investigating the relationship between Tobin's Q (an indicator of future investment opportunities) and firm physical capital and R&D investment (Hayashi, 1982; Hall, 1992; Mairesse and Siu, 1984). Even though the theoretical justification for marginal Q as a determinant of firm investment is strong and appealing, the empirical findings have been mixed. Probably, this is due to the common practice of using Tobin's average Q as a proxy for the unobservable marginal Q and the set of strict assumptions (including perfect market competition) that underpins the relationship between Tobin's Q and investment (Chirinko, 1986; Summers et al., 1981). However, this state of affairs does not justify overlooking the importance of Tobin's marginal Q (or an appropriately constructed proxy thereof) in shaping managerial expectations about investment in general and R&D investment in particular.

I argue that the issue at hand is more empirical than theoretical and the challenge is to construct a proxy for the marginal Q that can reflect the source of information observable to the managers in forming their expectations about desired investment. In addition, even though the existing literature allows for asymmetric information in capital markets by acknowledging a role for cash flow constraints, it tends to overlook the other types of market imperfections (e.g., knowledge spillovers) that may confound the relationship between Tobin's Q and physical capital or R&D investment. In other words, the choice of control variables in semi-augmented Tobin's Q models of investment tends to be ill-defined if not arbitrary.

[1] To the best of our knowledge, there have been only few studies that models R&D investment as a function of spillovers, especially in a standard model of firm investment in the literature.

The summary above suggests a need for returning to basics and building an R&D investment model that takes account of the theories on its determinants, including Tobin's Q, the theory of market structure, and the agency theory of R&D investment.

1.3. Is there a case for an augmented Tobin's Q model of R&D investment?

Based on the literature, there are both theoretical and empirical reasons for developing an augmented Tobin's Q model of R&D investment. The theoretical perspectives on R&D investment draw attention to various factors that affect the managerial incentives for R&D investment and as such they are not rival or mutually exclusive. Whereas Tobin's Q emphasises the role of expectation about future profitability on firm investment, the market competition and agency theories focus on the factors that affect incentives for R&D investment through their disciplining effects on managers. Finally, the knowledge externalities perspective draws attention to disincentives caused by incomplete appropriability of the returns to R&D investment. Then, theoretically, there is no *a priori* reason to treat each theoretical perspective in isolation as each looks at different channels through which the firm's incentives for R&D investment can be influenced.

There is no empirical case for isolation either because omitting some variables informed by one or more theoretical perspectives amounts to model misspecification. Therefore, in what follows, I will investigate the case for an augmented Tobin's Q model by summarising the need to take account of market competition, CG provisions, and the level of externalities. Following this exercise, I will state my research questions and summarise the structure of the thesis.

1.3.1. Tobin's Q and the incentive for R&D investment

Tobin's Q theory – introduced by Keynes (1936) and revitalised and elaborated by Brainard and Tobin (1968) and Tobin (1969) – has been a dominant theory of investment for several decades. Its appealing intuition is that it incorporates forward-looking behaviour, reflects optimal choices, and contains estimated coefficients that are readily identified with underlying structural parameters (Chirinko, 1986). Yet, empirical findings on the relationship between Tobin's Q and investment remain mixed. The existing literature identifies two possible reasons. First, the common approach using average Q as a measure of marginal Q with the set of strict assumptions including perfect market competition is unconvincing. Several studies have documented the very low correlation between average Q and marginal Q (for example, see Ang and Beck, 2000). Secondly, and in relation to the first, if average Q cannot be a good measure of marginal Q, using it as the sole determinant of firm investment could bring another serious problem of omitted variable bias. In fact, the significant effects of other factors such as financial constraints or the past investment in Tobin's Q model have been reported in Chirinko (1986), Fazzari et al. (1988). Hence, this literature leads to the question of whether it is possible to find another measure of expectations (or a proxy for marginal Q), which allows also for relaxing the strict and unrealistic assumptions that hinder the empirical work. It might be more reasonable to consider that firms are operating in imperfectly competitive markets and therefore, whether the role of expectations in explaining the firm's investment decisions might be different after controlling for market power or agency problems.

Despite these concerns, a number of studies have argued that the Tobin's Q can be used for investigating investment not only in physical capital but also in R&D activity. It is attributable to two main reasons. First, even though R&D is a distinct type of investment, it has similar characteristics with physical capital investment. "The Modigliani-Miller theorem states that a firm which is choosing 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. The last dollar spent on each type of investment should yield the same rate of return" (Hall, 1992, p.5-6). Chung et al. (2003) confirm that under similar corporate governance characteristics, there are significant correlation between firm value and both physical capital as well as R&D investment.

Second, both physical capital and R&D investment have the same final purpose of improving productivity and/or increasing profitability (Aw et al., 2008; Castellani et al., 2016). Hence, they are likely to be substitutes and may be determined by similar factors. In addition, Abel et al. (1996) argue that a firm decides its level of investment based on marginal value of capital, which is irrespective of whether it is physical capital or R&D investment. Empirically, with the same set of explanatory variables in an extended Tobin's Q model for regressing both R&D and physical capital investment, Hall (1992) concludes that even though the coefficients are different, these two types of investment are determined by similar factors (Tobin's Q and cash flow in her case). Mairesse and Siu (1984), along the same line, apply the accelerator model to confirm that both R&D and physical capital investment react very similarly to the movements in stock market one-period holding rate of return, and even the response of R&D is more stable or less irregular than that of physical investment. In Himmelberg and Petersen (1994), Tobin's Q even has significant effect on R&D regression only, not for physical capital investment regression.

Bearing all that in mind, my thesis provides a check for the role of expectations on firm R&D investment using a different measure of Tobin's Q. Instead of using the average Q itself, I apply the one-period-ahead growth rate of Tobin's average Q as a measure of market movements as well as the signal for the profitability of future investment. Similar to Fischer and Merton (1984), Ben-Zion (1984) and Mairesse and Siu (1984), I argue that it is stock market movements and reactions that induces managers to revise their R&D investment plan, and therefore it plays an important role in determining the optimal level of R&D investment at firm-level. However, I take another step and demonstrate that the one-period-ahead rate of market returns should be weighed by the one-period-ahead rate of change in the replacement cost of capital. This is because future investment opportunities depend not only on market value of the firm but also on the replacement cost of capital – as demonstrated by the original Tobin's Q theory.

In addition, I argue that the revision of expected profitability might only reflect one part of the information set that managers take consideration in choosing the desired level of R&D investment for their firms. Hence, another aim of this thesis is to test for the extent to which Tobin's Q can be linked to other theories of R&D investment. To address this issue, my proposed measure of the one-period-ahead growth rate of Tobin's average Q helps to remove the assumption of perfect market competition, as the equality between average Q and marginal Q is no longer required. From that, I examine whether the actual level of product-market competition can be a significant additional factor in my augmented Tobin's Q model. The other two factors which potentially affect the firm's investment decisions, the level of knowledge spillovers and corporate governance quality, will also be tested in my model, with the theoretical justifications are presented in the next sub-sections.

1.3.2. Product-market competition and the incentive for R&D investment

One factor that should be controlled for in the augmented Tobin's Q model is product-market competition, as its role has been discussed extensively in the literature on the determinants of innovation in general and R&D spending in particular. It was originally postulated by Schumpeter (1934, 1942) as two major patterns of innovative activities with regard to different market structures. The first pattern, labelled by Nelson and Winter (1982) and Kamien and Schwartz (1982) as Schumpeter Mark I, is from his *The Theory of Economic Development* book in 1934. In this book, he examined the typical European industrial structure of the late nineteenth century characterised by several small firms. According to this view, new innovating entrepreneurs come in an industry would challenge incumbent firms by introducing new ideas, new products or new processes that make current technologies and products obsolete. This effect of creative destruction indicates the importance of low entry barrier and small firms on economic development. However, the main problem with this earlier work (Schumpeter Mark I) is that he failed to take the organizational dimension properly into account. In later work (Schumpeter, 1942), he acknowledged this weakness and emphasised the relevance of existing capacity and industrial R&D laboratory for technological innovation and the key role of large firms in a more concentrated market to induce more innovative activities (Nelson and Winter, 1982; Malerba and Orsenigo, 1995; van Stel et al., 2005). This Schumpeter Mark II had dominated the literature for a while, until it was challenged by Arrow (1962), where the author argues that monopolies have less incentive to innovate, as they can earn positive profits with or without innovation. Hence, it must be small and medium businesses in the competitive market who are the main innovative actors, because they will not earn positive profits unless they start inventing.

Before 2005, the debate on the competition-innovation relationship revolved around the ‘Schumpeter negative’ and ‘Arrow positive’ arguments. A turning point in the debate was reached when Phillippe Aghion and his colleagues published a paper titled ‘Competition and Innovation: An Inverted-U Relationship’ in 2005. In that paper and in later work summarised in Aghion et al. (2014), the non-linear relationship between competition and innovation has been related to two factors: (i) the distance of the innovating firm to the technology frontier in its industry; and (ii) whether the competition in innovation is between neck-and-neck or leader-laggard firms. Since 2005, a number of empirical papers have reported supportive findings for the existence of a non-linear relationship between product-market competition and innovation (Tingvall and Poldahl, 2006; Polder and Veldhuizen, 2012; Berube et al., 2012; Ugur and Hashem, 2012).

Despite the pivotal role accorded to market structure in the literature on innovation, product-market competition has been usually neglected in Tobin’s Q models of R&D investment.

Economists often accept unconditionally the assumption of perfect market competition, in order to have the equality between two measures of Tobin's Q: the average and marginal Q. However, even when this assumption is applied, Tobin's average Q often fails to emerge as a significant determinant of investment. In an attempt to relax the perfect market competition assumption, Chirinko and Fazzari (1988) and Galeotti and Schiantarelli (1991) have reported the significance of output measures in Tobin's Q models of investment. In this thesis, I take a step further and verify if product-market competition is significant in Tobin's Q model of R&D investment, where I use the one-period-ahead growth rate of Tobin's average Q as a proxy for both expected profitability and investment opportunities.

1.3.3. Corporate governance and the incentive for R&D investment

Another strand in the literature looks inside the organisation and investigates whether the corporate governance structure matters. The intuition behind this research direction derives from 'agency theory', in which 'agency costs' that arise from the separation of ownership and management might have strong effect on firm R&D investment. On the one hand, shareholders may be motivated to invest in innovative firms in order to diversify their portfolios. On the other hand, the executive's wealth is a function of compensation which may be affected adversely by the risks involved in R&D investment. Hence, the agency problem arises whenever the executives prefer maximizing their utility rather than the wealth of the shareholders (O'Connor and Rafferty, 2012).

More specifically, corporate governance quality can affect the level of firm R&D investment through three main dimensions. The first dimension is the level of ownership concentration, as the large stockholders have an obvious incentive to monitor top management's decisions closely in order to promote the firm's long-term performance, whereas the diversion of many stockholders creates more opportunities for managerial myopia to occur. The second component of corporate governance relates to the strength and usefulness of anti-takeover defence tools the firm is applying. On the one hand, the work that focuses on shareholder welfare hypothesis postulate the use of strong anti-takeover defence tools such as poison pills or classified or staggered board, as the reduced risk of takeover induces managers to focus more on long-term rather than short-term returns. On the other hand, the work that focuses on management welfare argue that the use of strong anti-takeover defence tools may be harmful in a way that managers are likely to opt for 'quiet life' and have less incentive to commit to R&D investment with uncertain returns. The third dimension relates to board structure. Given the fact that board members are responsible for evaluating and rewarding executives' performance, the composition and functioning of the board, its strategic orientation and its effectiveness all emerge as important factors that have disciplining effects on firm managers and the latter's decisions concerning firm investment in R&D.

Although there has been a rich literature on the relationship between corporate governance quality and the optimal level of firm R&D investment, the results remain inconclusive. The effect of different measures such as ownership concentration, the level of board independence, the separation and diversification of board of directors are often reported as significant determinants, but the reported effects are conflicting (more details are presented in chapter 2 of literature review below).

In addition, some studies also investigate the combined effect of corporate governance and market competition on R&D investment. The idea is that both factors shape the cost-incentive structure that managers are likely to face when they choose the level of innovation effort (Ugur and Hashem, 2012). This strand of work in Aghion et al. (1999, 2002) and Ugur and Hashem (2012) is another source of motivation for this research, as they treated the different theories on the determinants of R&D investment as complementary rather than mutually exclusive.

1.3.4. Knowledge spillovers and the incentive for R&D investment

Last but not least, insights from 'endogenous growth models' (e.g. Romer, 1986, 1990; Grossman and Helpman, 1991) indicate that knowledge spillovers may cause a firm's actual level of R&D investment to be less than optimal. Since knowledge spillovers are unobservable, this prediction is tested indirectly, by estimating the effect of external knowledge (spillover) pool on the firm's, industry's and country's knowledge production or productivity. If the effect is positive, the evidence indicate the existence of knowledge spillovers.

After more than two decades of intensive research, knowledge spillovers is often reported to have a positive effect on knowledge production or productivity (Coe and Helpman, 1995; Keller, 2002; Abdih and Joutz, 2006). As explained by Nadiri (1993), an important feature of the linkage between innovation and productivity is the imitation process. Firms devote their resources to two goals: to improve the quality of their existing products and production processes or to discover the new products or processes. When they are successful, the others will devote their resources to be able to copy the new knowledge from the innovating firm. Empirically, Keith Pavitt in 1984 showed that out of 2000 innovations introduced in the UK, only about 40% were developed in the sector using the innovation. The remaining innovations were borrowed from new technologies developed in other sectors. These findings suggest that the spillover pool constitutes a substitute for the firm's own R&D investment; and the larger the spillover (external knowledge) pool, the lower the firm's R&D investment effort should be found.

On the other hand, the high level of spillovers might induce firms to engage more in their own investment, due to two possible reasons. First, this is because of the threat of the creative destruction effect that their own knowledge and technology might become obsolete because of new inventions from their competitors. Second, the hope of overtaking existing leaders and stealing their market shares by successful investment, the so-called 'market-stealing' effect, might encourage firms to accept uncertainty and invest more in R&D activities (Bloom et al., 2013). In this case, the spillover pool constitutes a complement for the firm's own R&D investment; and the larger the spillover pool, the higher the firm's R&D investment effort.

Therefore, the overall effect of spillovers on the firm's R&D investment depends on whether the substitution or complementary effect dominates. This can be established only through empirical investigation, which this thesis is aiming to undertake.

1.4. Research questions

Given the discussion above, my first research question is about whether the one-period-ahead growth rate of Tobin's average Q, my measure of expected future profitability and investment opportunities, is a factor that affects firm decisions about the desired level of R&D investment? I hypothesize that the one-period-ahead growth rate of Tobin's Q has a positive and significant effect on managerial incentives for R&D investment, because an upward traction in Tobin's average Q is an indication of increased investment opportunities after taking account of the replacement costs of the firm's capital assets.

My second research question is twofold and relates to whether the one-period-ahead growth rate of Tobin's average Q, (i) is the sole determinant of the firm's R&D investment; and (ii) remains a significant determinant of R&D investment when the model is controlled for other factors known to be associated with R&D investment decisions. To address this question, I augment the Tobin's Q model with three other factors that have been reported to have a bearing on managerial incentives for investing in R&D: product-market competition, knowledge spillovers and corporate governance quality. My hypothesis is that the traction in Tobin's average Q, which shapes the manager's expectations about the profitability of new investment, is not the sole determinant of R&D investment but it is a consistently significant determinant when competition, knowledge spillovers and governance quality are controlled.

My third and fourth research questions relate to the partial effects of competition, knowledge spillovers and corporate governance quality on R&D investment; and whether the effect of the growth rate of Tobin's average Q is heterogeneous. I hypothesize that: (i) the effect of competition on R&D investment is non-linear; (ii) the effect of spillovers on R&D investment depends on the balance between the negative effect of knowledge externalities and the positive effects of creative destruction and/or 'market-stealing'; (iii) better corporate governance quality is associated with higher levels of R&D investment; and (iv) the effect of the growth rate of Tobin's average Q on R&D investment is not uniform across firm types, industry characteristics and legal regimes.

1.5. Research contributions

My thesis contributes to the literature on firm R&D investment along two dimensions. First, it presents a novel approach to the traditional Tobin's Q theory using the one-period-ahead growth rate measure of Tobin's average Q that takes account of firm entry and exit into the data set. Different from the common but unsuccessful approach using average Q as a measure of marginal Q with a set of strict assumptions, my approach focuses on information from the market rate of returns weighted by the change in replacement cost of capital. This is in line with the perspective in Fischer and Merton (1984) and Ben-Zion (1984), who demonstrate that a rational manager's investment decisions depends on existing information that shapes his/her expectations about the future. However, different to Mairesse and Siu (1984), I use the one-period-ahead growth rate of Tobin's average Q instead of their use of one-period holding rate of return on stock prices. This is because the growth rate (traction) of Tobin's Q provides information not only about the market returns but also about the change in the latter's magnitude relative to the replacement cost of capital. As such, the proposed measure here not only reflects the role of expectations about future profitability but also helps relaxing the strict assumptions required for the equality between marginal Q and average Q in the common empirical approach to Tobin's Q theory.

From that, my research builds bridges between different but not mutually exclusive theories of investment. On the one hand, Eklund (2013) argues that one of the main problems of the literature on determinants of firm investment is that expectations play no role in most of the existing theories. R&D study is not an exception. On the other hand, the theoretical claim that marginal Q can be the sole determinant of firm investment from Hayashi (1982), Abel (1979) has blocked the link between Tobin's Q and other theories. This issue is released by using the new measure of the growth rate of Tobin's average Q, and therefore I test whether the other factors (product-market competition, the level of knowledge spillovers and corporate governance quality) can contribute towards building an augmented Tobin's Q model of firm R&D investment.

A further contribution of this thesis is that it provides evidence on whether the relationship between the one-period-ahead growth rate of Tobin's average Q and R&D investment decisions is homogeneous or heterogeneous across firm types, industry characteristics and legal traditions. I am able to check for heterogeneity using a rich data set of 3,718 R&D-active listed firms from 15 OECD countries. These firms account for approximately 29% of the total R&D investment in the whole world (data in 2013).[2]

Finally, the empirical findings in this thesis is obtained from a system generalised method of moments (system GMM) estimator that is shown to be effective in taking account of endogeneity, time-invariant heterogeneity, and path dependence in the outcome variable (R&D investment as a ratio of lagged total assets).

[2] Total R&D expenditure is 1,558 billion $US (reported in Battelle and R&D Magazine's 2014 Global R&D Funding Forecast), while in my dataset, total R&D expenditure in 2013 is 449.7 billion $US.

1.6. Thesis structure

The rest of this thesis is organised as follows. Chapter 2 reviews the theoretical and empirical literature on both Tobin's Q theory and other factors (product-market competition; knowledge spillovers, and corporate governance quality) as determinants of R&D investment. Then, the chosen theoretical framework, methodology and data are presented in chapter 3. Chapter 4-6 provide my empirical results. Specifically, chapter 4 reports the empirical work on my baseline model taken and modified from Mairesse and Siu (1984) where the role of expectations about future profitability and capacity need are tested in firm R&D investment model. It also presents the results of the first augmented Tobin's Q model with the presence of product-market competition. Whether the latter contributes significantly to the model will verify the possibility of an augmented Tobin's Q model. Then, chapter 5 continues the work with another check for the level of R&D spillovers in the empirical model. It should be noted here that the model developed in chapter 5 nests that model in the previous chapter. Then, the last empirical chapter, chapter 6, carries out the same procedure by controlling for corporate governance quality. Finally, chapter 7 concludes the thesis with the summary of findings and contributions, following by the policy implications, research limitations and recommendations for further study.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

This chapter reviews the theoretical and empirical literature on both the Tobin's Q theory and other factors related to the optimal level of R&D investment. Fundamentally, it identifies the strengths and weaknesses of the existing empirical models and their theoretical underpinnings with respect to determinants of R&D investment, based on two critical issues. First, it re-emphasises the appealing intuition of Tobin's Q theory, in which all the relevant information to managers in forming their investment decisions are captured in the marginal Q – the marginal profitability in an additional unit of investment. However, it indicates the failure of empirical literature in reflecting this theoretical framework. Second, it synthesizes the existing evidence to verify whether the Tobin's Q model of R&D investment should be augmented with other potential determinants of investment such as product-market competition, knowledge spillovers and corporate governance quality.

There are three sections in this chapter. Section 2.2 presents a survey of Tobin's Q theory of investment, starting with part 2.2.1 where I introduce the intuition that Tobin's marginal Q provides all the relevant information to explain firm investment in general and part 2.2.2 where this relationship is proven through theoretical framework. Then, in part 2.2.3, I discuss the extension of the traditional Tobin's Q theory of firm investment as a result of the relevance of stock market value not only physical capital but also for R&D investment. Part 2.2.4 reviews the empirical literature, especially on that expansion of Tobin's Q theory with regard to R&D investment. I conclude this section by indicating that Tobin's Q is a necessary but not sufficient determinant of R&D investment if: (i) market imperfections (deviations from perfect competition) exist; (ii) variations in corporate governance quality are conducive to variations in managerial incentives and effort, and (iii) R&D spillovers (knowledge externalities) affect R&D investment decisions.

In each of the next three sections, I review first the theoretical and then the empirical literature on the three factors that reflect departures from perfect competition and absence of agency problems – namely: product-market competition, corporate governance quality and the level of knowledge spillovers. I first re-emphasise the theoretical explanation for the relationship, before the reviewing the measurement issues and the empirical results. I then conclude the chapter by indicating that there is a possible solution for the fragmented nature of the research field by augmenting the Tobin's Q model with product-market competition, corporate governance quality and R&D spillovers as additional determinants of managerial incentives for R&D investment.

2.2. Tobin's Q theory of investment

This section reviews the literature on Tobin's Q theory of investment. I first re-emphasise the appealing intuition of Tobin's Q theory, in which Tobin's marginal Q is considered as the sole determinant of firm investment. Then, I summarise the expansion of its effect in determining the optimal level of not only physical capital but also R&D investment. Finally, I review early work that estimates the effect of Tobin's Q on R&D investment and conclude that Tobin's Q, an important source of information on why firms invest in R&D, may not provide the full set of information relevant for R&D investment decisions if industry-level product-market competition, corporate governance rules and R&D spillovers vary between firms.

2.2.1. Tobin's Q theory and firm investment

Along with neoclassical theory, Tobin's Q theory of investment has made a significant contribution to the literature of investment in the 1970s and 80s. The intuition behind it can be found back in Keynes (1936):

> "There is no sense in building up a new enterprise at a cost greater than that at which a similar existing enterprise can be purchased; whilst there is an inducement to spend on a new project what may seem an extravagant sum, if it can be floated off the stock exchange at an immediate profit" (p.151).

In comparison to previous theories of investment, Tobin's Q theory is particularly appealing because it incorporates forward-looking behaviour, reflects optimal choices, and contains estimated coefficients that are readily identified with underlying structural parameters (Chirinko, 1986). The theory suggests a positive correlation between Tobin's Q and the level of firm investment, since "both investment and the value of Q react to the same state of long-run expectations about future output and prices. When real capital is expected to be profitable in the future, both investment and Q rise. Conversely, pessimistic expectations about profitability in the near future should depress both variables. Investment and Q could be positively correlated, even if both are reacting to changes in output and prices" (Clark et al., 1979, p.84).

The neoclassical investment models or models based on Tobin's Q theory were developed from that idea, where the firm is assumed to choose an investment plan to maximise the present discounted value of net cash flow subject to the production technology, cost of adjustment function, initial capital stocks, and other appropriate constraints. However, explicit solutions of the first-order conditions are intractable without very restrictive assumptions of perfect market competition and heterogeneity in both production and adjustment cost functions.

Another strand of literature is dedicated to the Keynes and Kalecki's idea of an investment model where investment in fixed capital depends on a firm's demand expectations relative to its existing capacity and its ability to generate investment funding through internal cash flow and external debt financing. The history of estimating this so-called accelerator model of investment began with Meyer and Kuh (1957). One of the most important contributions to these Kaleckian and post-Keynesian theories can be found in Mairesse and Siu's (1984) extended accelerator model of investment, in which not only demand but also profitability expectations are important in determining the level of firm investment. The reason behind their approach is that in a well-functioning and rational stock market, changes in stock market values should reflect both revised expectations about future corporate earnings and changes in the discount rate at which these expected earnings are capitalised. Hence, investment decisions should respond to stock market movements, whether or not those movements coincide with the manager's own assessments. This theoretical approach can also be found in Malinvaud (1980) and Fischer and Merton (1984).

However, this approach has its own problems. Blanchard et al. (1993) indicate that even though the stock market movements matter, its role is limited in explaining investment decisions. In other words, even though expectations claim a role in determining the optimal level of firm investment, it is more reasonable to consider that managers might rely on other factors as well in forming their investment decisions. Hence, there is a scope for developing a more general model of firm investment in which expectations about future profitability and other factors can be considered together.

2.2.2. Theoretical model of Tobin's marginal Q and firm investment

The basic investment-Q relationship is derived from a standard model of a perfectly competitive firm that maximises the net wealth of existing shareholders when facing convex adjustment costs in changing its capital stock. To specify the maximization problem, the formula of the firm's present value as the discounted future value after tax net receipts is:

$$V(0) = \int_0^\infty R(t)\exp[-\int_0^t r(s)ds]\, dt \tag{2.1}$$

Where $V(0)$ is market value, $R(t)$ is after tax net receipts and *r(s)* is the nominal discount rate. The after tax net receipts, in turn, are equal to profits after tax plus depreciation tax deductions (for investment in the past) minus net purchases of investment goods (for current period):

$$R(t) = [1 - u(t)]\pi(t) + u(t)\int_0^\infty D(x, t - x)\, p_I\,(t - x)I(t - x)dx - [1 - k(t)]p_I(t)I(t) \tag{2.2}$$

Where $\pi(t)$ is profit before tax; $u(t)$ is corporate tax rate; $D(x, t - x)$ is depreciation allowance per dollar of investment for tax purposes on an asset of age *x* according to the tax code that was in effect at time $(t - x)$; $p_I(t)$ and $p_I(t - x)$ are the price of investment goods at time *t* and $(t - x)$; $I(t)$ is investment and $k(t)$ is the rate of investment tax credit.

Assume the adjustment cost function is represented by $G(I, K; t)$, where *I* is firm investment and *K* is capital stock, we have the production function with adjustment costs (Lucas, 1967; Gould, 1968; and Treadway, 1969).

$$\pi(t) = p(t)[F(K, N; t) - G(I, K; t)] - w_N N(t) \tag{2.3}$$

Where $p(t)$ is the price of output at time *t*, $N(t)$ is the vector of variable factor inputs, and w_N is associated vector of input prices.

In the earlier version of the neoclassical investment theory, following the perpetual inventory method, investment appears in the capital accumulation equation as:

$$K(t+1) = [1 - \delta(t)]K(t) + I(t) \tag{2.4}$$

Where $\delta(t)$ is the depreciation rate of total capital. However, a more compelling and practical formula of investment was introduced by Uzawa (1969):

$$K(t+1) = \psi(I, K; t) - \delta(t)K(t) \tag{2.5}$$

In (2.5), not all I units of gross investment necessarily turn into capital, instead only a share (indicated by the rate ψ) is.

Thus, a firm is assumed to maximize (2.1) with profits before tax $\pi(t)$ defined by (2.3) subject to the capital accumulation constraint (2.5) (the use of (2.4) instead of (2.5) proves no significant difference (Hayashi, 1982), so for expositional reasons, I do not attach it here), as in the formula below:

$$V(0) = \int_0^\infty \{\big[(1 - u(t)]\pi(t) - \big(1 - k(t) - z(t)\big)p_I(t)I(t)\big]\}\exp[-\int_0^t r(s)ds]dt$$

$$+\int_0^\infty \{u(t)[\int_{-\infty}^0 D(t-v, v)p_I(v)I(v)dv]\exp[-\int_0^t r(s)ds]\}dt \tag{2.6}$$

Where:

$$z(t) = \int_0^\infty u(t+x)D(x,t)\exp[-\int_0^x r(t+s)ds]dx \tag{2.7}$$

The second term on the right hand side of (2.6) represents the present value of current and future tax deductions attributable to past investments, which can be denoted as $A(0)$. It should be noted that $A(0)$ is independent of current and future decisions made by the firm, hence, the optimization problem is equivalent to maximizing the first term in (2.6) with respect to *I* and *K* subject to constraint (2.5).

The first-order condition for a maximum with respect to investment *I* is:

$$\frac{\partial V(0)}{\partial I} = [1 - k(t) - z(t)]p_I = \lambda\psi_I \tag{2.8}$$

Where λ is shadow value of investment for constraint (2.5), and ψ_I is the rate of investment that finally turns into capital.

From (2.8), one can easily derive the optimal investment equation:

$$I = F(\frac{Q}{1-k-z}, K; t) \tag{2.9}$$

Where *k* is the rate of investment tax credit, *z* corresponds to *uz* in the notation in Hall and Jorgenson (1973) which assumes static expectations about future tax rate *u(t)*. Also, the marginal Q, the shadow value of an additional unit of investment, can be expressed as:

$$Q = \frac{\lambda}{p_I} \tag{2.10}$$

Then because the adjustment cost function $G(I, K; t)$ is linear homogeneous in $I \ and \ K$, (2.9) can be re-written as:

$$\frac{I}{K} = \beta(\frac{Q}{1-k-z}, t) \tag{2.11}$$

Equation (2.11) demonstrates the direct relationship between Tobin's marginal Q and the optimal level of investment. Once marginal Q is known, a firm can decide its optimal level of investment, while other information about the demand curve for the firm's output, the production function and the rate of investment tax credits are no longer necessary.[3]

Moreover, any change in the values of marginal Q might induce managers to revise their expectations about future profitability, and hence their decisions regarding the future investment budget. This is because a positive reaction of the market to the firm's performance is likely to lower the cost of external finance, because it allows the firm to either issue new shares or increase its debt. Hence, even if the firm does not have sufficient internal finance, it might be more willing to raise capital externally, in order to utilize all the investment opportunity until the marginal Q moves back to the value of unity. This issue is already discussed by Gugler et al. (2004), in which the authors suggest that the greater the difference between the marginal return to investment and its cost, the greater the firm's incentive to raise capital externally, even when the external finance's cost exceeds the cost of investment.

2.2.3. Theoretical justification for extending the Tobin's Q model to investment in R&D capital

Following the insights of Keynes (1936) and Tobin (1969), a number of studies have investigated the relationship between Tobin's Q and the level of firm investment, but only in physical capital. As argued by Salinger (1984), one of the critical problems in applying Tobin's Q theory for R&D investment is that R&D is not capitalised, hence firms that have heavy investment in R&D have larger Q's because the replacement cost of assets does not include the capitalised value of R&D spending.

Nevertheless, an important characteristic of R&D investment is that it elicits quick reactions from the stock market. As reported by Doukas and Switzer (1992), the announcements of increases in planned R&D investment have a positive and significant effect on market value of firms. The announcements here are classified as the unexpected increases from a previous announcement if it exceeds previous amount of announced level (i.e. if E[R&D(t)] > R&D(t-1)). Supporting this idea, Chauvin and Hirschey (1993) document the immediately positive

[3] By applying Cobb Douglas production function and assuming the cost of adjustment function has constant elasticity $\beta > 1$, Abel (1983) arrives at the same conclusion that optimal rate of investment is an increasing function of q_t, the expected present value of marginal products of capital. In that paper, with the same twin assumptions of constant returns of scale production function and perfect market competition as Hayashi (1982), q_t is also proven to be the sole determinants of the firm's investment I.

effects of advertising and R&D expenditures on the market value of firm in a broadly representative samples of COMPUSTAT firms over the 1988-1990 period. That positive relationship between R&D investment and the firm's market value is consistent with the findings from Chan, Martin and Kensinger (1990) and Ehie and Olibe (2010). Hence, it is necessary to investigate whether the significant and immediate market's reactions and movements can influence back the R&D investment decisions.

Moreover, R&D investment also shares some similarities with physical capital investment. As indicated by Cohen and Levinthal (1989), both R&D and physical capital investment signals performance-related information that is relevant for the pricing of any investment that offers option value. Hence, it is reasonable to argue that models for the determinants of R&D investment can be derived from a standard theory of investment, as long as this theory takes into account the higher levels of uncertainty that characterizes R&D investment and measurement issues that surrounds the Tobin's Q theory (Driver and Guedes, 2012).

Hence, there is a need to examine whether Tobin's Q model should be applied in examining the determinants of R&D investment and whether the augmented Q model is better than the original one where the Tobin's Q measure is the sole factor that determines the optimal level of firm investment. This augmented model will be tested with the presence of some other factors that are proven to significantly affect R&D investment decisions: product-market competition; the level of technological spillovers; and corporate governance quality. The paragraphs below provide further theoretical explanations as to why these additional factors matter in the study of R&D investment.

2.2.4. *Empirical literature of Tobin's Q and R&D investment*

There are several studies investigating the relationship between R&D investment and firm performance measured by Tobin's average Q (e.g. Jose et al., 1986; Connolly and Hirschey, 2005; Lin et al., 2006). However, number of studies about the effect of Tobin's Q on R&D investment is relatively small. Salinger (1984) indicates that the replacement cost of capital in the denominator of Tobin's average Q does not take account of the value of R&D investment. Therefore, firms with high levels of R&D investment can have an imprecise but higher value of Tobin's average Q. In fact, few studies have documented the very small explanatory power of Tobin's average Q in R&D investment model at firm-level. For instance, O'Connor and Rafferty (2012) apply Tobin's Q framework as their base model to estimate the relationship between corporate governance and the level of innovative activity (reflected by R&D expenditures). Their results document the positive effect of Tobin's average Q on the level of R&D investment, even though it is sensitive to some econometric issues: serial correlation, unobserved heterogeneity and endogeneity problem. Similarly, Gugler et al. (2004) confirm that even though average Q cannot be the sole determinant of either physical capital or R&D investment, it does play an important role in firm investment models.

Nevertheless, the issue of imprecise value of Tobin's average Q with regard to R&D investment can be mediated by considering the stock market movements instead of the actual value of Tobin's average Q. The reason is stated in Blanchard et al. (1993): 'Investment should respond to stock market movements, whether or not those movements coincide with the manager's assessment of fundamentals'. Hence, it might be true that it is the positive or negative feedback from the stock market that induces managers to revise their investment plan upwards or downwards. In fact, Mairesse and Siu (1984) use one-period holding rate of return on stock prices to show that its movements strongly relate to firm R&D investment. More in line with my approach in this thesis, Malkiel et al. (1979) and Chappell and Cheng (1982) use the deviation of Tobin's average Q relative from its mean as a determinant of the firm's physical capital investment. In this thesis, I propose using the one-period-ahead growth rate of Tobin's average Q as a measure that captures not only the one-period-ahead change in the stock market valuation of the firm as suggested by Mairesse and Siu (1984) but also the change in the replacement cost of capital. The proposed measure is a weighted measure of the change in market value one period ahead of the R&D investment expenditures in the given year, where the weight is the change in replacement cost of capital.[4] This simple transformation enhances the informational content of the rate of return measure in Mairesse and Siu (1984) by preserving the information about the replacement cost of capital. Also, it is not subject to the measurement problem encountered when the unobservable marginal Q is proxied by the Tobin's average Q. This is because the emphasis here is on the change in market values (or the rate of return) weighted by change in the replacement cost of capital.

Another issue raised by the empirical studies is that they do not discuss the extent to which the average Tobin's Q they utilise reflect all the relevant information that managers take into account in their R&D investment decisions. However, the Tobin's average Q (or other

[4] See Chapter 3 for formal statement of the proposed measure.

proxies) under the perfect competition and perfect information assumptions that underpins Tobin's marginal Q imply that: (i) the market value of the firm reflects a correct market assessment of the firm value and the effect of R&D investment on the latter; (ii) perfect competition ensures equalisation of the market rates of return on R&D investment across firms; and (iii) there are no between-firm variation in the agency costs of the separation of management from ownership; and (iv) the disincentive effects of R&D spillovers is equal across firms. As a result of inadequate attention to these sources of between-firm variations in the incentives for R&D investment, the estimates in the existing work are either biased due to omitted variable bias or the incorporation of additional covariates into the model remains an *ad hoc* exercise. In this thesis, I take account of the additional factors that reflect market imperfections, variations in agency costs and the effects of R&D spillovers altogether rather than separately and in a haphazard manner. In the remaining sections below, I discuss the theoretical justification for taking into account these deviations, and then demonstrate how these sources are theoretically relevant to managerial incentives for R&D investment and should not be neglected as in the existing literature.

2.3. R&D investment and product-market competition

Theoretical explanation

In the field of industrial organisation, the central question is about how firms and markets should be organised to achieve the optimal level of economic performance. Despite the voluminous works, however, the theory yields ambiguous predictions about the effects of product-market concentration on innovation in general and R&D investment in particular (Levin et al., 1985).

Schumpeter (1934, 1942) postulates the idea that the incentive to innovate requires some exclusive advantages from transient market power. The latter reflects higher capability to exploit well-equipped R&D laboratories and to appropriate the returns from successful innovation. Second, market-power enables firms to generate and rely on internal finance that can be used to respond to competition by hiring highly qualified R&D personnel. Third, this imperfect competition often makes rival behaviour more predictable, and thereby reduces the uncertainty associated with excessive rivalry that tends to undermine the incentive to invent. This Schumpeterian negative effect of competition on innovation is supported theoretically by Mansfield et al. (1977): "If the innovator is faced with a highly competitive environment, it is less likely that it will be able to appropriate a large proportion of the social benefits than if it has a secure monopoly position or if it is a tight oligopoly" (p.235).

However, Arrow (1962) challenges Schumpeter's hypothesis by providing theoretical evidence that postulates a positive relationship between competition and innovation. In his paper, Kenneth Arrow argues that a monopoly shielded against competition has less incentive to invest in innovative activity because it can earn positive profits, irrespective of whether it invests in innovative activities. Comparing a monopolistic and competitive firm's incentive to innovate with the cost reduction on the post-invention output, he demonstrates that a monopolist's incentive is always smaller than the cost reduction, which is exactly the competitive firm's incentive. Although he examines only the unique case of a pure monopolist and a perfectly-competitive firm, his appealing theoretical perspective was supported by many others (Globerman, 1973; Acs and Audretsch, 1988). Interestingly, it is also supported by Steve Jobs, the CEO of Apple in *Business Week* interview in 2004: 'What's the point of focusing on making the product even better when the only company you can take business away from is yourself?'.[5]

Hence, conflicting findings tend to be the norm in both theoretical and empirical literature of competition-innovation relationship (Gilbert, 2006). Later, in an attempt to review the debate, Peneder (2012) provides an appealing explanation. On the one hand, Schumpeter (1934, 1942) assumes that the initial level of market power is high and this is evident from his argument that endogenous innovation under perfect competition is strictly valid only at very high-levels of initial competition. Whereas, in Arrow (1962), the initial degree of market power is low, and the competition is mostly between a legally protected monopoly and duopoly. Therefore the incentives analysed by Schumpeter and Arrow unfold completely at the opposite ends of the market-power spectrum.

Specially, a turning point of that debate was reached in 2005 in the paper published by Phillippe Aghion and his colleagues, which reports an inverted-U shape for the relationship between innovation and competition. In fact, the idea of a non-linear shape appeared earlier in the literature by the works of Scherer (1967); Kamien and Schwartz (1976); and Levin et al. (1985). However, Aghion et al. (2005) is the first paper that provides both theoretical and empirical explanations for that concave relationship. Specifically, they developed an

[5] Interview with Steve Jobs, *Business Week,* October 11, 2004, p. 96.

extension of Aghion et al. (1997)'s model, in which both current technological leaders and their followers in an industry can innovate, and innovations by leaders and followers all occur step-by-step. The latter assumption expresses that the follower must catch up with the incumbent leader before becoming a new leader itself. From that, the two determinants of the effect of competition on innovation are: (i) the distance of firm to the technology frontier in its industry; and (ii) the difference between two kinds of intermediate sector: level (neck-and-neck) sector or unlevelled (leader and laggard) sector. At one extreme, when the level of product-market competition is low, there is less incentive for neck-and-neck firms in a levelled sector to innovate than laggard firm in an unlevelled one. In that situation, the sector will be quick to leave the unlevelled state and slow to leave the levelled state. Hence, most of the time the industry will be at the levelled state where the escape competition effect is dominant and the effect of competition on innovation is positive. At the other extreme, when the initial level of competition is high, the laggard firms in unlevelled sector will have less incentive to innovate than the neck-and-neck firms in levelled sector. Hence, industries will be quicker to leave the levelled state than the unlevelled state, which means that the Schumpeterian negative effect will dominate the case. The combination of these two extremes gives us the inverted-U shape for competition-innovation relationship.

The influential hypothesis in Aghion et al. (2005) has encouraged a new literature focusing on a non-linear relationship between competition and innovation. The full details of this literature will be provided in the empirical part below. Overall, the significant effect of product-market competition on innovation is documented in most of the works, even though it is sensitive to the different measures of both innovation and competition.

Measurement issues

Overall, the empirical results have often documented a significant impact of competition/concentration on R&D investment. However, the review by Becker (2013) reports that both the significance and the shape of this relation are sensitive to different measures of competition.

The existing work utilizes four main measures of competition/concentration: the concentration ratios based on market shares of top 4, 5 or 8 firms; the Herfindahl index; the Price-Cost Margin and the Profit Elasticity.

During the 1950-1980 period, the most popular measure of imperfect competition was the concentration ratio of some of the largest firms in the market (see Table 1 below). This measure captures structural features of the market (Bikker and Haaf, 2002) and information about largest firms with an innovative advantage compared to their smaller counterparts, and as such it is considered as an appropriate measure of competition (Acs and Audretsch, 1987; Kamien and Schwartz, 1975). Although the number of largest firms varies (4, 5 or 8 firms), the most common measure is based on market shares of the largest four firms.

Another measure of concentration ratio is the Herfindahl-Hirschman index (hereafter HHI), with the formula as below:

$$HHI_{jt} = \sum S_{ijt}^2 \qquad (2.12)$$

Where S_{ijt} is the share of firm *i* in the total sales of industry *j* for a given year *t* (Ugur and Hashem, 2012).

The value of *HHI* ranges between 0 and 1 and the closer it is to 1 indicates the higher the level of market concentration is.

Compared to concentration ratio of 4, 5 or 8 largest firms, the *HHI* is better as it contains more market information. However, the measure may be biased if data is unavailable for all firms in the industry or the sample of each industry is not random.

The problem of using these concentration ratios as proxies for competition is mentioned in Gilbert (2006), as markets with only a few companies can be highly competitive, and in the reversed direction, competition level can be low in markets with many firms. He argues that beside the number of firms, there are many other factors that affect the level of market competition, such as the strength of barriers to entry, the characteristics of demand.

Therefore, in recent studies, the direct measures of product-market competition are preferred. The most popular measure of competition is constructed based on the Price-Cost Margin index (hereafter PCM). In short, the idea behind this measure of competition is that under competitive pressure firms are less able to extract monopoly rents by setting prices above marginal costs. Denoting firm or industry price with P_{it} and marginal cost MC_{it}, the original PCM measure can be written as follows:

$$PCM_{it} = \frac{P_{it} - MC_{it}}{P_{it}} \tag{2.13}$$

Because the marginal cost is not observable, the latter is usually proxied with the average cost (AC_{it}), leading to:

$$PCM_{it} = \frac{P_{it} - MC_{it}}{P_{it}} \approx \frac{P_{it} - AC_{it}}{P_{it}} \tag{2.14}$$

When industry/firm prices and costs are not available in the data, the numerator and denominator of (2.14) are multiplied with output to obtain a new PCM_{it} measure based on sales and operating expenses – as indicated in (2.15) below.

$$PCM_{it} = \frac{Sales_{it} - OE_{it}}{Sales_{it}} \tag{2.15}$$

Where: OE_{it} is the operating expense. The PCM measure takes values between 0 (indicating perfect competition) and 1 (indicating absolute monopoly).

Finally, equation (2.15) can be manipulated to calculate the level of product-market competition (hereafter PMC) at the firm (2.16a) or industry (2.16b) levels, as indicated below:

$$PMC_{it} = 1 - PCM_{it} \tag{2.16a}$$

$$PMC_{jt} = 1 - mean(PCM_{ijt}) \quad (2.16b)$$

Where $mean(PCM_{ijt})$ is the mean value of the PCM measure for all firms in industry *j* (Aghion et al., 2005; Berube et al., 2012).

The *PMC* measure, both at firm and industry level, also has values between 0 (absolute monopoly) and 1 (perfect competition). The advantage of using the *PMC* measure is that it reflects directly the changes in firms' pricing behaviour and strategy (Tingvall and Poldahl, 2006). Also, Aghion et al. (2005) indicate that it also reflects information about diversification in the industry.

Nevertheless, the *PMC* measure is subject to criticism. The theoretical foundations of *PMC* as a competition measure are not robust – as argued in Amir (2003), Bulow and Klemperer (1999), Rosenthal (1980) and Stiglitz (1989). These scholars provide evidence that the *PMC* indicator can increase even when the level of competition decreases, which happens in case the firm is efficient (Boone, 2008). In the same paper, the author introduces a new measure of competition, the so-called 'Profit Elasticity' (hereafter *PE*). The intuition behind this measure is that competition rewards efficiency. In industries with increasing level of competition, the inefficiently operating firms will be punished more harshly than the more efficient ones (Boone et al., 2005; 2013; Boone, 2008). With this strong theoretical intuition, the industry-level PE measure has been used widely in recent research on market competition (Schiersch and Schmidt-Ehmcke, 2010; Polder and Veldhuizen, 2012; Berube et al., 2012; Koski and Pajarinen, 2013). As suggested by Boone et al. (2005), the *PE* measure can be obtained in accordance with (2.17) below:

$$\pi_{ijt} = \alpha_{jt} + \beta_{jt} AVC_{ijt} + \varepsilon_{ijt} \qquad \forall j, t \quad (2.17)$$

Where:

π_{ijt}: (log) operating profit for a firm *i* that is active in industry *j* at time t.

AVC_{ijt}: (log) average variable costs.

It should be noted that the average variable costs can be flexibly different depending on the availability of data. For instance, Polder and Veldhuizen (2012) calculate it as the sum of labour cost and the intermediate inputs, while Berube et al. (2012) assume average variable cost as the ratio between operating expenses and sales. Here, all firms in the same industry j will have the same PE value (β_{jt}) at time t, which should be negative given that profit is a negative function of cost (Clerides et al., 2015). In magnitude, a larger value of β in absolute term reflects a more competitive environment.

Although Boone's PE indicator helps to capture the firm's efficiency, it should not be applied empirically without caution. This measure may be biased if, again, the data is unavailable for all firms in the industry or the number of firms in an industry is not sufficient enough to conduct the estimated value of β_{jt} from equation (2.17). For instance Polder and Veldhuizen (2012) set a minimum of 20 observations per industry-year, otherwise the PE is considered to be missing.

Empirical literature

Table 2.1 below provides a summary of the evidence base on the relationship between different measures of concentration/competition and R&D investment. The table includes study characteristics such as data period, country of origin for the firms/sectors in the study, measure of competition/concentration used; and provides a summary of the findings reported in each study. Overall, in 22 studies reviewed in Table 2.1, 4 studies document the negative impact of market competition on R&D investment, 6 studies record the positive effect, two studies challenge the significance of competition effect, and 10 studies confirmed a non-linear relationship between firm R&D investment and product-market competition.

Table 2. 1: Empirical studies of R&D investment and market competition/concentration

Authors	Data period	Country	Measure of market competition	Findings
Negative competition-R&D investment relationship				
Horowitz (1962)	1947-1953	US	Four-firm concentration ratio	In more concentrated industries, research expenditures will be higher as a per cent of sales.
Hamberg (1964)	1960	US	Industrial concentration	Positive, but weak association between industrial concentration and R&D is found consistently with both R&D value and R&D intensity (R&D over sales) measures of innovation.
Doukas and Switzer (1992)	1965-1984	US	Four-firm concentration ratio	Investors tend to interpret a firm announcement of an increase in R&D spending as good news if it operates in a highly concentrated market, and the reversed result is applied for less concentrated market.
Grabowski and Baxter (1973)	1947-1966	US chemical industry	Industry concentration ratio	There is evidence for the positive relationship between research intensity and level of market concentration.
Positive competition-R&D investment relationship				
Globerman (1973)	1965-1969	Canadian manufacturing industries	Four-firm concentration index	For industries with greater technological opportunity, research intensity varied inversely with concentration.
Hopman et al. (2010)		23 OECD countries	*PMC*	There is a positive and monotonic relation between competition and R&D intensity, which is highly significant at the 5% level.
Mukhopadhyay (1985)	1963-1977	US	4-firm or 8-firm concentration ratios	Concentration ratios, on the average, went down in the technological progressive industries in the U.S.A.
Adam (1970)	1963-1964	300 largest firms in U.S. and France	Concentration ratio	_ Among the high-technology industries, there is definite association between high R&D intensity and low seller concentration. The only exception is in instrument industry. _ For the lower-technology industries, the results were mixed, with the same pattern was held in some but not all industries
Acs and Audretsch (1988)	1982	US	Four-firm concentration ratio	The negative coefficient of concentration in both model of industry and company-level R&D expenditures suggest that lower, not higher, level of concentration tend to be associated with increased innovation activity.

Griffith et al. (2010)	1987-2000	9 OECD countries	Average level of profitability	The EU Single Market Programme reduced the average level of profitability (which also means increasing level of competition) and from that had a positive impact on R&D investment.
Czarnitzki and Toole (2013)	1995-2011	870 Germany's manufacturing firms	*HHI* index	When significant, higher industry concentration (lower competition level) appears to reduce current R&D investment.
Manez et al. (2015)	1990-2011	2,093 Spanish manufacturing firms	CR4 concentration ratio	More competition, as captured by higher number of competitors and/or lower market concentration affects positively to the R&D spell duration, that is, encourages continuous engagement in R&D activities.
Others				
Comanor (1967)	1955-1960	US	Eight-firm concentration ratio	Only in market situations when the prospects for achieving product differentiation are limited, there is a statistically significant and positive link between market concentration and research activity. When these prospect are high, there is no evidence to conclude about that relationship.
Howe and McFetridge (1976)	1967-1971	Canadian sectors	*HHI* index	Within the chemical sector the R&D expenditures of foreign-owned firms are greater in the more concentrated industries, while the reverse is true of domestically-owned firms. In both the machinery and electrical sectors three-digit industry concentration exerts no effect on R&D expenditures.
Non-linear competition-R&D investment relationship				
Levin et al. (1985)	1970s	U.S. sample of firms	4-firm concentration ratio	There is a significant inverted-U shape relationship between R&D and concentration ratio at 1% level, where R&D effort typically reaches a maximum at level of 4-firm concentration between 50 and 60%
Aghion et al. (2005)	1973-1994	311 firms from 17 2-digit SIC code industries in UK	*PMC* at industry-level.	The significant inverted-U shape for competition-innovation relationship is confirmed for a number of controls and experiments in the models.
Tingvall and Poldahl (2006)	1990-2000	Swedish manufacturing firms	*HHI* index and *PMC*	Inverted-U shaped relation for the Herfindahl index measure of competition. But negative impact of competition on R&D investments when competition measure (*PMC*) is used.
Polder and Veldhuizen (2012)	1996-2006	6442 Netherland firms	*PMC* at both industry- and firm-level and *PE* at industry-level.	They find evidence to support the inverted-U shaped relationship at the industry-level with profit elasticity measure, but, possibly due to high level of aggregation, not with the competition measure (*PMC*).

				Also, at firm-level, the estimations strongly support the non-linear relation of competition with R&D investment, being positive when the spread is low and turns to negative when it exceeds a certain threshold, no matter which measure of competition is used.
Berube et al. (2012)	2000-2005	Canadian manufacturing enterprises	*PMC* at industry- and firm-level *PE* at industry-level	The authors applied *PCM* measure at both industry and firm level and also the Boone's PE at industry level, and report the consistent positive effect of rising competition on R&D expenditure. However, when checking the non-linear relationship, the significant inverted-U shaped only happens with the PE measure of competition. Furthermore, the technology gap is also added in the model, and the interaction between technology gap and the intensity of competition is another potential determinant for the non-linear direction with the negative impact on the level of R&D investment.
Kilponen and Santavirta (2007)	1990-2001	1487 Finnish manufacturing firms	*PMC* at industry-level.	The authors find support for an inverted-U shape relationship between patenting activity of the firms and the degree of competition.
Peroni and Ferreira (2012)	2006	Luxembourgish manufacturing and service industries	*PE* at industry-level.	The relation competition-innovation is found to be non-linear, and depends on the technical efficiency of firms within an industry. When firms are close to the efficient frontier, competition has positive effect on innovation. But when firms are far away from the frontier, increases in competition result in lower incentives to innovate.
Tingvall and Karpaty (2011)	1997-2005	Swedish service-sector firms	*PE* at industry-level.	The results point at an inverse U-shaped relationship between competition and R&D in the service sector, but does not apply for non-exporting firms. When separating innovation, inverse U-shaped can be found not only for intramural R&D but also for training and acquisition of external knowledge.
Ugur and Hashem (2012)	2004-2010	1400 non-financial US-listed firms	*HHI* index	The relationship between market concentration and innovation has a U-shape in the case of input measure of innovation (R&D expenditure), but it has an inverted-U shape in case of output measure of innovation (net book-value of brands and patents)
Askenazy et al. (2013)	1990-2004	15,000 French firms	*PMC*	The inverted-U shape for competition-R&D investment depends on firm size and the cost of innovation in the industry. To be more specific, it becomes flatter when firm size decreases and/or the cost of innovation is high.

Following Schumpeter's seminal contribution, a stream of research has examined the linear relationship between innovation and market competition. However, this empirical literature is perhaps most accurately described as fragile. Although some studies provide evidence in support of the negative Schumpeterian effect, a substantial number of studies report positive or mixed results (Cohen and Levin, 1989; Ahn, 2002).

A number of economists have reached the empirical results that an industry composed of a few large firms will conduct more R&D than the one with numerous small firms. Using the correlation between R&D as a percentage of sales and the industrial concentration for the two sets of surveyed data from the National Association of Manufacturers and a Harvard University group, Horowitz (1962) concludes that research intensity (research expenditures as a per cent of sales) will be higher in the industries with higher concentration ratio for sales of the leading 4 firms. Similarly, by establishing the least-squares and rank-order correlation tests for the sample of 340 large U.S. manufacturing firms in 1958, Hamberg (1964) demonstrates that industrial concentration has significant, but weakly positive effect on R&D. This finding is consistent with both measures of absolute R&D expenditures and R&D intensity (calculated by dividing R&D expenditures to sales). In addition, Doukas and Switzer (1992) find that the relationship between R&D announcement and the firm's market value is sensitive to the different level of seller concentration in the market. The R&D announcement here is any unexpected increase from a previous announcement if it exceeds previous amount or announced level (i.e. if E[R&D(t)] > R&D(t-1)). Their results obtained from the group of firms classified as operating in highly concentrated industries show that the increase in R&D announcement have a positive and significant impact on the firm common stock price and the contrary is confirmed for the industries characterized by low concentration. It demonstrates the preference of investors on interpreting a firm announcement of any increase in R&D spending as a good news if it operates in a highly concentrated market, or as a bad news when the announcing firm is operating in an industry with low seller concentration. Furthermore, for a cross-section analysis on U.S. sample at firm-level, Grabowski and Baxter (1973) conclude that: "the R&D allocation outlays of the largest firms (ranked by size) conform more to each other in industries where concentration levels are higher and where mean research intensity is larger" (p.234).

Nevertheless, as I have indicated earlier in the theoretical part (2.2.3), the negative Schumpeterian effect of competition on innovation has been challenged by a number of other studies. For instance, Globerman (1973) investigates this relationship in 15 Canadian manufacturing industries over the 1965-1969 period. His main conclusion is that research intensity varied inversely with concentration in the industries with higher technological chances, whereas it turns to be insignificant for the industries with lesser technological opportunities. Utilizing the panel data set of 52 industries in 23 countries over the period 1987-2007, Hopman et al. (2010) arrive at the same conclusion. In their empirical results, the relationship between competition (reflected by *PMC* measure) and innovation (measured by the ratio between R&D expenditure and the value added) is confirmed to be linear, positive and monotonic, both in level and the log form of the regressions. The positive sign remains consistent even when instrumental variables are added to control for the endogeneity problem in this relationship, only the coefficients changed slightly. Similarly, Mukhopadhyay (1985) also confirms a negative relationship between concentration ratio and the level of technological progression for the sample of 336 US industries over the 1963-1977 period, and the same conclusion can be found in Acs and Audretsch (1988) for the cross-section regressions for 247 four-digit SIC manufacturing industries in the US. In addition, Adams (1970) expands the literature by comparing the relationship between seller concentration and R&D spending intensity between France and the US. He finds that in both countries, among the high-technology industries (except only for instruments), there is definite association between high R&D spending intensity and low, not high, seller concentration level, which is measured by four-firm concentration index. However, for the lower-technology industries, the results were mixed, with the same pattern was held in some but not all industries.

Recently, Griffith et al. (2010) examine the impact of EU Single Market Programme (EU's SMP) on the level of competition and innovation in a multi-country study. Due to the convincing prediction that EU's SMP is created to reduce the non-tariff barriers to competition within the EU, its expectation is to have positive effect on firms' incentives to do innovation. Hence, the authors focus on linear rather than non-linear competition-innovation relationship. Their findings show that the EU's SMP has significant impact on reducing the average level of profitability; increasing the level of competition in the product markets and from that increasing the level of R&D investment. This result is compelling in the sense that the EU's SMP itself was likely to stimulate industries to be more neck-and-neck, therefore the 'escape competition' effect is more likely to be found (what have been mentioned in Nickell (1996) and Aghion et al. (2005)). Similarly, the positive effect of product-market competition on R&D investment can also be found in Czanitzki and Toole (2013) and Manez et al. (2015).

However, the competition-innovation relationship is not always statistically significant in the literature. In a research using U.S. industry-level data in 2 years of 1955 and 1960, Comanor (1967) concludes that there is some evidence that higher market concentration (the eight-firm concentration ratio exceeded 70 per cent) is associated with greater research, but only when the prospects for achieving product differentiation are limited. Where these prospects are high, competition in research is likely to be important, there is no evidence that an increase in concentration relates to any change in research activity. Similarly, by utilizing a sample of 81 firms in the Canadian electrical, chemical and machinery industries over the period 1967-71, Howe and McFetridge (1976) also find significant relationship of R&D expenditures and industry concentration (reflected by Herfindahl index) only in the chemical one. And, even in this chemical sector, there is a difference between this relationship of foreign-owned firms and domestically-owned firms. While R&D expenditures of domestically-owned firms are negatively associated with industry concentration, the reverse is true of foreign-owned firms. These others two sectors report no effect of industry concentration on R&D expenditures.

Besides, during the long-standing literature before 2005, there are also some suggestions for the non-linear shape for the competition-innovation relationship. For instance, a main conclusion of Scherer (1967) is that when the four-firm concentration ratio exceeds 50 or 55 percent, additional market power is probably not conducive to more vigorous technological efforts and maybe downright stultifying. This idea was reminded by Schmookler (1972) and Kamien and Schwartz (1976), when they stress that there might be an 'optimal' degree of competition for motivation of innovative activity between the extremes of monopoly and perfect competition. In other words, the rate of innovative activity increases with the intensity of rivalry up to a point, peaks, and declines thereafter with further increase in the competitiveness of the industry. Levin et al. (1985) test this hypothesis empirically by adding both the four-firm concentration ratio and its squared value into a model with the ratio of company-financed R&D expenditures to sales as dependent variable. Their results confirm the significant inverted-U shape relationship at 1% level, where R&D effort typically reaches a maximum at level of four-firm concentration between 50 and 60%.

Nevertheless, the remarkable change in the competition-innovation literature, in fact, happened in 2005, when Phillipe Aghion and his colleagues published an important paper, titled: 'Competition and Innovation: An Inverted-U Relationship'. It is the first paper that exhibits the inverted-U shape for competition-innovation relationship with both theoretical and empirical explanations (details of theoretical explanation are already recalled in section

2.2.3 above). Although these authors only test their hypothesis on output measure of innovation (patent data), almost immediately, the non-linear suggestion is examined on R&D data by Tingvall and Poldahl (2006). Their sample contains information of all Swedish manufacturing firms with at least 50 employees for the period of 11 years from 1990 to 2000. They find the competition-R&D investment relationship to be sensitive with respect to the different measures of competition. While the inverted U-shaped is documented for Herfindahl index, it changes to be negative when the *PMC* measure is applied. A possible reason is that in their work, the Herfindahl index was calculated at industry-level whereas the *PMC* was applied at firm-level. Similarly, the sensitive results for competition-R&D investment relationship due to different measures of competition are also reported in Polder and Veldhuizen (2012) and Berube et al. (2012). In respect to the former, by utilizing the data set of 6442 Dutch firms during the period from 1996 to 2006, the authors find evidence to support the inverted-U shape with *PE* measure, but, possibly due to high level of aggregation, not with *PMC* measure. These results are confirmed to be consistent in the latter research of Berube et al. (2012).

The non-linear relationship between product market competition and R&D investment is also found in Kilponen and Santavirta (2007). Their work focuses on applying Aghion et al. (2001) model to R&D subsidies in the unbalance panel data set of 1487 Finnish manufacturing companies between the years 1990 and 2001. In their conclusion, R&D subsidies accelerate innovation at different degrees of competition, but this effect becomes smaller when competition is fierce. Additionally, Peroni and Ferreira (2012) study competition-innovation relationship with respect to the distance of firms with the ‘efficient frontier’. By setting ‘efficient frontier’, they specify the firm with the highest total factor productivity (TFP) within each industry. Using Boone’s *PE* measure of competition and R&D measure of innovation, their results indicate that competition has positive effect on R&D expenses if firms are close to the efficient frontier. On the contrary, when firms are far away from the frontier, rising competition result in lowering firm incentive to innovate. Likewise, recognizing that the inverted-U shape has been tested only for manufacturing sectors, Tingvall and Karpaty (2011) contribute to the literature by examining it in the data set of Swedish service-sector firms from 1997 to 2005. Their results provide more evidence to support the inverse U-shape relationship, but the further breakdown of innovation expenditures reports only the inverse U-shape pattern holds for intramural R&D and training, not for extramural R&D.

Recently, for the data set of 1400 non-financial US-listed companies, Ugur and Hashem (2012) provide more evidence for the non-linear relationship between market concentration and innovation. Different to prior research, they indicate the reversed shapes of the relation when different measures of innovation are applied, while Herfindahl index is kept as the measure of market concentration in all of their models. Specifically, in the case of input measure (R&D expenditures in levels and relative to total assets), the relationship has a U-shape, while it is an inverted-U shape when net book-value of brands and patents is used as output measure of innovation. These inconsistent results on the shape of competition-innovation relationship is somehow in line with the recent theoretical models of Schmutzler (2010), which suggests: "no general case can be made that an inverse relation between competition and investment is more likely than a U-shaped relation" (p. 31). It is supported also by Tishler and Milstein (2009), where the two authors use the two-stage model describing the optimal R&D choice of firms operating in an oligopoly market for several substitute goods to indicate the possibility of a U-shape relationship between competition intensity and innovation in oligopoly market.

Furthermore, in a way to control for the effect of firm size and cost of innovation in the Aghion et al. (2005) model, Askenazy et al. (2013) find that the inverted-U shape becomes flatter when firm size is added in the model. If innovations are large-scale and costly in the firm's sector or relative to firm size, competitive shocks have to be sufficiently large to change innovation choices. Their results are robust with different measures of innovation and competition.

In conclusion, after several decades of the dominant debate between Schumpeter's negative impact and Arrow's positive effect, thanks to the seminal contribution of Aghion et al. (2005), the literature of competition/concentration-innovation has turned to the non-linear direction. This so-called Schumpeter-Aghion approach suggests that innovation only increase with competition until a specific point, and then additional competitive effect has reversed impact on innovation. It is consistently documented by empirical studies, even though the shape is heterogeneous across measures and data. Bear that in mind, I apply two different measures of competition/concentration: the Herfindahl index (*HHI*) or the measure of competition based on the Price-Cost Margin measure (*PMC)*, and include also the square term of them in my model. The constructing process of these two measures will be explained in details in the measurement issues section of the next chapter.

2.4. R&D investment and corporate governance quality

Theoretical explanation

Even with a long literature of competition-innovation relationship, both theoretical predictions and empirical outcomes have failed to explain why firms with similar external conditions could have different innovation performances. The variation in the empirical results raises the suspicion that seeing firms simply as players in a multi-actor economic game was not sufficient to understand the firms' innovation decision (Belloc, 2012). In a new approach of looking inside the organisation, corporate governance quality plays a central role in determining the firms' effort in innovation and technological change (Tylecote, 2007).

In theory, the relationship between corporate governance and innovation has been informed by the 'principal-agent' theory, which suggests that agency problems exist because principals (shareholders) and agents (managers) have differing risk preferences and conflicting interests. One of the particular activities in which the strategies pursued by stockholder-controlled firms and management-controlled firms could be remarkably different is R&D investment (Hill and Snell, 1988; Lee and O'Neill, 2003). To be more specific, investing in long-term investment is preferable for shareholders as it allows for widening their portfolios, whereas every executive's wealth is a function of salary and compensation, which is likely to be affected adversely by investing in uncertain activities like R&D. Moreover, the pressure of achieving the challenging return on investment (ROI) objectives also put managers under a good deal of stress. If these target cannot be achieved, managers face the prospect of intervention by the board, the loss of bonuses and, ultimately, the possible loss of their jobs (Hill et al., 1988). Hence, managers then do everything possible to meet the ROI targets, which may require reduced expenditures on long-term innovative activities such as R&D investment. Lee and O'Neill (2003) also support this idea by stating that although R&D investments have become increasingly important in a knowledge-based economy, any extent to firm investment in R&D can be subject to potential manager-shareholder conflicts.

Empirically, corporate governance quality are assessed in both country- and firm-level. Concerning the former, the country's legal origin, its level of protection for minority shareholders and creditors' rights, and the legal enforcement are the most important characteristics that have been defined and investigated in the literature (more details will be presented in section 2.3.3 below). Stated briefly, previous literature has paid little attention to the role of country-level governance quality on firm-level decision-making (Hillier et al., 2011). However, there might be a possible complementary between corporate governance at country- and firm-level (Doidge et al., 2007; Griffin et al., 2017), and hence whether the firm is located in a country with stronger governance policies might also affect its incentive in R&D investment.

With regard to the latter, at firm-level, there are three dimensions of corporate governance that can affect the level of firm R&D investment.

The first dimension is the ownership concentration/structure. Ownership 'represents a source of power that can be used to either support or oppose management depending on how it is concentrated and used' (Salancik and Pfeffer, 1980). Firms with high level of ownership concentration may increase the financial commitment of shareholders: large investors tend indeed to keep their relevant participation for long periods; and this increases owners' knowledge of firm activities and their monitoring capabilities. In addition, large creditors may also provide a stable flow of financial resources (Lacetera, 2001). Concerning the opposite situation, the agency cost approach suggests that diffuse equity ownership affects negatively the level of investment in innovative activity because it enables managers to pursue their own objectives without worrying much about agreement among few important owners. These arguments suggest a positive relationship between the level of R&D investment and ownership concentration.

On the other hand, it is argued that the effect of ownership concentration on R&D investment possibly depends on the type of owners. If largest owners are institutions, a negative relationship between ownership concentration and R&D investment can be expected. The view that institutional owners invest for the short term and neglect the long-term investment has been widely explored (Drucker, 1986; Mitroff, 1987). 'Institutions such as banks, insurance companies, investment companies, and investment advisors are judged on quarterly performance, and they review their holdings on a short-term basis' (Eng and Shackell, 2001). Therefore, when they are major shareholders, they wield pressure on the management to secure high short-term profits at the expense of long-term projects such as investment in innovation (Hill et al., 1988; Ugur and Hashem, 2012). Institutional investors are generally impatient and this impatience is communicated to corporate managers through pressure on stock prices. Hence, managers are discouraged from the long-term investment and instead focus on projects that can raise the short-term payoffs (Wahal and McConnell, 2000). By acting as 'traders' rather than 'owners', institutional investors allegedly place excessive focus on short-term development, leading managers to have myopic investment behaviour (or so-called 'managerial myopia'), which refers to underinvestment in long-term, intangible projects such as R&D activity, advertising (Porter, 1992; Bushee, 1998).

The second element of corporate governance that relates to the level of investment is the characteristics of the board of directors. Given that the board members are responsible for evaluating and rewarding executives' performance, the composition and functioning of a board, the company's evaluation systems, and its strategic orientation emerge as an important topic for research (Baysinger et al., 1991). The ratio of inside to outside directors on the board is argued to be of critical importance, because it balances the difference between managers and shareholders. While inside directors seem to be all professional managers themselves, outside board members are on the shareholders' side, in order to keep managers pursuing strategies consistent with maximizing stockholder wealth. Board with a higher percentage of outside board members are likely to provide more independent oversight of management (Mahoney et al., 1997). On the other hand, Lacetera (2001) argues that the presence of insiders on the board is also important and may improve rather than worsen the board's monitoring ability, as they are better informed about firm operations and their role is to share knowledge and competencies with outsiders. Baysinger and Hoskisson (1990) support this idea by giving the specific example of a pharmaceutical firm that does not know when a competitor will discover a new drug that will displace its dominant product. Thus, with that great residual risk, it is necessary to include inside directors as important players in the decision-control process. This issue is more crucial in making R&D investment decisions. Although the shareholders seem to prefer R&D investment for the firm's long-term development, the current situation of this firm with all the takeover pressures and the development opportunities in the market always need to be considered. Besides, the level of gender diversity has just been introduced as another factor that strongly affect firm R&D investment. Chen et al. (2016) suggest that: "Compared with men, women possess many favourable traits in value judgement, risk attitude, and decision-making style … female directors improve board effectiveness in risk management with respect to R&D investment" (p.599).

The last important factor relating to corporate governance issue is the level of anti-takeover provisions. O'Connor and Rafferty (2012) claim another aim of investing money with a more immediate payoff rather than in long-term investment like R&D activity from executives is to shield their firms against takeover threats. Similarly, Minetti et al. (2015)

argue that because shareholders are unable to evaluate properly the investments in long-term innovative projects, they tend to undervalue the stock of company. This situation, unwillingly, creates a chance for takeover. Therefore, to protect their firms from that dangerous situation, the executives prefer investing less effort and human capital in innovative projects that are difficult to understand by the market, and more in routine projects with quicker and more certain returns. Shleifer and Summers (1988) provide another explanation based on the theory of incomplete contracts between managers and shareholders. In this theory, incomplete contracts reduce managerial incentives to invest in innovative activities when takeover threats are high because of the possibility of losing their job after a hostile takeover. Moreover, Stein (1988) develops a model in which the threat of takeover encourages myopic behaviour on the part of managers. Here, firms that construct barriers to takeover are able to increase long-term investments in R&D activity. Anti-takeover provisions help to raise the cost of an acquisition and allow managers to have a degree of insulation from the market for corporate control and thus reduce the pressure on managers to maximize firm value.

However, this positive effect of anti-takeover provisions on R&D and other long-term investments is challenged by Jensen (1988). His ‘quite life’ approach argued that the stronger the anti-takeover defences tools and regulations a firm is using, the higher the level of managerial slack. As managers opt for ‘quite life’, they have less incentive to commit to investment in costly R&D activities with high level of uncertainty. The research by Sapra et al. (2014) demonstrates that the relationship between anti-takeover defence tools and innovation is more complicated, because it is non-monotonic. A firm can have more incentive to keep investing in innovative activity when the market for corporate control is well-developed and takeover pressure is high; or when anti-takeover laws and provisions are strict enough to deter takeovers.

Measurement issues

Before presenting a detailed survey of that literature, it is useful to recall the different measures of corporate governance (CG) that have been applied.

At country-level, governance quality is defined by the level of shareholders and creditors’ protection, the enforcement of those rights with a country’s laws, culture and norms, and institutions (Chang et al., 2015). La Porta et al. (1997, 1998) can be considered as the first attempts to address this issue, with their work focus on mainly the legal origins, creditor rights, and the level of legal enforcement in different countries. In more detail, there are 4 groups of legal origin: the English-common law, French-, German-, and Scandinavian-civil law (these latter three are developed from the original Roman civil law). The former is made by judges and subsequently incorporated into legislature, while the latter three, in contrast, are part of the scholar and legislator-made civil law tradition, which dates back to Roman law (La Porta et al., 1997). Besides, the level of creditor rights and legal enforcement often are reflected in the form of an index, where each country receives the value based on several assessment criteria with regard to its characteristics. The higher the index, the stronger the governance quality in that country. More recently, Djankov et al. (2007, 2008), Brockman and Unlu (2009), Hail and Leuz (2006), John et al. (2008) provide the revision and update for these measures.

At firm-level, the most common approach is to use a set of several independent variables that reflect the different dimensions of CG. Three of the main dimensions are the distribution of control rights and residual profit rights within the corporation – the so-called corporate ownership structure; the adoption of takeover defences in dealing with takeover pressure; and the different characteristics of the board of directors and executives. The CG variables can be binary variables with value of 1 if a firm adopts a certain CG dimension (e.g., if a firm relies on poison pill as a measure of discouraging takeovers) or a value of 0 if that CG dimension is not adopted. It can also take scale values (e.g., the level of board independence can be measured as the ratio between the number of board members outside and inside the firm). Over the few decades of extant research, the most frequently used CG variables are: ownership concentration, board independence, number of board members, board diversity (number of woman on board), and whether a firm adopts some of the most important antitakeover defences: poison pills and staggered board.

The main obstacle for this strand of literature is the persistence of data, as the firm does not often change its corporate governance structure for several years. Combined with the frequently high level of missing data for corporate governance indicators, it can strongly affect the estimated results. Therefore, some researchers prefer using the general index to reflect and discriminate the different level of corporate governance between firms. This complementary measure can be found in Gompers et al. (2003); Bebchuk et al. (2009); and O'Connor and Rafferty (2012), who combine different data sources to construct a CG variable that reflects the restriction to shareholders rights (Gompers et al., 2003, p.114). The drawback of this general index comes from its simple equal-weighting scheme which cannot accurately reflect the relative impacts of different provisions. However, Gompers et al. (2003) still argue that in almost every case, these provisions increase the power of managers and weaken the control rights of large shareholders, no matter how different their effects are on firm performance.

Empirical literature

Table 2.2 below provides detailed summary of some most important contributions to the relationship between corporate governance quality and the level of firm R&D investment.

Table 2. 2: Empirical studies of R&D investment and corporate governance quality

Authors	Data period	Sample	Measure of Corporate Governance	Findings
			Ownership concentration	
Hill and Snell (1988)	1980	94 large U.S. enterprises.	_ Stock concentration	_ Stock concentration was positively related to R&D expenditure.
Hosono et al. (2004)	1987-1998	515 Japanese machine-manufacturing firms	Shareholding ratio by top 10 shareholders	_ The shareholding ratio by top 10 shareholders is significantly positively correlated with R&D.
Lacetera (2001)	1994-1999	27 U.S. large pharmaceutical companies	_Ownership concentration	_ Ownership concentration has a significant and positive effect on research intensity.
Cho (1992)	1986	265 U.S. manufacturing firms	3 measures of management stockholding: _ The percentage of stockholding held by the CEO. _ The market value of stockholding by CEO divided by CEO's annual salary and bonus. _ The market value of stockholding by CEO divided by CEO's annual total cash compensations.	_ Empirical results show that R&D intensity increases as the importance of management stockholding increases in the manager's personal wealth.
Battaggion and Tajoli (2001)	1991-1995	1,233 Italian firms	_ Dummy variable for ownership concentration	_ In the most innovative sectors, firms whose ownership is more dispersed display a higher probability of being innovative. But it turns to be insignificant in the other industries.
Ortega-Argiles et al. (2005)	2001	Spanish manufacturing firms	Ownership concentration	_ The mechanism based on the concentration of capital in a small number of owners does not favour carrying out investments in innovation.
Lee and O'Neill (2003)	1995	1044 U.S. firms 270 Japanese firms	Stock concentration	_ Stock concentration is positively related to R&D-to-sales ratio in U.S firms. _ But in Japan, increasing concentration does not affect the level of R&D investments.
Lee (2005)	1995	1044 U.S. firms 270 Japanese firms	Stock concentration	Stock concentration and R&D productivity varies by country. For the US, stock concentration is negatively related to innovations at low levels of R&D investment, and positively related to innovations at high levels of R&D investment. The opposite is true for Japanese firms.
Cho (1998)	1991	230 U.S. firms	Insider ownership	OLS regressions suggest that ownership structure affects R&D investment. However, simultaneous regressions reveal that R&D investment affects corporate value which, in turn, affects ownership structure, but not vice versa.
Cebula and Rossi (2015)	2005-2013	369 firm-year observations from	Ownership concentration	Findings indicate a negative relationship between R&D outlays and ownership concentration.

		41 Italian companies		
Institutional ownership				
Jarrell et al. (1985)	1980-1983	324 U.S. firms	The percentage of common equity held by institutions	The percentage of equity held by institutional investors and average R&D-revenue ratio increase together.
Graves (1988)	1976-1985	22 U.S. computer-manufacturing companies	The percentage of total shares held by institutions	R&D spending was higher in firms where institutional ownership was lower.
Mahoney et al. (1997)	1984-1988	261 U.S. firms	_ Institutional ownership	_ Firms with high insider ownership and institutional ownership decrease subsequent long-term investment as R&D.
David et al. (2001)	1987-1993	73 U.S. firms	Cumulative count variable for institutional activism	_ Activism is positively associated with R&D inputs. This relationship is stronger in strategic contexts where R&D investments are likely to enhance firm value – that is, in firms with favourable growth opportunities and in firms in high-technology industries.
Eng and Shackell (2001)	1981-1989	58 U.S. industrial firms	Percentage of shares owned by institutional investors	_ Holdings of institutional investors are positively associated with R&D intensity following the introduction of a long-term performance plan.
Wahal and McConnen (2000)	1988-1994	2500 U.S. firms	_ Institutional ownership	_ Not only do institutions not 'cause' myopia, the higher institutional share ownership appears to lead to greater expenditures for R&D.
Aghion et al. (2013)	1991-1999	803 U.S. firms	_ Institutional ownership	_ The presence of institutional ownership boosts R&D productivity, even after accounting for an increase in R&D and the potential endogeneity of institutional ownership.
Bushee (1998)	1983-1994	U.S. firms	Percentage of institutional holdings	_ The results indicate that high turnover and momentum trading by institutional investors encourages myopic investment behaviour when such institutional investors have extremely high levels of ownership in a firm; otherwise, institutional ownership serves to reduce pressures on managers for myopic investment behaviour.
Rim and Ghazi (2010)	2003-2007	531 U.S., Japanese and French firms	_ Percentage of equity held by resident banks; public and private residents' pension funds; resident mutual funds.	_ For U.S.: low bank ownership and strong participation of pension funds and mutual funds in corporate capital are accompanied by a realization of R&D investment. _ In Japan, R&D investment is positively related to all the participation of banks, pension funds and mutual funds. _ In France, strong ownership of banks and low participation of pension funds and mutual funds in firm capital promote investment in R&D.

Board of directors				
Hill and Snell (1988)	1980	94 large U.S. enterprises.	_ IN/OUT (the proportion of inside to outside directors)	_ There is ample evidence that board composition has significantly positive effect on R&D expenditure. But more insider on the board is associated with higher R&D investment, the result that is counter to the expectation of agency theory.
Baysinger et al. (1991)	1980-1983	176 Fortune 500 Companies	_ The percentage of inside directors on a board	_ The percentage of inside directors on a board was positively related to R&D spending.
Czarnitzki and Kraft (2004)	1999	474 firm-year observations from 7 OECD countries.	_ Dummy variable to separate own-led and manager-led firms	_ In comparison with own-led firms, the manager-led firms are more active innovators
Mahoney et al. (1997)	1984-1988	261 U.S. firms	_ Percentage of outsider ownership	_ The effect of board composition variables are insignificant.
Lacetera (2001)	1994-1999	27 U.S. large pharmaceutical companies	_ Insider presence in the board of directors	_ No significant impact on research intensity.
Ugur and Hashem (2012)	2004-2010	1400 US-listed companies	_ Dummy variable indicates whether 'outside' directors of a board constitute a majority over 'inside' and 'outside related' directors	_ The effect of board independence is statistically insignificant across model specifications.
Chen and Hsu (2009)	2002-2007	369 Taiwanese firms	_ CEO duality _ Independent directors	_ An independent board may decrease the willingness of firms with high family ownership to reduce their R&D investment
Kor (2006)	1990-1995	77 U.S. firms	_CEO/chairperson separation _The proportion of outside directors who were appointed before the current CEO took office	_ Separating the CEO and board chairperson duties is associated positively with R&D investment intensity. _ There is not enough evidence to conclude a significant effect of board outsiders on R&D investment.
Chung et al. (2003)	1991-1995	1,448 firm-year observations	_ The ratio of the number of outside directors to the total number of directors	_ For the group of firms with high proportion of outside directors, there is significant and positive correlation between firm value and both capital and R&D investment
Lu and Wang (2015)	1999-2009	1824 U.S. firms	_ The separation of CEO and board Chairman _ The percentage of outside directors _ The independence of nominating committee	Board independence is positively associated with R&D investment.
Yoo and Sung (2015)	1998-2005	100 Korean large nonfinancial listed firms.	Outside director: the percentage of non-management directors on the board of registered directors.	Outside director has negative relationship with R&D activities.

Chen et al. (2016)	1999-2013	7,380 firm-year observations	_ The fraction of women on the board _ The number of female directors	_ Gender-diverse boards reduce the positive relation between R&D and earnings/returns volatility

Anti-takeover				
Meulbroek et al. (1990)	1985	203 U.S. firms	Shark repellent	There is a significant decrease in R&D/sales following the implementation of anti-takeover amendments. It suggests that shark repellents may exacerbate, rather than mitigate, managerial myopia.
Mahoney et al. (1997)	1984-1988	261 U.S. firms	_ Anti-takeover provisions' adoption. _ Poison pill dummy	_ Firms that adopted anti-takeover provisions subsequently reduce long-term expenditures.
Ugur and Hashem (2012)	2004-2010	1400 US-listed companies	_ Anti-takeover defences (staggered boards and business combination provisions)	Firms with staggered boards and business combination provisions tend to spend less on R&D (both in level terms and relative to total assets), and this negative effect is statistically significant.
Sapra et al. (2014)	1980-1995	10377 U.S. firm-year observations	State-level index of anti-takeover laws	Using ex ante and ex post measures of innovative activity, they show strong empirical support for the U-shape relationship between the level of innovation and the takeover pressure the firm faces.

First, the traditional approach links the corporate ownership structure to the level of R&D investment. It argues that concentrated ownership is critical for effective governance, since only large investors have incentives to monitor managers and, if necessary, intervene to correct value-destructive actions (Edman and Manso, 2011). This view is corroborated by Hill and Snell (1988), where the two authors find a significantly positive effect of stock concentration on R&D investment in a small sample of 94 U.S. firms in five research-intensive industries. These industries are chosen by two criteria: (i) the ratio between R&D expenditure and sales must be higher than 0.02; and (ii) at least 10 firms from each industry had to be in the *Fortune* 500. Similarly, Hosono et al. (2004) find that shareholding ratio of large shareholders is positively correlated with R&D intensity in the data set contains 515 Japanese machine manufacturing firms over the 1987-1998 period, and the same result is reported in Lacetera (2001) for his small sample of 27 U.S. large pharmaceutical companies. In addition, R&D intensity rises as the importance of management stockholding increases in the manager's personal wealth is the main finding of Cho (1992) for the data set of 265 U.S. manufacturing firms in 1986. His empirical results provide support to the argument that a manager with stocks of his firm is less risk-averse than other managers, therefore the level of managers' ownership may be an important factor to determine the level of the highly uncertain activity like R&D investment.

On the other hand, two studies that document the opposite sign for the effect of ownership concentration on R&D investment are Battaggion and Tajoli (2001) and Ortega-Argiles et al. (2005). In respect to the former, the authors conclude that in the most innovative sectors in Italy, firms whose ownership is more dispersed display a higher probability of being innovative. Concerning the latter, the mechanism based on the concentration of capital in a small number of owners in Spanish manufacturing industries is confirmed not to favour carrying out investments in innovation, due to higher levels of supervision of administrators' work. Recently, Cebula and Rossi (2015) also confirm a negative relationship between R&D outlays and ownership concentration on their small panel of 41 Italian firms.

Furthermore, Lee and O'Neill (2003) and Lee (2005) give some conclusions about the more complicated relationship between stock concentration and R&D productivity. Using the sample of 1044 firms for the U.S. and 270 firms for Japan, the results in both papers demonstrate that this relationship is varied significantly by country. In the 2003 paper, the positive effect of ownership concentration on R&D has been found in U.S. firms, but it turned out to be insignificant in the data set of Japanese firms. These results, in some ways, provide support to the difference between theories of corporate governance system in the U.S. and Japan. In the U.S., increasing concentration helps to balance the power of owners versus the self-interested managers in leading to increased R&D investment, whereas the stewardship theory represents Japanese firms indicates that increasing concentration may or may not affect the level of R&D investments, because managers are already aligned with the objectives of their principals (Davis et al., 1997). For the later paper in 2005, Peggy Lee applies Poisson regression on the same sample, and the results turn to suggest a non-linear relationship. With the U.S. data set, stock concentration is negatively related to innovation at low levels of R&D investment, while positively related to innovations at high levels of R&D investment, and the opposite is true for Japan.

In addition, Cho (1998) cautions researchers to be careful with the assumption of exogenous ownership structure in the models of long-term investment. In his study, a simultaneous regression was run for the data set of 230 *Fortune 500* manufacturing firms in 1991. The results show that even though there is strong evidence for the positive effect of insiders' ownership on R&D expenditures, there is a signal of possible reverse causality because R&D spending also impacts corporate value and, in turn, ownership structure.

Inside the literature on the relationship between ownership concentration and R&D investment, there is one specific type of owners that is considered to have strongly negative effect on the level of R&D investment: the institutional ownership. It is based on the idea that institutional investors are likely to prefer short-term profits than long-term investment in R&D activity. Therefore, the higher the level of institutional owernship, the lower the level of R&D investment should be found to the firm (Jarrell et al., 1985). Nevertheless, the empirical results seem to rarely support the argument. Most of the studies have concentrated on the U.S. data, due to the strong criticism that short-term horizontal influence from institutional owners leads to the myopic investment behaviour by U.S. corporate managers. In the early 1990s, it was argued as the main reason for the fall of U.S. firms behind German and Japanese firms in terms of competitiveness and technological development (Jacobs, 1991; Porter, 1992).

Empirically, it was first tested by Jarrell et al. (1985) in a data set of 324 U.S. companies over the 1980-1983 period. Their results indicate a positive association between the level of institutional ownership and R&D intensity. However, using the same methodology as Jarrell et al. (1985) but focusing only on a single industry – the computer manufacturing, Graves (1988) reports an opposite result of higher R&D spending in firms where the level of institutional ownership is lower. From that, Samuel B. Graves points the way toward a more definitive study of the linkage between R&D investment and institutional ownership, which requires more effects controlled for the cross-section of industries over the long period. The weakness of Graves's (1988) results comes from the small size of his sample with only 22 companies in 1 single industry. Only 1 year later, Hill and Hansen (1989), once again, report a positive relationship by confirming higher levels of institutional ownership are associated with greater R&D expenditures. In addition, the research of Mahoney et al. (1997) also conclude that firms with greater level of institutional ownership tend to have higher long-term investment in R&D activities than firms with less external monitoring by institutional owners. Along the same line, David et al. (2001) find that the institutional investors' activism is positively associated with R&D expenditure, especially in firms with favourable growth opportunities or in firms in high-technology industries that underinvest in R&D in their data set of 73 U.S. companies over the period 1987-1993. This result is also consistent with the finding from Eng and Shackell (2001) on the data of 58 U.S. industrial firms in 1981-1989 period.

In addition, the research of Wahal and McConnen (2000) was recognized as the first one which investigated this relationship on a big panel data set that contains information of 2500 U.S. firms during the period from 1988 to 1994. Once again, the authors find ample evidence to support the positive relationship between industry-adjusted expenditure for R&D and the fraction of shares owned by institutional investors. Similarly, by trying both input and output measures of R&D investment for the data set of 6208 firm-year observations on 803 U.S. firms, Aghion et al. (2013) confirm the significant impact of institutional ownership on innovation. Although the association is positive but small in the case of R&D input-measure, a larger positive effect on the productivity of R&D (as measured by future cite-weighted patents per R&D dollar) is also documented.

Furthermore, Bushee (1998) demonstrates that the effect of institutional ownership on R&D investment relies on different types of institutional owners and also the level of their ownership in a firm. To be more specific, the author expresses that on the one hand, the sophistication of institutional investors allows them to monitor and discipline managers, ensuring that managers choose R&D levels to maximize long-run value rather than to concentrate on meeting the short-term earnings goals. On the other hand, there is another type of institutional investors, who show their high portfolio turnover, diversification and momentum trading (normally called 'transient institutional owners'). This type of institutional owner tends to increase the probability that managers will act in 'management myopia' way towards R&D investment. Similarly, Eng and Shackell (2001) reveal that bank and insurance companies' investment is lower than the 'other' institution (colleges and universities, private foundation, private pensions and public pensions) in firms with higher R&D intensity. Moreover, Rim and Ghazi (2010) investigate the effects of 3 different kinds of institutional investors: banks, pension funds and mutual funds on the behaviour of managers to encourage R&D investment. Empirically, the data set of 3 countries: US, Japan and France show the very different results. While all the kinds of institutional investors positively affect R&D investment in Japan, there is contrast conclusion for US and France. For US, the low bank ownership and a strong participation of pension funds and mutual funds in corporate capital are associated with higher R&D outlays, while the opposite results are found for French companies.

The next dimension of corporate governance reflects the board of directors and CEO characteristics. This strand of literature includes the level of board independence; the structure of board with or without women and some other regulations related to electing board members such as the experience requirement; the separation of CEO and chairman position; CEO experiences and other characteristics.

Empirically, one of the main variables that reflects the effect of corporate governance quality on innovation in Hill and Snell (1988) is the ratio of insiders to outsiders in board of directors (IN/OUT). Their findings indicate the importance of board composition, but the sign of IN/OUT variable is counter to the expectation from the theory. They find that greater insider representation on the board was associated with greater R&D, while the theory suggests firms must have higher level of outsiders to stimulate innovation (see section 2.2.4 above). Baysinger et al. (1991) find the same result that top executives may be more willing to invest in risky R&D activity if they are well-represented on a board and therefore less dependent on the judgment and evaluation of outside directors. The theoretical perspective then is summarized by Lacetera (2001) that in order to engage in such an uncertain activity like R&D, firms must fulfil the requirement of a certain degree of intra-firm integration. Czarnitzki and Kraft (2004) also conclude that in comparison with own-led firms, the manager-led firms are more active innovators in their sample of 7 EU countries. Similarly, Yoo and Sung (2015) investigate this relationship on their panel of 100 large Korean nonfinancial listed firms and conclude that outside directors have negative or at least insignificant, not a positive relationship with R&D activities. The only study documenting positive effect of board independence on R&D investment is Lu and Wang (2015), where that relationship is economically significant and robust to endogeneity.

Besides, no significant effect of board independence on R&D investment is the conclusion of Mahoney et al. (1997) and Lacetera (2001). While in the former, the proportion of outsiders on the board, the fraction hired before the CEO took office, and the separated CEO/chairperson indicators are used as proxies for board independence, only the percentage of insiders in the board is applied in the latter. But, again, the small size of their data sets is an obvious problem, with 261 firms for Mahoney et al. (1997) and only 27 pharmaceutical firms for Lacetera (2001). However, the same conclusion can be found recently in Ugur and Hashem (2012) with the large panel of 1400 US-listed firms. In their study, the board independence variable seems to have positive effect on the level of firm R&D expenditure, although the effect is statistically insignificant across model specifications. However, a weakness of this research comes from their use of a dummy variable to reflect the level of board independence, which might not adequately reflect the real issue.

Furthermore, Chen and Hsu (2009) subsume board independence (CEO duality and independent director) to investigate its influence on the family ownership-R&D investment relationship. Based on a panel of 369 Taiwanese firms, their results show that the negative family ownership-R&D investment relationship is weakened by board independence. In more detail, an independent board may decrease the willingness of firms with high family ownership to reduce their R&D investment. Using the same variables, Kor (2006) investigates both direct and interaction effects of board independence and top management team on R&D investment. The author finds that only the separation of CEO and chairperson has direct effect on R&D, while the level of board outsider has not. However, the high correlations of board outsider variable with other governance mechanisms suggest that it may not be appropriate to conclude that outsiders do not have an effect on R&D investment.

In another attempt to examine the relationship between firm valuation and R&D investment, Chung et al. (2003) use board independence as a condition to divide different groups of firms. Their results show that there is significant and positive correlation relationship between firm value and R&D investment in the group of firms with high proportion of outside directors.

Another factor in boardroom that affects firm R&D investment is gender diversity. In fact, it is already a long-standing literature on the relationship between gender diversity and firm value. However, the link to R&D investment has just been introduced by Chen et al. (2016). Utilizing the U.S. sample, they conclude that gender-diverse boards reduce the positive relation between R&D and earnings/returns volatility. By improving the effectiveness of managerial decision-making in R&D risk management, the level of gender diversity on board of directors may indeed induce managers to engage in R&D activity.

The last important dimension of corporate governance is the firm's strategy to face with takeover pressure. There are also two opposite directions of theories for the relationship between the level of anti-takeover tools a firm is using and its R&D investment. Firstly, if a firm is applying some strong anti-takeover defence tools like poison pill or staggered board, its manager is considered to have more protective environment and might be more likely to invest in innovative activity. On the contrary, there is another argument that the strong anti-takeover defence tools might lead managers to live in the 'quite life', which reduce their incentives to take more R&D activity (Jensen, 1988). Overall, the empirical literature tends to support the latter perspective, with many authors postulate the negative impact of the level of anti-takeover tools to firm R&D investment. For instance, Meulbroek et al. (1990) examines whether there are changes in the level of expenditures on R&D surrounding the introduction of anti-takeover amendments. Their empirical results document a significant decline in R&D intensity for the sample of 203 U.S. companies. Mahoney et al. (1997) provide supportive evidence by concluding that firms that adopt the anti-takeover provisions subsequently reduce long-term investment in R&D. This negative effect is also consistent with the finding from Ugur and Hashem (2012) on U.S. manufacturing sample.

Recently, Sapra et al. (2014) indicate that the relationship between innovation and the level of antitakeover provisions is more complicated than studied before. By developing a parsimonious model and using R&D intensity as an ex ante measure of innovation, these authors show strong empirical results for the U-shape relationship. It can be explained theoretically as when takeover pressure is very low, the low likelihood of a takeover induces managers to choose greater innovation with higher unconditional expected payoff. Also, when the level of takeover pressure is extremely high, the expected takeover premium increases with the degree of innovation, and therefore it is again optimal to choose greater innovation. However, for moderate levels of takeover pressure, it is better for managers to choose lower level of innovation to reduce the likelihood of losing their control benefits.

To conclude, the effects of different dimensions of corporate governance quality on firm R&D investment are often reported significantly. However, the main weakness of this literature is that most of the studies have focused on the U.S. data, due to the fact that there seems to be no database that allows for the comparison between different corporate governance characteristics across countries. Another approach is to use country-level governance indicators, as country fixed effects explain approximately 70% of the variation in firm-level corporate governance ratings (Doidge et al., 2007). Moreover, Griffin et al. (2017) claim that firm-level corporate governance practices vary primarily at the country level. Hence, even though the country-level governance indicators might not be as precise as firm-level data in reflecting corporate governance characteristics, the former can still be relevant and of more appropriate in research on multi-nations. Empirically, Seifert and Gonenc (2012) provide supportive evidence by documenting the significantly negative impact of the level of creditor rights in a country with firm R&D investment. Their results base on a firm-level data set from 41 countries. Hence, in this thesis, I test the additional effects of several country-level governance indicators in the augmented Tobin's Q models on the data set from 15 OECD countries.

2.4.1. The combined effect of product-market competition and corporate governance quality

Another conclusion from the review above is that both market competition and the quality of corporate governance shape the cost-incentive structure that managers have to control when they decide the optimal level of innovation effort. Hence, there is a need to assess the combined effect of both factors in one model. However, there are still very few works on this issue. Earlier, market competition is often used as the control variable in research about the relationship between corporate governance and R&D investment (Grave, 1988; Cho, 1992). As a move towards investigating the inverted-U shape relationship between market structure and innovation, the move towards joint examination of market structure and corporate governance is first recognized by Aghion et al. (1999 and 2002). Specifically, Aghion et al. (2002) conclude: "the product market competition can be a substitute for governance for one group of firms (where agency problems are rife) and complementary to governance for another group" (p. 22). The idea is developed further in Aghion et al. (2013), when the authors assemble a panel data of 803 U.S. firms over the 1990s to affirm that the positive effect of institutional ownership on innovation is even stronger with the presence of the increase in product market competition. In addition, by utilising the data set of 1400 non-financial US-listed firms, Ugur and Hashem (2012) provide a similar result for the complement of corporate governance and market competition in determining the level of innovation. In their results, the estimated coefficients for the interactions term between corporate governance variables and concentration ratio are mostly positive and statistically significant.

However, the check for whether the effects of corporate governance quality and product-market competition on the firm's investment are substitute or complementary is rather suitable for research on specific country with firm-level governance indicators. Since I apply country-level governance indicators on a data set from 15 OECD countries instead, I will not test for this combined effect between governance quality and product-market competition on firm R&D investment.

2.5. R&D investment and knowledge spillovers

Theoretical explanation

Another possible determinant of firm R&D investment is technological spillovers. "As a public good, knowledge has two properties: it is non-excludable and it is non-rival, since it can be used by multiple firms at the same time and the innovator cannot impede other firms from using it. For this reason, knowledge produces externalities are referred to in the literature as knowledge spillovers" (Aldieri, 2011, p. 598). Similarly, De Bondt (1997) defines a 'knowledge spillover' as 'involuntary leakage' of technological knowledge.

The attention to the role of technology spillovers has increased considerably since the discovery of their important role in 'endogenous growth models' (Romer, 1986, 1990; Grossman and Helpman, 1991). According to Griliches (1992), there are two distinct notions of R&D spillovers which are often confused in the literature: the rent spillovers and the knowledge spillovers. The former is defined as the R&D-intensive inputs purchased from other industries at less than their 'full-quality' price. It occurs because the producer does not charge a price which captures the full economic benefits of its innovation. "As a result, productivity improvements accrue to the user firm from the R&D expenditure of the producer" (Wakelin, 2001, p.1085).

However, the rent spillovers is not real knowledge spillovers. They are just consequences of conventional measurement problems, of the difficulty to estimate the social returns to innovation. The true knowledge spillovers are the ideas borrowed by the research teams of industry (or firm) *i* from the research results of industry (or firm) *j* (Griliches, 1992). Knowledge spillovers arise because of the imperfect appropriability of the knowledge associated with innovations. Poor patent protection, the inability to keep new knowledge secret, and reverse engineering practices all contribute to the pervasiveness of R&D activity, which is the root of knowledge spillovers (Mohnen, 1996). However, it is hard to empirically make a distinction between rent and knowledge spillovers. It is often suggested that proximity measures based on intermediate input flows (conducted from Input-Output table) are more likely to reflect rent spillovers, while the weighting matrices based on patent and innovation flows should be considered as more reflecting knowledge transmission (Cincera, 2005; Cincera and van Pottelsberghe, 2001; van Pottelsberghe, 1997; Mohnen, 1996).

Theoretically, why is spillovers issue important in determining the level of firm R&D investment?

The effect of knowledge spillovers on the level of innovation was first proposed by Arrow (1962), where he suggests that the inability to appropriate full returns to new inventions might decline the inventors' incentives for further innovative activities. Besides, if potential buyers can imitate an innovation at a cost that is substantially below the cost of developing this innovation, they may have little or no incentive to be innovative (Mansfield, 1984).

On the other hand, Cohen and Levinthal (1989) challenge that common perspective of a negative knowledge spillovers effect on firm investment by suggesting that firms must invest in R&D activities up to a certain level, in order to assimilate and exploit new inventions from outside. This relates to the second "face" of R&D activities, which is to enhance technology transfer (absorptive capacity), together with the first role of stimulating innovation.

Empirically, there are few papers taking into account the effect of knowledge spillovers in R&D investment models. However, most of them report a positive effect (Jaffe, 1988; Cohen and Levinthal, 1989; Harhoff, 2000). However, the limitation in these empirical works is due to their limited samples, which often relate to industries with high innovation intensities. In such industries, R&D investment by other firms (the spillover pool) may induce higher levels of R&D investment by the spillover-recipient firm. This is because the spillover pool faced by high R&D-intensive firms is more likely to be a source of creative destruction or 'market-stealing' effect rather than a source of knowledge to be emulated. Both the creative destruction and 'market-stealing' effects are expected to be higher when the firm is closer to the knowledge technology frontier. In such cases, the competition between firms is neck-and-neck and a successful new innovator is more likely to overtake the existing leader, causing the latter to suffer market-share loss or causing its technology to become obsolete or both (Bloom et al., 2013). The implication is that the external knowledge (spillover) pool is complementary to the firm's own R&D effort.

However, there is an extensive empirical literature indicating that external knowledge is a source of productivity gains by spillover-recipient firms/industries/countries (Coe and Helpman, 1995; Cincera, 1998; Griliches and Lichtenberg, 1984b). These findings indicate that the spillover pool is a source of knowledge externalities that spillover-recipient firms can actually emulate. In this case, the existing external knowledge (spillover) pool will act as a substitute for the firm's own R&D effort. Therefore, the overall effect of spillovers on firm R&D investment depends on whether the complementarity or substitution effect of spillover dominates.

Measurement issues

While there are ample evidence on the effect of spillovers on economic growth, the estimates vary greatly across studies (Wakelin, 2001). One of the main reasons is the difficulty in obtaining a proper measure of knowledge spillovers. It is not only because of the diversified sources of spillovers (i.e. from the movement or communication of scientists or other important technological people between companies; or from the diffusion of knowledge in scientific journals), but also because of the complexity of the linkages between inventions or technology in different industries. The example from Griliches (1979) can be used to clarify the latter: whether the leather industry is closer to food or to textiles industry still has no precise answer.

Two proximities have been developed and applied, in order to reflect the level of spillovers: the geographical and technological proximity.

As suggested by Krugman (1991), there may be geographic boundaries to information flows or knowledge spillovers, particularly tacit knowledge, among firms in an industry. This proximity is based on the belief that it is easier for knowledge to be spilled over when firms are located in the same region, because of the probability of interaction between employees in social and professional organisations. These interactions would be more difficult in the long distance and different languages situation. A number of studies have confirmed that effect of local geographical spillovers on the level of investment (Feldman, 1994; Audretsch and Feldman, 1996; Jaffe et al., 1993; Medda and Piga, 2014).

The second measure of spillovers is the technological proximity. The intuition behind this proximity is that spillovers will be higher between ‘technological neighbours’, both at firm- and industry-level. Following this perspective, the ability to make productive use of another firm’s knowledge depends on the degree of technological similarity between firms or industries. Apparently, every technological field embodies a specific kind of unique language and concerns a similar set of applications. Additionally, researchers in any specific technological field all over the world are likely to publish their studies in the same journals and join the same professional organisations (Greunz, 2003). But even within the literature of this proximity, there have been several approaches to measure ‘technological distance’ between firms.

In the first - the so-called symmetric approach, all firms in an industry are treated equally. This simplest approach is supported by Wakelin (2001): “While not all R&D conducted by other firms in the same sector will necessarily spill over to the firm, the level of R&D activity in the sector gives an indication of the level of technological opportunity and the size of the available pool of technological spillovers” (p. 1085,1086). Hence, it is applied in several studies, such as Bernstein and Nadiri (1989); Evenson and Kislev (1973); Huffman and Evenson (1993); and Bartelsman (1994) (see Griliches (1992) for a review). Nevertheless, the idea of treating all firms or industries with equal weights cannot draw a precise picture of how knowledge is truly spilled over in practice, where the level of spillovers could be notably different between firms or industries.

The second approach is to measure the ‘technological similarity’ between firms or industries, using the technological ‘distance’ as a weight. In order to measure the knowledge flows, it is useful to compute a ‘weighting matrix’, in such a manner that the diffusion of knowledge will be proportional to the degree of transaction between firms (Aldieri, 2011). Earlier suggestion is based on ‘vertical’ borrowing, in which the Input-Output table is used to calculate the measure of the ‘closeness’ of industries (Schmookler, 1966; Brown and Conrad, 1967; Terleckyj, 1974, 1977, 1980). Recently, the advantage of this approach is reminded in Plunket (2009). In more detail, she states that innovation is diffused along the value chain through the introduction of technologically advanced inputs introduced by suppliers themselves or developed at the demand of lead-users or through the co-development between users and producers in order to customize inputs and share complementary skills. So far, the relative importance of user-producer linkages has been investigated not only at the industry (Terleckyj, 1974, 1977, 1980; Wolff & Nadiri, 1993, Medda and Piga, 2014) but also at country level using national Input-Output tables (Coe and Helpman, 1995).

In addition, a similar approach is applied by Scherer (1984), except that his measure of spillovers is based on patent citations data distinguishing between industries of origins and users of innovation using the Federal Trade Commission Line of Business Survey data for 1974. He argues that using the number of patents issued by sector *i* which falls in sector *j*'s industrial classification is more related to the definition of spillovers than using Input-Output data to calculate the similarity between industries. In fact, Professor Frederic M. Scherer is not the only scholar who criticize the user-producer approach in constructing a measure of technological spillovers. This approach is often criticised as more related to economic transactions rather than pure technological links between two firms or industries (Cincera, 2005; Verspagen, 1997b). A clear example is provided by Verspagen (1997b): "One may think of sectors such as rubber and plastic products which, by the chemical nature of their technology base, may benefit from technical knowledge of fertilisers, although their relationship in terms of user-producer interactions with the fertiliser industry will be marginal" (p. 49).

Another way to construct a measure of technological 'similarity' is based on the patent histories. Apparently, Adam B. Jaffe is considered as a forerunner of this approach as his works (1986, 1988, 1989) started a stream in the literature for using firm patent data to compute the distribution of patenting across 49 technological categories based on the Patent Office's Classification system, and from that evaluating technological similarities between firms. To be more specific, his measure of 'closeness' between any two firms uses the overlap in the distribution of their patents by detailed patent classes and indexes it by the uncentered correlation coefficients between them. The original assumption for this measure is that two firms that are active in the same technological category (recognizing by their taking out patents in the same patent classes), will be more likely to benefit from each other's new knowledge and innovation. He constructs for each firm an outside 'technological pool' matrix, where each element reflects the effect of another firm's (or outside industry) R&D

which is weighted inversely to their estimated technological distance from the investigated one. Similarly, Goto and Suzuki (1989) take up Jaffe's approach, except that they use the distribution of R&D investment in different technological areas instead of patents. The process of calculating the technological proximity between industry *i* and industry *j* can be summarized as below:

The formula of the 'technological distance weight' at industry level:

$$P_{ij} = \frac{F_i F_j'}{[(F_i F_j)(F_{ji})]^{1/2}} \tag{2.18}$$

Where

P_{ij}: the weight of technological 'distance' between industry *i* and industry *j*.

F: the technological position vector of the respective industries, in which $F_t = [F_{t1}, F_{t2} \ldots F_{tm}]$ is made up of m elements, each reflect the fraction of the industry's R&D expenditures on a specific technological area.

P_{ij} receives the value between 0 and 1, with the higher the value denotes the closer the technology distance of two industries is.

After having the weight P_{ij}, the equal level of technological spillovers for all firms in industry *i* is constructed by the formula:

$$S_i = \sum_{j \neq i} P_{ij} R_j \tag{2.19}$$

Where R_j is the R&D spending of industry *j*.

Another version of Jaffe's technological proximity can be found from Adams (1990). The difference in his research is that the proximity measure was calculated based on number of scientists hired with the same type of qualification. Some other works that applies Jaffe's approach for measuring spillovers are Aldieri (2011); Cincera (2005).

However, it should be noted that even the Jaffe's technological proximity measure based on this detailed technological 'distance' construction is not free of criticism. The full discussion can be found in Cincera (2005), of which the following are worth highlighting. First, it is due to the complication of R&D investment and the number of patents registered. For some reasons, such as the strategy to keep the new knowledge in secret, firms may not register their patents or only register it partly. The fact that not all inventions are patented, nor all are patentable and that not all patented inventions are economically valuable are two major drawbacks of patent statistics (Griliches, 1990; Jaffe and Trajtenberg, 2002). This issue can be eliminated by using the input measure of innovation (such as R&D expenditure) to construct the proximity, which is applied by Goto and Suzuki (1989). However, it requires the hard-to-reach specification and data of how firms divide their R&D expenditures to different outputs. Second, the technological proximity is supposed to be the same in both directions. The challenge here is quite obvious, as normally in the relationship between two firms A and B, A can be better in capturing the fruits of B's innovative activities or vice versa. But how can we reflect this difference in a measure is still a question to answer. Third, how do we capture the time lags of spillovers effect? It involves both the period until firms can reach a new invention and also the time spending for successful imitating the new invention or even applying it into new product.

Empirical literature

Below, I provide table 2.3 with the summary of few studies that have investigated the effect of technological spillovers on the level of firm R&D investment.

Since it is difficult to fully understand the spillovers concept and have a precise measure, the empirical literature on the effect of technological spillovers on productivity and R&D investment has not quite kept up with the theoretical development. In general, even though the estimated magnitude of this effect varies largely with the specific industries and countries under investigation and also with the different methods of estimation, many have supported that the importance of technology spillovers is beyond dispute (see Nadiri (1993) for a survey).

Table 2. 3: Empirical studies of technological spillovers as a firm R&D's determinant

Authors	Data period	Country	Findings
Jaffe (1988)	1976	537 U.S. firms	When R&D in a firm's vicinity increases, the firm does more R&D itself.
Cohen and Levinthal (1989)	1975-1977	318 U.S. firms	Intra-industry spillovers may encourage equilibrium industry R&D investment.
Bernstein and Nadiri (1989)	1965-1978	4 U.S. industries: Chemicals, Petroleum, Machinery and Instruments	An increase in the R&D spillover decreases the rate of accumulation of both R&D and physical capital.
Harhoff (2000)	1977-1989	443 German firms	Spillover R&D actually encourages the R&D activity of firms in high-technology sectors while there is little or even a negative effect in the other industries.
Belenzon (2006)	1981-2001	512 U.S. firms	Firms are able to internalise dynamically some of their knowledge that spills to other firms. To the extent that such internalisation occurs, the classical underinvestment problem in R&D will be mitigated, as the negative effect of spillovers on private returns weakens.
Yang et al. (2010)	1977-2005	87 U.S. telecommunications manufacturers	From a dynamic perspective, knowledge that spills over may generate future private returns to the originating firms and increase their incentives to invest in innovation.
Capron and Cincera (2001)	1987-1994	625 world-wide R&D-intensive manufacturing firms	The firms of the sample react aggressively to an increase of R&D outlays of competitors.
Nieto and Quevedo (2005)	2001	406 Spanish manufacturing firms	Negative effect of unweighted intra-industry spillovers on the firm's research effort.
D'Aspremont and Jacquemin (1988)	Case study: For a duopolistic industry characterized by R&D activities generating spillover effects		For large spillovers, the level of R&D increases when firms cooperate in R&D and/or output.
Chun and Mun (2012)	2001-2002	3,775 Korean manufacturing SMEs	Incoming spillovers have a significant and positive effect on the probability of SMEs' R&D cooperation.

To be more specific, there are justifications for an effect of knowledge spillovers on the firm's incentives to undertake R&D investment. For instance, if the 'In-house' R&D investment is complementary to the external knowledge, firms will have more incentive to increase their R&D expenditures and vice versa. Harhoff (2000) supports this idea by stating: "externalities in the form of information or knowledge 'spillovers' play an important role in shaping the incentives for R&D activities of private firms, but researchers are nonetheless still far from reaching definite conclusions for this relationship" (p.238). Moreover, since there is the need for intellectual property rights when knowledge externality is at high level, it may lead to ‘underinvestment’ (from an economy-wide perspective) in knowledge-creating activities such as R&D (Verspagen, 1997a).

While the early papers (Nelson, 1959; Arrow, 1962) tend to argue that research spillovers diminish firm incentives to invest in R&D by undermining the appropriability of returns to it, the later empirical results seem to rarely support this theoretical prediction. In fact, Jaffe (1986; 1988) observes significant and positive effects of R&D spillovers on not only the firm’s productivity growth but also its R&D intensity. To be more specific, Jaffe (1988) finds that the effect of R&D spillover pool remains positive and significant in all of his estimates, no matter with or without the present of industry and technological position effects. In economic point of view, he explained, the elasticity of own R&D with respect to the weighted sum of all others is between 0.2 and 0.3 (Jaffe, 1988, p. 434). Similarly, Cohen and Levinthal (1989) suggest that increasing intra-industry spillovers may elicit more firm R&D effort, due to the appropriability conditions that requires firms to innovate, in order to be capable of assimilating and exploiting externally available knowledge. These results are in line with the finding of Capron and Cincera (2001), in which the authors confirmed that the firms in their sample seem to react aggressively with any increase in R&D outlays of competitors.

In Harhoff (2000), however, the effect of spillovers on firm R&D spending is varied across different types of industry. While it is documented significantly with even higher magnitude than the results of Jaffe (1998) in high-technology industries, the little or negative impact of it on R&D spending is found in others.

In addition, based on a dynamic perspective, Belenzon (2006) and Yang et al. (2010) indicate that the firms might be able to internalise dynamically some of their knowledge that have spilled over to other firms. When such internalisation occurs, the commonly accepted negative effect of knowledge spillovers on private returns weakens, and hence it might not induce the underinvestment for these originating firms.

On the other hand, using the dynamic dual approach towards firm cost minimization problem, Bernstein and Nadiri (1989) find that in all four industries (Chemicals, Petroleum, Machinery and Instruments) in their sample, R&D spillovers have a negative effect on the rate of investment and are actually capital-reducing, both for R&D and physical capital. Similar negative impact from the unweighted intra-industry spillovers on R&D investment can be found in Nieto and Quevedo (2005) for the sample of 406 Spanish manufacturing firms, even though its effect is very small in terms of magnitude. "The influence of the variable spillovers may be considered almost residual but still significant, since it is able to explain a percentage of only around 2% of the variance of the dependent variable - R&D intensity" (p.1153).

Furthermore, observing the specific case of a duopolistic industry which is characterized by R&D activities generating spillover effects, D'Aspremont and Jacquemin (1988) suggest that the level of firm R&D is positively correlated with the level of R&D spillover when there is any cooperation between two firms. The effect of spillovers on R&D cooperation is also a topic of interest for researchers (see De Bondt (1996) for a survey). Recently, Chun and Mun (2012) confirm that incoming spillovers in terms of the relative importance of publicly available information to the innovation process and estimate their impact on R&D cooperation.

In addition, the significant effect of spillovers on productivity is another reason for the possible link between it and the optimal level of firm R&D investment. After a long-standing literature of private and social rate of return to R&D investment, the findings usually demonstrate the significant difference between these two, in which social rate remains significantly above private rate (see Griliches, 1979, 1992; Hall et al., 2010 for detailed surveys). Because of the non-rival and non-excludable characters of knowledge, a positive difference between social returns and private returns to R&D occurs and the economy as a whole faces increasing returns to scale (Los and Verspagen, 2000). However, the estimated social rates of return vary considerably across studies: from 11% in Bernstein and Nadiri (1988) to 183% in Terleckyj (1980) (Wolff and Nadiri, 1993). As a result, Corderi and Lin (2011) conclude that it is difficult to have the specific interval for the social rate of return on R&D investment, when it not only varies across countries but also across time periods. Additionally, Hall et al. (2010) provide another list of possible reasons for the wide range of empirical estimation for the social rate of return. One of the strongest is: "nothing in the system constrains the social rate of return on R&D to take on any particular value, precisely because they are unpriced and to a great extent, an accidental side effect of firm R&D strategy, even if some conscious management of disclosure does occasionally take place" (p.1071). Besides, another research direction attempts to investigate the effect of intra- and inter-industry level of spillovers. Overall, studies usually document the significant effect of both intra- (see Medda and Piga (2014), table 2) and inter-industry spillovers (see Hall et al. (2010), table 5) on productivity growth, however, the estimated results, again, are greatly varied with respect to measure of spillovers and empirical specification.

Overall, even though there is still small number of studies, the level of technological spillovers often matters in determining firm R&D investment. However, its effect is varied across not only different types or measures of spillovers but also different groups of industries. Therefore, it is necessary to have a model in which technological spillovers can be a joint determinant of firm R&D investment. By estimating that model empirically, how significant the spillovers effect is on the level of firm R&D is likely to be revealed.

2.6. Conclusions

Based on the detailed review of both theoretical and empirical literature, there are some principal remarks that must be summarized here.

First, even though in the traditional Tobin's Q theory, the marginal Q can be a sole determinant of firm investment, its empirical failure indicates several issues. The most critical one is that it often relies on an inadequate measure: the Tobin's average Q, with the set of strict assumptions that underpins the equality between marginal Q and average Q. However, it does not mean that expectation plays no role in managerial incentives for firm investment. Instead, the failure of empirical literature calls for another measure of expectation that can be relevant to the R&D investment decision-making process at firm-level. The studies from Fischer and Merton (1984), Ben-Zion (1984) and Mairesse and Siu (1984) provide a digression to the Tobin's Q theory by linking the stock market movements with managers' revision of expected profitability, one of the factors that might affect their future investment decisions.

Besides, other strands of industrial organisation literature show that product-market competition, the level of knowledge spillovers and corporate governance quality all matter in determining the optimal level of firm investment. Both the theoretical and empirical review suggest that the existing literature are fragmented, and there is necessary to build bridges between these different but not mutually exclusive theories.

These issues call for an augmented Tobin's Q model of investment. On the one hand, it tests whether the expectation about future profitability, reflected by the stock market movements' measure, has significant effect on firm R&D investment. On the other hand, it examines whether that role of expectations can be outweighed by other relevant factors in the literature on the determinants of firm R&D investment so far: product-market competition; the level of knowledge spillovers and corporate governance quality, and whether these factors appear to contribute significantly to the augmented model. The detailed framework of this augmented model is presented in chapter 3 below.

CHAPTER 3: METHODOLOGY AND DATA

3.1. Introduction

In this chapter, despite the failure of Tobin's Q theory of investment in the empirical literature, I argue that expectations about future profitability still play an important role in explaining the firm's investment decisions. However, I also demonstrate that the measures we have for the marginal return to investment are imperfect and there are a range of other firm and industry characteristics that impinge on managerial incentives for R&D investment but are not captured by any proxy of Tobin's marginal Q. Therefore, I propose a solution using the measure of expected profitability from an accelerator model of investment in Mairesse and Siu's (1984 and argue that it can be an important determinant of the optimal level of firm investment. In addition, I will also demonstrate why my proposed measure of one-period-ahead growth rate of Tobin's average Q is better than their one-period holding rate of return on the stock market valuation by taking into account the change in replacement cost of capital. Then, I explain why the Tobin's Q model of R&D investment should be augmented not only with an indicator of future capacity needs (proxied by past change in demand/sales), but also with other determinants of firm investment. Finally, I also discuss a range of measurement and estimation issues that the augmented Tobin's Q model poses for researchers.

A second task of this chapter is to introduce the data set I use for estimation. It is an unbalanced panel data set of 3,718 manufacturing firms from 15 OECD countries over the 2005-2013 period. The countries' choice is based on the *World Top R&D Scoreboard* published by European Commission in 2011-2013 period. My sample comprises listed firms that are available in the *Datastream* database.[6] After the cleaning process, my estimation sample consists of 31,493 firm-year observations from 3,718 manufacturing firms.

The rest of the chapter is structured as follows. Section 3.2 discusses the problems of the common empirical approach. As a way to deal with these issues, this section also introduces the appealing accelerator approach expressed in Mairesse and Siu (1984), and the possibility of building up an augmented Tobin's Q model from that, where the growth rate of Q is a measure of expectation about future profitability that can be considered together with several

[6] The constituent lists are kindly provided by *Datastream* supporters, and are available from the author upon request.

different factors in explaining firm R&D investment. Then, section 3.3 discusses the measurement issues and illustrates that most of my chosen variables are in line with the literature. I explain the data collection and estimation sample's characteristics in section 3.5, and finally section 3.6 concludes the chapter.

3.2. Empirical models and estimation issues

With its appealing intuition about the relationship between investment and expectations of future profitability, Tobin's Q theory has dominated the literature on firm investment in the 1970s and 80s. However, the main issue is that marginal Q is unobservable (Hayashi, 1982; Blundell et al., 1992). The common approach uses average Q as a proxy for marginal Q, taking the advantage of the simple formula and the availability of financial data for the construction of average Q. However, this approach is problematic because of two main reasons. First, several studies have shown that the correlation between average Q and marginal Q is rather low (see, for example, Ang and Beck, 2000). Second, the equality between average Q and marginal Q only comes with a set of strict assumptions, including perfect market competition and linear homogeneity in the production and adjustment cost functions (Hayashi, 1982).[7]

Nevertheless, I argue that it is still possible to accord the Tobin's average Q a role in explaining managerial decisions on R&D investment. In an attempt to bring back the Tobin's Q into the theory of R&D investment, I will draw on a parsimonious model proposed by Mairesse and Siu (1984) who, in turn, draw on theoretical perspectives on why the firm's R&D investment is related to managerial expectations about profitability and capacity need.

Of the relevant literature, Ben-Zion (1984) suggests that the firm's investment plans might respond to the changes in market value. Fischer and Merton (1984) also illustrate that the change in stock prices has predictive power for the change in investment. Finally, Mairesse and Siu (1984) synthesize the insights from this work and refer to Pakes and Schankerman (1984) to state that *expected* demand and profitability are important determinants of the desired net investment in both R&D and physical capital.

[7] With respect to the perfect-competition assumption, Hayashi (1982: 14) states the following: "If the firm is a price-taker with constant returns to scale in both production and installation, then marginal Q is equal to average Q. If the firm is price-maker, then average Q is higher than marginal Q by what is legitimately called the monopoly rent."

Formally, the change in desired net investment in R&D or in physical capital, $i*$, can be stated as follows:

$$i_t^* = \gamma q_{t-1}^e + \phi s_{t-1}^e \tag{3.1}$$

In (3.1), the change in desired net investment depends on two factors: the expected future profitability and the expected capacity need, referring directly to Malinvaud's book in 1980. However, because the *expected* profitability and capacity need are unobservable, Mairesse and Siu (1984) propose two proxies: (i) the stock market one-period holding rate of return for approximating expected profitability; and (ii) a distributed lag specification of the sales growth for approximating expected demand. The coefficients (γ and ϕ) are assumed to have positive values. This is because an increase in expected profitability indicates the existence of profit opportunities than can be exploited by the introduction of innovative products; whereas an increase in expected sales indicates the need for R&D investment as a means of catering for the increased demand for the firm's products.

$$i_t^* = \log(NI_t \,/\, NI_{t-1}) \tag{3.1a}$$

$$q_{t-1}^{et} = \log(Q_{t-1}^{t} \,/\, Q_{t-2}^{t-1}) \tag{3.1b}$$

$$s_{t-1}^{et} = \log(S_{t-1}^{t} \,/\, S_{t-2}^{t-1}) \tag{3.1c}$$

Equation (3.1a) states that the change in desired net investment in year t (i_t^*) is equal to the difference in net investment between year *t*-1 and *t*. Equation (3.1b) states that profitability for year *t* as *expected* in year *t*-1 is determined by the change or revision of profitability between *t*-2 and *t*-1. Here, the change in profitability is defined as the change in the stock-market value of the firm – i.e., as the one-period holding rate of return on equity. Finally, equation (3.1c) states that the *expected* demand for year t as expected in year *t*-1 is also determined by the change or revision of the sales forecast between *t*-2 and *t*-1.

The revision in the expected profitability is due to arrival of new information about the future, which emerges between *t*-2 and *t*-1. On the other hand, the revision in expected demand is based on the assumption that current sales can be forecasted from an auto-regressive distributed lag (ARDL) model, conditional on all information available in period *t*-1. Under this assumption, change in expected sales should differ from change in actual sales only by a forecast error (Mairesse and Siu, 1984: 275).

Then, the model can be stated as in (3.1d), where $\varepsilon_{i,t}^{1}$ is a disturbance term that I will discuss in detail below.

$$\log(NI_t \,/\, NI_{t-1})_{i,t} = \alpha_0^1 + \beta_1^1 \log(Q_{t-1}^{t} \,/\, Q_{t-2}^{t-1})_{i,t-1}$$

$$+\beta_2^1 \log(S_{t-1}^{t} \,/\, S_{t-2}^{t-1})_{i,t-1} + \varepsilon_{i,t}^{1} \qquad (3.1d)$$

In equation (3.1d), the firm's desired net R&D investment in year t is determined by expectations about profitability and sales formed in year *t*-1. In year *t*-1, the managers decide on the desired investment for next year, taking into account the expected change (traction) in profitability and sales in year *t*-1 relative to the previous year *t*-2. Assuming no change in expected sales, a positive change in the expected profitability will induce the managers to decide in favour of an increase in the desired net R&D investment to exploit the perceived profit opportunities. Similarly, keeping expected profitability constant, a positive change in expected sales will induce managers to increase the desired net R&D investment to cater for increased demand. The theoretical expectation then are $\beta_1^1 > 0$ and $\beta_2^1 > 0$. The R&D budget is implemented in year *t*, when the firm hires the necessary R&D personnel, expands its R&D labs or purchases the necessary software or hardware to be used in the R&D activity.

In their empirical investigation, Mairesse and Siu (1984) report that both R&D and physical investment react similarly to changes in profitability (measured as market rate of return) and sales growth. They also report that the response of R&D to changes in the one-period holding rate of return is more stable than that of physical capital investment. However, they also acknowledge that their proposed model should be augmented with more explanatory variables such as relative cost of labour and capital and financial liquidity of the firm. In what follows, I will discuss the model specification issue and a range of measurement and estimation issues that arise from the theoretical model above. My discussion will be in a reverse order, starting with the measurement issues followed by the model specification and estimation issues.

Mairesse and Siu (1984) use the change in R&D (or physical capital) levels as the indicator for desired net investment. However, the common practice in R&D investment models (including, Hall, 1992; Cincera, 2003; Gugler et al., 2004) is to use R&D intensity – i.e., R&D investment as a proportion of total assets or sales. This measure not only controls for the effects of size and heteroscedasticity, but also reflects the firm's commitment to innovative activity and permits relative comparison among firms (Hambrick et al., 1983; Hoskisson and Hitt, 1988). Furthermore, the use of R&D intensity is in line with the theoretical conclusion from Hayashi (1982), which is stated in equation 3.10 above. Therefore, my dependent variable is R&D intensity, which is R&D expenditures as a ratio of total assets.

A second measurement issue in Mairesse and Siu (1984) relates to the expected change in profitability, which is proxied by the one-period holding rate-of-return – i.e., by the change in market valuation of the firm independently of the replacement cost of capital. The authors justify their choice by arguing that their measure will be equal to the percentage change in Tobin's Q, provided that firm debt is proportional to equity and that the replacement cost of the firm capital remains constant between years *t*-2 and *t*-1. Therefore, they argue that their model is related to other studies (e.g., Engle and Foley, 1975; Von Fustenberg, 1977; and Summers et al., 1981) that consider Tobin's Q as a determinant of investment.

Irrespective of whether or not this is the case, I argue that Tobin's average Q should be the preferred measure for three reasons. First, the lack of consideration for replacement cost of capital is problematic if the market does not price capital correctly or the replacement cost of capital changes between *t*-2 and *t*-1. In either case, the rate-of-return proxy used for Tobin's Q by Mairesse and Siu (1984) would be mis-measured, and therefore provide unreliable information about expected future profitability. Second, the ratio of market value to replacement cost of firm capital takes into account the effect of firm size and heteroscedasticity. Third, the assumption of constant replacement costs of the firm capital is also unnecessary, as its values in both years *t*-2 and *t*-1 are observable to managers. In fact, Malkiel et al. (1979) and Chappell and Cheng (1982) both use the change in Tobin's average Q as their measure of expected profitability in their investment models.

A third measurement issue arising from the theoretical model is the use of log difference as a conventional measure of change in expected profitability or sales. I argue in favour of using a symmetric rate of growth measure that has more desirable properties compared to the conventional growth rate. This symmetric growth rate measure has become standard in analysis of establishment and firm dynamics because it not only shares some useful properties with the growth rate reflected in log differences but also accommodates entry (newly-listed firms or listed firms that appear in the data for the first time) and exit (de-listed firms or firms that disappear for unknown reasons) (Davis and Haltiwager, 1992; Haltiwanger et al., 2013). More specifically, this growth rate has a symmetric distribution around zero, with a minimum profitability (or Tobin's Q) growth rate of -2 when the firm exits and maximum profitability (or Tobin's Q) growth rate of +2 when the firm is new entry. The third property is that it is monotonically related to the conventional growth rate and the two are equal when the symmetric growth rate is small (Davis and Haltiwanger, 1992, p.825-826).

Therefore, equations 3.1a – c can be re-stated as follows:

$$i_t^* = RD_{i,t} - RD_{t-1} = \Delta RD_{i,t} \qquad (3.1a')$$

$$q_{t-1}^e = \frac{Q_{t-1}-Q_{t-2}}{\frac{Q_{t-1}+Q_{t-2}}{2}} = \frac{2(Q_{t-1}-Q_{t-2})}{(Q_{t-1}+Q_{t-2})} = \Delta Q_{i,t-1} \qquad (3.1b')$$

$$s_{t-1}^e = \frac{S_{t-1}-S_{t-2}}{\frac{S_{t-1}+S_{t-2}}{2}} = \frac{2(S_{t-1}-S_{t-2})}{(S_{t-1}+S_{t-2})} = \Delta S_{i,t-1} \qquad (3.1c')$$

And the model to be estimated is stated in (3.1d'), where $\varepsilon_{i,t}^2$ is a disturbance term to be discussed below.

$$\Delta RD_{i,t} = \alpha_0^2 + \beta_1^2 \Delta Q_{i,t-1} + \beta_2^2 \Delta s_{i,t-1} + \varepsilon_{i,t}^2 \qquad (3.1d')$$

Here $\Delta RD_{i,t}$ is the change in R&D intensity (R&D expenditures over total assets) between year *t* and *t*-1. The proxy for expected profitability of future investment ($\Delta Q_{i,t-1}$) is the one-period-ahead market rate of return weighted by one-period rate of change in replacement cost of capital. Section 3.4.1 below demonstrates how this measure can be de-composed into one-period-ahead rate of return and one-period-ahead rate of change in replacement cost of capital. I consider this as a better proxy because it contains the two pieces of information in the Tobin's average Q or marginal Q: the market value and the replacement cost of capital.

Observing this information in period t-1, the managers decide about R&D investment for period *t*. The R&D investment decisions in period t-1 is implemented in year *t* – after the R&D budget is agreed and the necessary hiring and capacity-building preparations are completed.

In (3.1c), $\Delta S_{i,t-1}$ is the symmetric growth rate of sales between period *t*-2 and *t*-1; and provides information about the revision of capacity needed to cater for the demand for the firm's goods/services. The justification for sales as a potential determinant of R&D investment is based on the accelerator theory of investment, as discussed in Mairesse and Siu (1984). However, I expect the effect of the expected capacity need to be less relevant to R&D investment for two reasons. First, R&D investment is a special kind of investment with more than 50% of R&D expenditure being often in the form of wages for R&D personnel (Cincera, 2003). Second, for R&D investment, the primary output of resources is the knowledge of how to improve products or make new goods and services. Hence, the effect of expected capacity need on R&D investment may be less stable/robust compared to its effect on physical capital investment. This expectation is in line with Aghion et al. (2012) and Guney et al. (2017), who report that firm R&D investment is only weakly correlated with sales growth and its own lags.

Having discussed the measurement issues and the ways in which they can be addressed, it is now necessary to focus on the model specification. In line with Mairesse and Siu (1984), but using R&D intensity (the ratio between R&D expenditure and total assets) as the dependent variable, the baseline model can be stated as follows:

$$\Delta RD_{i,t} = \alpha_0^3 + \beta_1^3 \Delta Q_{i,t-1} + \beta_2^3 \Delta S_{i,t-1} + \varepsilon_{i,t}^3 \quad (3.2a)$$

Where the composite disturbance term consists of industry, country and year effects and an idiosyncratic error term:

$$\varepsilon_{i,t}^{3} = u_c + u_j + d_t + v_{i,t} \quad (3.2b)$$

Here i, j and c denote firm, industry and country respectively. The composite error term ($\varepsilon_{i,t}^{3}$) consists of time-invariant industry and country effects (u_j and u_c), year-specific effects (d_t) and an idiosyncratic error term ($v_{i,t}$).[8]

Equation (3.2a) expresses the importance of expectations about future profitability and capacity need on the change in firm investment. However, I argue that this model poses several specification and estimation issues, some of which are also acknowledged by Mairesse and Siu (1984).

Dynamics

As indicated in Mairesse and Siu (1984), the change in the desired net investment i_t^* might diverge from the actual change in investment, due to various kinds of delays occurring between the decision and the execution of investment plans, as well as an approximate proportionality of retirements to past investments. In addition, R&D investment typically behaves as though it has high adjustment costs. In fact, Hall (2002) reports that at least 50% of R&D budgets are in the form of wages and salaries of highly qualified scientists and engineers. Therefore, firms often tend to smooth their R&D investment over time (Becker, 2015).

Bearing that in mind, the investment equation should control for lagged investment terms. Similar approach can be found in Hall (1992), Cincera (2003). Hence, equation (3.2a) can be re-written in the level form of R&D investment with the dynamic control for the lagged dependent variable as follows.

[8] In the estimations to follow, I will control for industry, country and year effects by using industry, country and year dummies. The firm-specific fixed effect is eliminated through time differencing. Both $\varepsilon_{i,t}^{1}$ and $\varepsilon_{i,t}^{2}$ above can also be written and explained similarly.

$$R\&D_{i,t} = \alpha_i^4 + \beta_1^4 R\&D_{i,t-1} + \beta_2^4 R\&D_{i,t-2} + \beta_3^4 \Delta Q_{i,t-1} + \beta_4^4 \Delta S_{i,t-1} + \varepsilon_{i,t}^4 \quad (3.3)$$

The only remark to note here is that the second lag of R&D intensity is also controlled in (3.3). It is based on results of an auto-regressive distributed lags (ARDL) model on my specific data set, which show that the first two lags of R&D intensity affect its contemporaneous value significantly.[9]

Risk of omitted variables

Equation (3.13) is likely to suffer from omitted variable bias, due to two main reasons. First, the long-standing empirical literature has shown that there is always a degree of measurement error for any measure of the unobservable marginal Q. Hence, it might be inappropriate to consider any of the Q measures to be the sole determinant of firm investment, as the theory suggests for marginal Q itself. Second, which is related to the first, the set of strict assumptions for the equality between marginal Q and average Q, including perfect market competition and homogeneity in production and cost functions, are unnecessary, provided that average Q fails to be a good measure of marginal Q. This common approach probably overlooks several factors that might affect firm investment decisions. For instance, a number of studies have indicated that the level of internal finance can be a source of friction for Tobin's Q theory, since the wedge between the cost of internal and external finance could prevent the firm from raising as much capital as it needs to utilize full investment opportunity. In fact, internal finance is a main source of friction in the literature on Tobin's Q theory of investment (Fazzari et al., 1988; Blundell et al., 1992).

In addition, the debate on the relationship between product-market competition and innovation dates back to Schumpeter (1942), who postulate that competition may induce investment in innovation but the latter may fall if the level of competition is too high and hence eliminates the scope for rents. Recently, Aghion et al. (2005) provide both theoretical

[9] Full results of the ADRL model are presented in Table A4.1 in the Appendix.

and empirical evidence for the non-linear relationship between product-market competition and the level of firm innovation. Besides, the costs due to the 'agency problem' emanates from the separation of ownership and management might influence firm investment. While stockholders are interested in maximizing the firm's long-term profitability, managers' objectives when running their firms focus more on personal wealth, job security, and prestige (Baysinger et al., 1991; Mahoney et al., 1997). This divergence of managers' and stockholders' objectives may lead to acute conflicts of interest in making strategic decisions such as the level of firm R&D investment.

Furthermore, the role of knowledge spillovers has been expressed recently, following the endogenous growth models (e.g. Romer, 1986; 1990; Grossman and Helpman, 1991). The existence of knowledge spillovers, while accelerating technological advances in the industry, might also influence the managerial incentives for R&D investment. The typical inference here is that spillovers temper research efforts, since they tend to limit the appropriability of individual activities (De Bondt, 1996).

To address this omitted variable bias, other covariates will be added into the so-called augmented Tobin's Q model of firm investment, where the growth rate of Tobin's average Q is used as a measure of expected profitability.

First, the set of nested models start with the control for internal finance through cash flow ratio in equation (3.4).

$$R\&D_{i,t} = \alpha_i^5 + \beta_1^5 R\&D_{i,t-1} + \beta_2^5 R\&D_{i,t-2} + \beta_3^5 \Delta Q_{i,t-1} + \beta_4^5 \Delta S_{i,t-1} + \beta_5^5 CF_{i,t-1} + \varepsilon_{i,t}^5 \quad (3.4)$$

Where: $CF_{i,t-1}$ is the cash flow ratio (the ratio between cash flow and total assets).

In line with the consideration of firms setting their investment budget for period *t* at the end of period *t*-1, I use the first lag of cash flow ratio in my models.

Then, equation (3.4) is augmented with other factors that are relevant for the optimal level of firm R&D investment:

$$R\&D_{i,t} = \alpha_i^6 + \beta_1^6 R\&D_{i,t-1} + \beta_2^6 R\&D_{i,t-2} + \beta_3^6 \Delta Q_{i,t-1}$$
$$+\beta_4^6 \Delta S_{i,t-1} + \beta_5^6 CF_{i,t-1} + \sum_{p=1}^{3} \beta_{(5+p)}^6 X_{i,p,t-1} + \varepsilon_{i,t}^6 \quad (3.5)$$

Where:

$X_{i,p,t-1}$: additional covariates, include product-market competition, the level of R&D spillovers and corporate governance quality. Further discussion on why the Tobin's Q model can be augmented with these additional variables will be provided in the relevant empirical chapters below. For each nested model, I also provide the theoretical justification followed by empirical work that controls for the additional variables.

In the next chapter, I start by testing the augmented Tobin's Q model with the first additional factor: the level of market competition. The results verify whether the level of market competition can contribute significantly to the model, and whether the growth rate of Tobin's Q remains its effect after the control of market structure. From there, I continue checking the effect of knowledge spillovers and country-level governance quality in chapter 5 and 6. This approach provides detailed track for the effect of the growth rate of Tobin's Q, my measure of expected profitability, after the model is controlled for other factors that are considered to determine level of firm investment.

Econometric issues

To address the econometric issues, it is useful to re-consider equation (3.2b):

$$\varepsilon_{i,t} = u_c + u_j + d_t + v_{i,t} \quad (3.2b)$$

Where u_c and u_j are country and industry unobserved fixed effects, d_t is a time effect common to all firms, and v_{it} is the idiosyncratic error term. Several econometric issues regarding to the dynamic panel model must be addressed. First, the OLS estimates will be biased due to the correlation between the lagged dependent variable and the unobserved firm-specific fixed effects. Bond et al. (2002) prove that at least in large sample, this upward bias can be found in OLS level estimators.

The fixed-effect (FE) method eliminates this source of bias by transforming the equation. However, the demeaning process also suffers from the correlation between the transformed lagged dependent variable and the transformed error term, which cannot be mitigated by increasing number of individual units. Nickell (1981) demonstrates that this bias from FE estimator is negative, and therefore the persistence of the dependent variable will be underestimated.

The fact that the OLS and FE estimators are likely to be biased in opposite directions is helpful in finding a better method for regressing a dynamic panel model, which probably produces consistent estimator in between the OLS and FE estimates for the lagged dependent variable.

Endogeneity is another econometric issue that must be addressed. If all the covariates are uncorrelated with country, industry and firm unobserved fixed effects, as well as the idiosyncratic error term v_{it} is uncorrelated across time, then the standard pooled OLS estimator is appropriate. In that case, all of my covariates are strictly exogenous. Alternatively, if some of the covariates are correlated with either country, industry or firm fixed effects, but may still be uncorrelated with the idiosyncratic error v_{it}, the within groups (fixed effect - FE) estimator would yield more precise results than pooled OLS estimation.

In this case, in line with the econometric approach from the literature on the determinants of R&D investment (Avazian 2011, Cincera, 2003) the growth rate of Q as well as other explanatory variables might not be strictly exogenous. In order to deal with this issue, I apply the generalised method of moments (GMM) framework developed by Arellano and Bond (1991), an instrumental variable method that is suitable for dynamic micro panel models and has been widely used in the literature (Bond, 2002; Kiviet et al., 2016). The GMM technique allows to utilize 'internal' instruments based upon lagged values of explanatory variables in the models. There are two different GMM estimators: the difference-GMM proposed by

Arellano and Bond (1991), and the system-GMM developed by Arellano and Bover (1995) and Blundell and Bond (1998). The latter carries a joint estimation of a regression model in both differences and levels.

In this thesis, I rely mainly on the system GMM estimator, since it benefits from including all lagged and differenced variables as instruments, as long as they are not correlated with the error term (Greene, 2008). It also addresses dynamic panel bias due to the correlation between lagged dependent variables and firm-specific fixed effects (Bond et al., 2003; Cincera, 2003).

Two necessary conditions are required for the reliability of system GMM estimates. First, the consistency of the GMM estimators hinges heavily upon the results of second order serial correlation of error terms. An important contribution of Arellano and Bond (1991) is to provide a test for autocorrelation appropriate for linear GMM regressions on panels. If the test shows that there is serial correlation of second order in the error terms, the second lag of the explanatory variables cannot be used as an instrument and we need to go for deeper lag of variables (Roodman, 2009). Second, a crucial assumption for the validity of GMM estimates is that all the instruments are exogenous. Sargan-Hansen test (Sargan, 1958; Hansen, 1982) help to check this condition under the null hypothesis of a valid set of instruments. Consequently, if the null hypothesis cannot be rejected, the set of instruments is valid in the estimation. Also, the difference-in-Hansen test's results (the *C* statistic, for more details, see Roodman, 2009, page 98) will be reported for the subset of instruments for the level equations, in order to verify whether the system GMM estimator is preferable to difference GMM.

The model and moment selection criteria for GMM framework is taken from Andrew and Lu (2001). It resembles the widely used Bayesian Information Criterion (hereafter BIC) model selection criteria in the sense that it makes the same asymptotic trade-off between the 'model fit' and the 'number of parameters'. The MMSC-BIC is constructed based on the *J* test statistic of the Hansen test for over-identification as follows:

$$MMSC - BIC = J_n(b, c) - (|c| - |b|) \ln n \tag{3.6}$$

Where b, c, and n denote the number of parameters, moments and included firms. $J_n(b, c)$ denotes the J test statistic.

The MMSC-BIC includes bonus terms that reward the use of more moment conditions for a given number of parameters and the use of less parameters for a given number of moment conditions. Using the similar assessment to BIC model selection criterion, the best model is the one with the smallest MMSC-BIC value (the least information loss relative to the true model) (Kass and Raftery, 1995; Andrew and Lu, 2001).

3.3. Variables and measurement

3.3.1. Measure of firm investment

A fundamental problem in any study of innovation is the absence of satisfactory measures which reflect both its incentives and its results. Despite this limit, a variety of measures of innovation have been employed in the empirical literature. They can be broadly classified as measures of either innovative inputs or outputs. The latter is often reflected in patent data, due to the fact that patents are related to inventiveness by definition and based on a relatively objective and stable standard which focuses on the novelty and potential utility. Moreover, patent statistics are often available in long period of time from national patent offices. However, the main weakness of these patent measures is that not all innovations are patented. In addition, the propensity to patent can vary across different types of industries and firms. Furthermore, even if all patents are recorded, their economic value is also highly heterogeneous. A great majority of patents are never exploited commercially, and only a very few are associated with major technological improvements (Cohen and Levin, 1989). These issues often challenge the use of patent data in research about innovation.

On the other hand, the innovative inputs are often reflected by R&D data, either R&D expenditure or R&D personnel. Even though both measures are intended to represent the current flow of resources devoted to innovative activities, both are flawed. The most obvious issue is that they both suffer from considerable error in reporting, since the definitions used for financial reporting give firms flexibility in their classification of activities.

Since the thesis focuses on the managerial incentives for innovative activities, a measure of innovation input is preferred. Specifically, I use R&D intensity as my measure of firm investment. This is constructed as the ratio between R&D expenditure and the lagged value of total assets at the end of period t-1. The use of lagged total assets is in line with my consideration that the firm decides their investment budget at period t-1 as a proportion of the observable value of total assets but only implements it at t. In addition, this measure reflects more precisely the firm's research effort with control for firm size and it allows relative comparison between firms.

3.3.2. Measure of Tobin's Q

In this thesis, I apply the simple approximation of Tobin's average Q from Chung and Pruitt (1994), with the formula stated below:

$$Q_t = \frac{MV_t}{RC_t} = \frac{MVS_t + PS_t + D_t}{TA_t} \tag{3.7}$$

Where:

MV_t: the firm's total market value.

RC_t: replacement cost of capital

MVS_t: market value of outstanding shares, which is equal the product of a firm's share price and the number of common stock shares outstanding.

PS_t: book value of preferred stocks

D_t: total debt

TA_t: book value of total assets

All of these financial indicators are obtainable from *Worldscope* database. Nevertheless, this measure of average Q contains some limitations for the assumptions of equality between market value and book value of physical capital, inventory, long-term and short-term debt. Consistent with previous studies (Gilchrist and Himmelberg, 1995; Vo and Le, 2017), I drop all observations that have the value of average Q greater than 10.

Then, I construct the one-period-ahead growth rate of change in Tobin's average Q in accordance with (3.1b') above. Measuring the change over two periods, t-2 and t-1, this symmetric growth rate measure is bounded between -2 and 2. This measure also shares some useful properties of log-difference form (Haltiwanger et al., 2013).

The main advantage of this measure, however, is that it can be de-composed to show that it depicts one-period-ahead change in market value (i.e. one-period-ahead market rate of return), weighted by one-period-ahead change in the replacement cost of capital. In other words, it combines the best of two proxies used in the existing literature to replace the unobservable marginal Q. On the one hand, it reflects the one-period-ahead rate of return used in Mairesse and Siu (1984). On the other hand, it reflects the information about the change in replacement cost of capital, which is one of the two main components of either marginal Q or Tobin's average Q. These properties can be demonstrated as follows.

$$\Delta Q_{i,t-1} = \frac{2(Q_{t-1} - Q_{t-2})}{(Q_{t-1} + Q_{t-2})} = \frac{2(\frac{MV_{t-1}}{RC_{t-1}} - \frac{MV_{t-2}}{RC_{t-2}})}{\frac{MV_{t-1}}{RC_{t-1}} + \frac{MV_{t-2}}{RC_{t-2}}}$$

$$= \frac{2(\frac{MV_{t-1} * RC_{t-2} - MV_{t-2} * RC_{t-1}}{RC_{t-1} * RC_{t-2}})}{\frac{MV_{t-1} * RC_{t-2} + MV_{t-2} * RC_{t-1}}{RC_{t-1} * RC_{t-2}}}$$

$$= \frac{2(MV_{t-1} * RC_{t-2} - MV_{t-2} * RC_{t-1})}{MV_{t-1} * RC_{t-2} + MV_{t-2} * RC_{t-1}} \quad (3.8)$$

Dividing both the numerator and denominator of (3.8) to the replacement cost of capital in *t*-1, RC_{t-1}, we have the final formula of the one-period-ahead growth rate of change in Tobin's average Q as:

$$\Delta Q_{i,t-1} = \frac{2(MV_{t-1} * \frac{RC_{t-2}}{RC_{t-1}} - MV_{t-2})}{MV_{t-1} * \frac{RC_{t-2}}{RC_{t-1}} + MV_{t-2}} \quad (3.9)$$

Equation (3.9) indicates that the one-period-ahead rate of return on stock market valuation is weighted by the ratio defined the change of replacement cost of capital in the given periods.

Also, in order to check the sensitiveness of this measure, I will use the common one-period-ahead ratio of Tobin's average Q, which is also weighted by the same ratio that signifies the change in the replacement cost of capital and can be constructed as follows:

$$\Delta Q'_{i,t-1} = \frac{Q_{t-1}}{Q_{t-2}} = \frac{\frac{MV_{t-1}}{RC_{t-1}}}{\frac{MV_{t-2}}{RC_{t-2}}} = \frac{MV_{t-1}}{MV_{t-2}} * \frac{RC_{t-2}}{RC_{t-1}} \tag{3.10}$$

3.3.3. Measure of product-market competition

My first measure of product-market competition is constructed based on the Price-Cost Margin (*PCM*), the so-called Lerner index, following Nickell (1996). The idea behind the *PCM* measure is that under competitive pressure firms are less profitable, so that profit margins are negatively correlated to competition. Using the same construction process as Bloom et al. (2010), I first calculate the *PCM* index for each firm as below:

$$PCM_{it} = 1 - \frac{EBIT}{Sales} \tag{3.11}$$

Then, the product-market competition measure (*PMC*) is one minus the average of that PCM_{it} across firms within each 2-digit SIC industry:

$$PMC_{kt} = 1 - \frac{1}{N_{kt}} \sum_{i \in k} PCM_{it} \tag{3.12}$$

Where *i* indexes firms, *k* indexes industry, *t* indexes time, and N_{kt} is the number of firms in industry *k* in period *t*. PMC_{kt} is the same for all firm *i* in industry *k* at time *t*. A value of 1 indicates perfect competition (price equals marginal cost) while the values below 1 indicate some degree of imperfect competition.

To check the robustness of my empirical results, I use the second measure of product-market competition: the Herfindahl-Hirschman index (HHI). Following Ugur and Hashem (2012), the index is calculated for each 2-digit SIC industry by the formula:

$$HHI_{kt} = \sum S_{ikt}^2 \qquad (3.13)$$

Where:

S_{ikt}: the share of firm *i* in the total sales of industry *k* for a given year *t*.

This measure of market concentration also ranges from 0 to 1, with the value closer to 1 indicates the higher levels of concentration in the market.

It should be noted here that I consider the 15 OECD countries as a single market for all firms in my sample, due to the fact that most of them are multinational companies with high level of foreign income.[10] Acknowledging the limited sample I have (for only R&D-active listed firms), I believe that this 'globalised' approach is still more realistic in the sense that it controls for the true competitors of each firm, which can be located in different countries. For instance, it seems unrealistic to consider Honda (Japan), BMW (Germany) and Ford (the US) do not compete to each other in the same 2-digit SIC code 37 (Transportation Equipment).

3.3.4. Measure of technological spillovers

Following Plunket (2009), the first two variables I apply for measuring the unweighted intra- and inter-industry spillovers are:

$$S_{intra,t-1} = \log(\sum_{j \neq i} RD_{j,t-1}) \qquad (3.14)$$

$$S_{inter,t-1}^1 = \log(\sum_{l \neq k} RD_{l,t-1}) \qquad (3.15)$$

[10] In 2,664 firms with at least 1 year of data for the ratio between foreign and total incomes, the mean value of this variable is 36% and more than 700 firms in my sample have more than 50% of their total income from international trade in at least one year in the period of investigation.

Where:

$RD_{j,t-1}$: R&D expenditure of all other firms j in the same industry k with the investigated firm i at period t-1.

$RD_{l,t-1}$: total R&D expenditure of all other industries l except the industry k of the investigated firm i at period t-1.

My third measure of technological spillovers is the patent citations weighted inter-industry spillovers. The intuition is that patent documents can be considered as scientific papers which contains references to earlier patent documents. Hence, these citations may be interpreted as spillovers from knowledge described in the cited patent to the knowledge in the citing patent (Maurseth and Verspagen, 2002). This measure can be constructed as:

$$S^2_{inter,t-1} = \log(\sum_{l \neq k} RD_{l,t-1} * \frac{p_{kl}}{p_k}) \qquad (3.16)$$

Where:

p_{kl}: number of patent citations from industry k to industry l

p_k: total number of patent citations from industry k.

In line with the construction of product-market competition's measures, I collect the data for patent citations at 2-digit SIC industry-level for 20 manufacturing industries (SIC code from 20 to 39). However, since most of patent database uses IPC code for industry-level, the data collection requires the use of the IPC-SIC concordance provided by Brian Silverman and available to download from his website. Then, the patent data is merged with my financial sample using the same 2-digit SIC code.[11]

[11] More details of this measure are presented in Chapter 5 below.

3.3.5. *Measure of corporate governance*

The set of country-level governance variables are taken from several recent studies, including:

<u>Legal origin (*LOS*)</u>: Following La Porta et al. (1997, 1998), there are 4 groups of countries with different legal origins: English common law, French-, German- and Scandinavian-civil law. However, since several papers already postulate that there is no significant difference between German- and Scandinavian-civil laws (La Porta et al., 1998, 2000), I combine these two together. Hence, 3 dummy variables are created to specify whether the firm is organised in either English-common, French-civil or German/Scandinavian-civil law origins.

<u>Creditor rights (*CR*)</u>: Brockman and Unlu (2009) claim that cross-country variations in creditor rights have even more explanatory power of governance quality than cross-country variations in shareholder rights. The creditor rights index from that paper is the sum of four dummies: *NO_AUTOSTAY*, equals one if there is not automatic stay on assets; *SECURED_FIRST*, equals one if secured creditors are given the absolute priority claims during bankruptcy; *RESTRICT_REORG*, equals one if management cannot file for reorganisation unilaterally; and *MGMT_NOT_STAY*, equals one if either creditors or courts can change the incumbent management during bankruptcy proceedings (Brockman and Unlu, 2009, p.279). The higher the index, the stronger the creditor rights is maintained by laws and governance in this country.

<u>Rule of law (*RL*)</u>: the assessment of the law and order tradition of the country. The scale is from zero to 10, with lower scores for less tradition for law and order (John et al., 2008).

3.4. Estimation sample and data description

This section describes my data collection process and the characteristics of the estimation sample. The main sources of financial data is the *Worldscope* database provided by Thomson Reuter and is available through *Datastream*. However, similar to previous studies of the firm's innovation, I face the problem of data quality, due to the fact that firm R&D expenditure is not required by any law or regulation, hence not all firms report the amount of R&D expenditure in their financial statements, creating problems in sample selection and data quality (Hall and Oriani, 2006). Hence, few restrictions have to be applied in the cleaning process, in order to conduct more reliable findings.

3.4.1. Estimation sample

I examine the empirical models using an unbalanced panel data at micro-level. The distinct advantage in exploiting data on individual firms is that it strictly follows the intuition of Tobin's Q theory developed in the context of a 'representative' firm (Blundell et al., 1992).

My initial data set is collected from *Worldscope* financial database through *Datastream*. According to Thomson Financial, there are over 61,800 companies contain in *Worldscope* in November 2010. It provides financial statement data, the professional analysts and portfolio managers with the most comprehensive, accurate and timely data on publicly quoted companies around the world (Thomson Reuters, 2012).

The investigated countries are chosen based on the *Scoreboard* top R&D investors all over the world in 2011-2013 period. The *Scoreboard*, provided by European Commission, is a reliable source for tracking the countries with highest number of firms on the top 2000 most R&D spending companies all over the world. It is published based on a multi-indicator methodology that provides an annual assessment of R&D top performance (Moncada-Paterno-Castello et al., 2010). From the data of R*&D Scoreboard* in 2011-2013, 15 OECD countries are chosen for my thesis, including: Australia, Canada, Denmark, Finland, France, Germany, Italy, Japan, Korea, the Netherlands, Spain, Sweden, Switzerland, the UK, and the US.[12]

3.4.2. Data collection and description

The sample is initially collected on the condition that firms must be research-active and publicly traded on stock markets, which brings together 20,735 firms in total for 15 chosen OECD countries. The period of investigation spans from 2005 to 2013. Overall, my initial sample consists of 186,608 firm-year observations.

In the cleaning process, I first omit firms with no information about which industry they are operated in (no Standard Industrial Classification SIC code), as they provide very little or no information for all R&D expenditure, financial and corporate governance data. The

[12] Full table of the top 20 countries with highest number of firms in the R&D Scoreboard 2011-2013 is provided in table A3.2 in the Appendix.

number of dropped firms is 158. Next, to eliminate the errors in collecting data, I drop all observations with negative value of sales, R&D expenditure, preferred stock, and 0 value of total assets. More importantly, similar to prior studies, my main problem is of zero or missing data for R&D expenditure. “The R&D data available from *Datastream* are of mixed quality … Some firms have not registered any R&D expenditure over the period and this may not be an accurate reflection of their actual expenditure” (Wakelin, 2001, p.1082). To reduce its impact, first, I assume that the error is equally distributed in different industries and countries so that it will not cause the selection bias in my results. Second, I exclude all firms with less than 5 consecutive years of data for two main variables: R&D intensity and average Q values, as it is one of the necessary conditions in applying GMM estimator (Hillier et al., 2011; Yermack, 1995, 1996). I also exclude any duplication of multinational firms by equal values in 3 variables: R&D expenditure, total assets and sales for a given year to eliminate redundancies (Rapp and Killi, 2016). In addition, consistent with prior research, I keep only manufacturing firms in my sample, due to the problem of noticeable difference in the values of Tobin’s Q between manufacturing firms and others. After all these restrictions, my preliminary data set consists of 31,493 firm-year observations from 3,718 manufacturing firms.

Table 3.1 provides the distribution of my preliminary sample by identifying the number of companies per country.

Table 3. 1: Distribution of preliminary data set by country

Country	Number of firms	Percentage of sample
Australia	63	1.69%
Canada	113	3.04%
Denmark	20	0.54%
Finland	42	1.13%
France	84	2.26%
Germany	131	3.52%
Italy	25	0.67%
Japan	1,300	34.97%
Netherlands	17	0.46%
South Korea	610	16.41%
Spain	6	0.16%
Sweden	60	1.61%
Switzerland	76	2.04%

UK	155	4.17%
US	1,016	27.33%
Total	3,718	100%

It can be seen from table 3.1 above that firms from the US, Japan, and South Korea make up the majority of my sample, while several EU countries have the lowest number of firms (Spain, the Netherlands, Italy, Denmark).

Then table 3.2 below presents a further breakdown of my sample by economic sector. I apply the standard industrial classification (*Datastream* code WC07021) to categorize the companies. Two 2-digit SIC industries with the highest number of firms are 28 (Chemicals and Allied Products) and 36 (Electronic and Other Electrical Equipment and Components, Except Computer Equipment). Industry with the least number of firms is 21 (Tobacco Products).

Table 3. 2: Distribution of economic sector classification

SIC 2-digit	Name of economic sector	Number of firms	Percentage of sample
20	Food and Kindred Products	206	5.54%
21	Tobacco Products	8	0.22%
22	Textile Mill Products	39	1.05%
23	Apparel and Other Finished Products Made from Fabrics and Similar Materials	41	1.1%
24	Lumber and Wood Products, Except Furniture	23	0.62%
25	Furniture and Fixtures	33	0.88%
26	Papers and Allied Products	71	1.91%
27	Printing, Publishing, and Allied Industries	35	0.94%
28	Chemicals and Allied Products	719	19.34%
29	Petroleum Refining and Related Industries	18	0.48%
30	Rubber and Miscellaneous Plastics Products	88	2.37%
31	Leather and Leather Products	10	0.27%
32	Stone, Clay, Glass and Concrete Products	93	2.5%
33	Primary Metal Industries	137	3.68%
34	Fabricated Metal Products, Except Machinery and Transportation Equipment	147	3.95%

35	Industrial and Commercial Machinery and Computer Equipment	543	14.6%
36	Electronic and Other Electrical Equipment and Components, Except Computer Equipment	731	19.66%
37	Transportation Equipment	235	6.32%
38	Measuring, Analysing, and Controlling Instruments: Photographic, Medical and Optical Goods; Watches and Clocks	471	12.67%
39	Miscellaneous Manufacturing Industries	70	1.88%

Then, table 3.3 presents the descriptive statistics of my sample of 3,718 companies. It can be seen that the average value of R&D intensity is approximately 6.44%, which is close to 9.2% in the research of Francis and Schipper (1999) for the high-technology sample. Besides, there is a wide range in the value of Tobin's average Q, from 0 to approximately 10. The mean value of average Q is 1.3055. The growth rate of Tobin's Q, however, receives values between -2 and 2, with the mean of -0.041.

Table 3. 3: Descriptive statistics

Variable	*Obs.*	*Mean*	*Std.Dev.*	*Min*	*Max*
Rd intensity	31,179	0.0645	0.1311	0	1.2958
Tobin's average Q	30,702	1.3055	1.2993	0	9.9868
Growth rate of Q	23,282	-0.0410	0.3658	-1.7775	2
Competition (*PMC*)	30,852	0.9096	0.0321	0.6403	0.9675
Competition (*HHI*)	31,489	0.0457	0.0469	0.0174	0.6901
Governance (*LOS*)	31,493	0.3588	0.4797	0	1
Governance (*CR*)	31,493	1.9066	0.9013	0	4
Governance (*RL*)	31,493	9.3010	0.9333	7.23	10
Cash flow ratio	30,859	0.0428	0.2407	-2.8029	0.3605
Growth rate of Sales	23,669	0.0575	0.3783	-2	2

Also, table 3.3 demonstrates that the level of product-market competition in my sample is also quite high (the average value of *PMC* is 0.9096, while this value of *HHI* index for market concentration is 0.0457). It can be attributable to the fact that I consider the 15 developed countries as a single market, which is more appropriate to the globalisation nowadays.

Then, figure 3.1 below presents the Kernel density plot for my dependent variable: R&D intensity for the whole sample of 3,718 firms.

From figure 3.1, it can be seen that the level of R&D intensity skewness in the sample is very high (4.62). The number of observation with zero R&D intensity is 695 (2.23% of the sample). The number of observations with R&D greater than 1 is 106 (0.34% of the sample). This problem of high level of skewness in R&D intensity is well-known in the literature (Klette and Kortum, 2004; Aghion et al., 2014; Ugur et al., 2016b).

Figure 1: Kernel density plot for R&D intensity in the sample

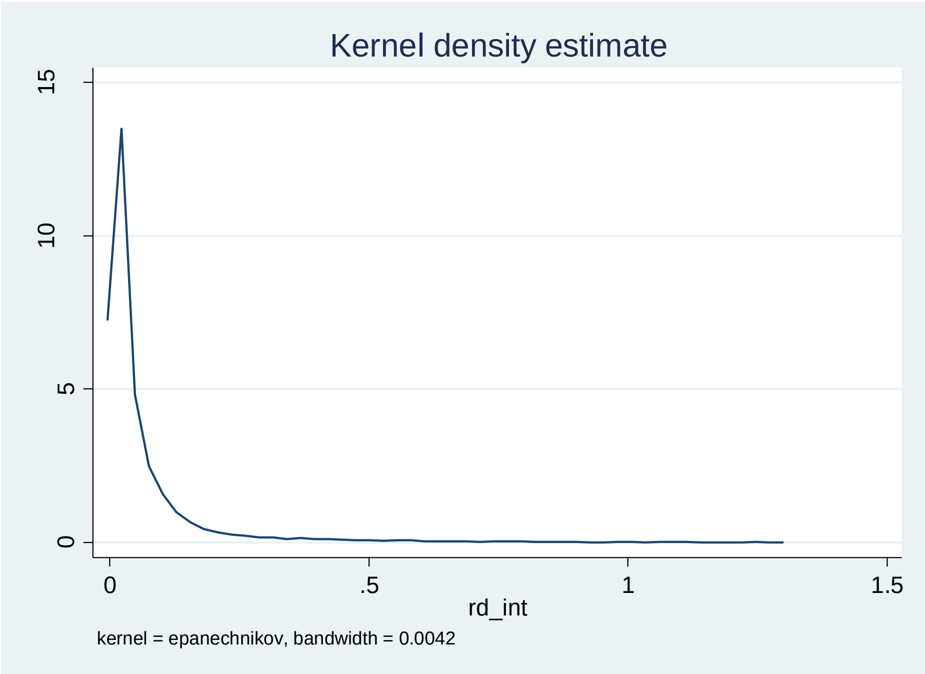
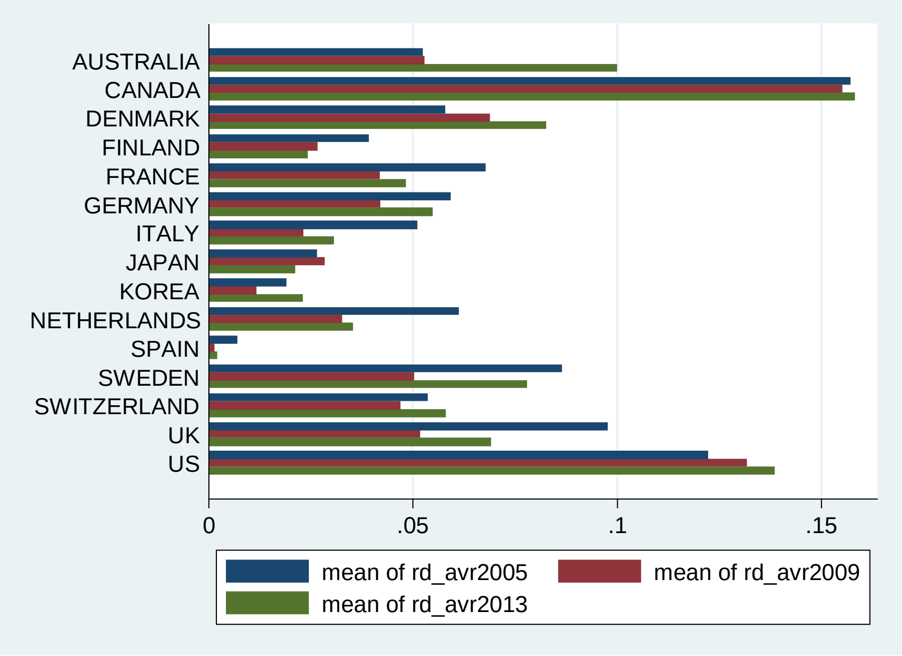


Figure 3.2 presents the average R&D intensity over 15 countries in my sample. As it appears from figure 3.2, the common trend is that the level of R&D intensity decreased in 2009 due to the financial crisis, but it seems to recover in 2013. Only few exceptions: while Japan and Finland show the decreasing trend in the average level of R&D intensity at firm-level, Australia, Denmark and the US document the increasing trend instead. The lowest level of average R&D intensity can be found for Spain (only around 0.5% of the firm's total assets), while the highest level of R&D intensity are from Canada and the US.

Figure 2: Average R&D intensity over the 2005-2013 period



Then, figure 3 illustrates the movement of Tobin's average Q and its growth rate, my proposed measure of expected profitability.

Figure 3: Tobin's average Q and its growth rate over 2005-2013 period

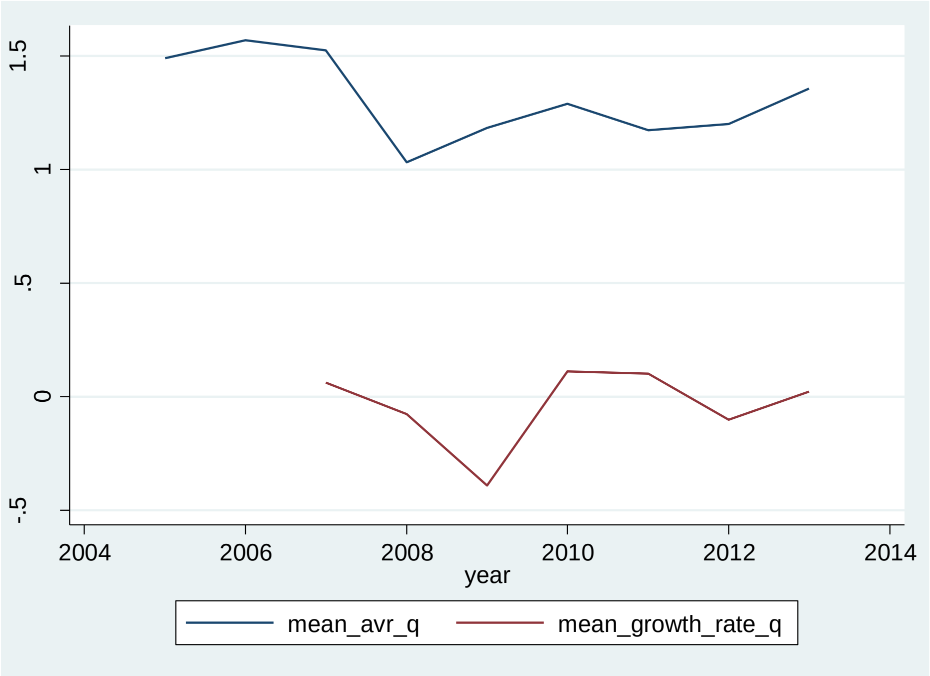


Figure 3 indicates that the movement of both measures are fairly similar over the 2005-2013 period. However, the correlation between these two measures is surprisingly low (only 0.1377), which means that there are some variations in the range of values in these two variables.

There are two main sources of firm heterogeneity that might affect my estimated results. First, firm size has been strongly linked with firm investment decision. For instance, large firms are considered to have more advantages to engage in R&D investment because of their capability to exploit well-equipped R&D labs or the availability of internal finance to utilize all investment opportunities. On the other hand, small firms might rely heavily on their investment, in order to produce more competitive products that allow them to survive in the market. Therefore, controlling for firm size is necessary for any study on firm investment. In this thesis, I apply the European Commission classification to separate between small and medium-sized firms and large firms, in which the former group contains all firms with fewer than 250 employees or a turnover of less than €50 million.

The second source of firm heterogeneity is about the level of firm R&D intensity, since these two categories might react differently to any change in the market. Also, their purposes for engaging in R&D investment might be different, as the low R&D-intensive firms might invest in order to exploit the R&D knowledge spilled over from outside, while the highly R&D-intensive firms might invest to gain more monopoly power. Therefore, in this thesis, I also control for the different level of R&D intensity, by separating firms with lower or higher R&D intensity than the average R&D intensity of the 2-digit SIC industry it is belong to.

Table 3.4 below presents basic statistics to these subsamples.

Table 3. 4: Subsamples' number of observations and mean of main variables

Variables	R&D intensity	Growth rate of Q	Cash flow ratio	Growth rate of sales
Full sample				
Obs	31179	23282	30859	23669
Mean	0.0645	-0.0410	0.0428	0.0575
Large firms				
Obs	20132	15466	20009	15482
Mean	0.0346	-0.0345	0.1011	0.0529
Small or medium-sized firms				
Obs	10778	7663	10595	8004
Mean	0.1174	-0.0536	-0.0587	0.0650
Highly R&D-intensive firms				
Obs	12739	9229	12494	9591
Mean	0.1309	-0.0468	-0.0118	0.0636
Low R&D-intensive firms				
Obs	18440	14053	18365	14078
Mean	0.0186	-0.0372	0.0799	0.0533

3.5. Conclusions

This chapter has provided the theoretical and empirical approach to my augmented Tobin's Q model of firm R&D investment. First, I re-emphasise the appealing intuition of Tobin's Q theory of investment that demonstrates the important role of expectations about the marginal return on investment on firm investment decisions. However, the empirical approach to Q theory is problematic, due to measurement issues and the problem of too strict assumptions. From that, I propose using the one-period-ahead growth rate of average Q as a measure of expectations about future profitability and verify its relationship with future R&D investment decisions. My empirical model is taken and built up from Mairesse and Siu's (1984) accelerator model, where several additional factors are considered together with the growth rate of Q in explaining firm investment decisions.

In order to address the potential issues of persistent R&D investment data and the potential endogeneity from the growth rate of Tobin's Q measure and other explanatory variables in my models, I apply the system generalised method of moments (system GMM) estimator. My main data set of 3,718 manufacturing firms is collected from the *Worldscope* database.

Utilizing the system GMM estimator on the main sample of 3,718 manufacturing firms, results from the first augmented Tobin's Q model with product-market competition are presented and discussed in chapter 4 below.

CHAPTER 4: THE AUGMENTED TOBIN'S Q MODEL OF FIRM R&D INVESTMENT WITH PRODUCT-MARKET COMPETITION

4.1. Introduction

This first empirical chapter has two aims. First, it re-examines the accelerator model taken from Mairesse and Siu (1984), which expresses the role of expectations about future profitability and capacity need in determining the optimal level of firm investment. The expected profitability and capacity need are unobservable at the time managers have to form their investment decisions, but the revision of these expectations can be done using the existing information that has appeared in recent periods. This information, then, is reflected in the movements of stock market values. With the fundamental deviation of using the one-period-ahead growth rate of Tobin's average Q as a measure of expected profitability (instead of their use of a one-period holding rate of return on the stock price), I examine its effect on firm R&D investment. Second, I argue that these expectations cannot fully explain the investment decision-making process at firm-level, as they overlook several other factors that might also affect the managerial incentives for R&D investment. In this chapter, the first additional factor, the level of product-market competition, is tested in the so-called augmented Tobin's Q model.

The link between product-market competition and the optimal level of firm investment has been a topic of interest for economists for a long time. The idea dates back to Schumpeter (1942), who suggests that competition might have a negative impact on firm investment, as the firm's incentive for investment requires some exclusive advantages from transient market power, such as the capability to exploit well-equipped R&D labs or the availability of internal finance to utilize all investment opportunities. However, Arrow (1962) challenges the Schumpeterian hypothesis by arguing that a monopoly might have less incentive for innovative activity because it can earn positive profits, irrespective of whether it invests or not. The debate between Schumpeter's negative effect and Arrow's positive effect only reached the tipping point in 2005, when Phillippe Aghion and his colleagues published a paper that provides both theoretical and empirical evidence for the non-linear relationship between competition and innovation. After that, several empirical works have confirmed the non-linear relationship between competition and innovation (Ugur and Hashem, 2012; Polder and Veldhuizen, 2012).

With regard to Tobin's Q theory, the common approach often assumes perfect market competition unconditionally, since it is one of the main assumptions for the equality between average and marginal Q (Hayashi, 1982). This can be one of the main reasons for the unsuccessful empirical performance of Tobin's average Q, since the omitted variable bias of important variables can have a severe impact on the reliability of the estimations. In this thesis, using the growth rate of Tobin's average Q as a measure of expected profitability, my novel approach allows for the removal of this strict assumption of perfect competition. From that, I test whether the actual level of product-market competition can play a role in the so-called augmented Tobin's Q model.

Utilizing the system generalised method of moments (GMM) estimator on the data set of 3,718 manufacturing firms from 15 OECD countries over the 2005-2013 period, the chapter reports several findings. First, it confirms the importance of expectation about future profitability in forming firm R&D investment decisions. The estimated coefficient of the one-period-ahead growth rate of Tobin's average Q is positive and highly significant in all specifications and across different methods of estimation. However, my results also show that the additional control for product-market competition is necessary. The non-linear relationship between competition and R&D investment is confirmed by the negative and highly significant estimated coefficient of the squared term of competition measure. This inverted-U shape is in line with the recent literature postulated by Aghion et al. (2005). Overall, the results provide support for an augmented Tobin's Q model, in which the one-period-ahead growth rate of Tobin's average Q, my measure of expected profitability, can be considered together with other factors in explaining firm R&D investment decisions.

The rest of the chapter is structured as follows. Section 4.2 presents my model specifications, data and estimation issues. The empirical results are presented in section 4.3, followed by section 4.4 on the sensitivity checks. Finally, section 4.5 concludes the chapter.

4.2. Model specification, data and econometric issues

This section presents my empirical approach to the augmented Tobin's Q model of firm R&D investment with the presence of product-market competition, including model specifications and the characteristics of my rich data set of 3,718 companies from 15 developed countries. It also specifies the potential econometric issues and how they are dealt with by suitable methods of estimation.

4.2.1. Baseline model

To address the role of expectation about future profitability on firm R&D investment, I adopt the accelerator model suggested by Mairesse and Siu (1984) as my baseline model:

$$R\&D_{i,t} = \alpha_i^4 + \beta_1^4 R\&D_{i,t-1} + \beta_2^4 R\&D_{i,t-2}$$

$$+\beta_3^4 \Delta Q_{i,t-1} + \beta_4^4 \Delta S_{i,t-1} + \varepsilon_{i,t}^4 \quad (4.1)$$

Where:

$RD_{i,t}$:	R&D expenditure at year *t* over total assets at year *t*-1
$R\&D_{i,t-1}$, $R\&D_{i,t-2}$:	lagged values of R&D intensity at *t*-1 and *t*-2
$\Delta Q_{i,t-1}$:	growth rate of Tobin's average Q
$\Delta S_{i,t-1}$:	growth rate of sales
$\varepsilon_{i,t}^4$:	the composite error term as defined in equation (3.12b).

Equation (4.1) is a dynamic version of the firm R&D investment model, in which the R&D investment budget for period *t* is decided at period *t*-1, based on the available information regarding past investments and past changes in Tobin's average Q and sales. The last two covariates reflect the revision of the expectations about future profitability and capacity need, which have been suggested to be the main determinants of the managerial incentives for firm investment.

Then, equation (4.1) is controlled for the effect of internal finance, the common source of friction in the literature on Tobin's Q theory. The reason is that firms with high level of investment opportunity might be unable to utilize it fully because of inadequate internal cash flows, and there is a considerably high wedge between internal and external finance. The cash flow ratio, a measure of internal finance, is often documented to be significant in Tobin's Q model.

$$R\&D_{i,t} = \alpha_i^5 + \beta_1^5 R\&D_{i,t-1} + \beta_2^5 R\&D_{i,t-2} + \beta_3^5 \Delta Q_{i,t-1} + \beta_4^5 \Delta S_{i,t-1} + \beta_5^5 CF_{i,t-1} + \varepsilon_{i,t}^5 \qquad (4.2)$$

Where:

$CF_{i,t-1}$: the ratio between cash flow and total assets at the end of period t-1.

One thing that should be noted here is that equation (4.2) includes both the growth rate of sales and the lagged cash flow ratio as explanatory variables. It is due to the fact that, following Mairesse and Siu (1984), I apply the growth rate of sales here as a measure of the expected capacity need. Hence, even though sales can sometimes be used as an indirect measure of internal finance in the literature, its growth rate might not reflect the true relationship between internal finance and R&D investment decisions. Instead, the cash flow ratio directly reflects the role of internal finance and has commonly been used in the literature on R&D investment (see Hall, 2002 for a survey of this literature). It is stated clearly in the seminal Fazzari et al. (1988): ‘A firm’s internal cash flow may affect investment spending because of a ‘financing hierarchy’ in which internal funds have a cost advantage over new debt or equity finance’. Therefore, in order to control fully for the effect of internal finance on R&D investment decisions, I add also the lagged cash flow ratio to equation (4.2).

The other main purpose of this chapter is to test whether the actual level of product-market competition could be another additional factor in the augmented Tobin’s Q model. There has been a long-standing literature on the competition-innovation relationship, and often researchers have found that competition matters in determining firm R&D investment (see, for example, Cohen and Levin, 1989 for a survey, or more recently, see the special issue of *Journal of Industry, Competition and Trade,* 2012). Hence, equation (4.2) is augmented with the measure of product-market competition based on the Price-Cost Margin (the so-called Lerner index), which is calculated as follows:

$$PCM_{i,t} = 1 - \frac{EBIT_{i,t}}{Sales_{i,t}} \qquad (4.3)$$

Where:

$PCM_{i,t}$: the Price-Cost Margin index of firm *i* in industry *k* at year *t*.

$EBIT_{i,t}$: earnings before interest and taxes, a measure of profits.

$Sales_{i,t}$: the firm's net sales or revenues.

Then, my competition measure at the two-digit Standard Industry Classification (SIC) level is the average of this across firms:

$$PMC_{k,t} = 1 - \frac{1}{N_{kt}} \sum_{i \in k} PCM_{i,t} \quad (4.4)$$

Where *k* indexes industry and N_{kt} is the number of firms in industry *k* in year *t*. A value of 1 indicates perfect competition (marginal cost equals price), while values below 1 illustrate some degree of market power.

In line with the recent studies which provide support to the Schumpeter-Aghion non-linear relationship between market competition and firm investment, I add also the squared term of competition measure into model (4.5):

$$R\&D_{i,t} = \alpha_i^7 + \beta_1^7 R\&D_{i,t-1} + \beta_2^7 R\&D_{i,t-2} + \beta_3^7 \Delta Q_{i,t-1}$$
$$+\beta_4^7 \Delta S_{i,t-1} + \beta_5^7 CF_{i,t-1} + \beta_6^7 PMC_{k,t-1} + \beta_7^7 PMC_{k,t-1}^2 + \varepsilon_{i,t}^7 \quad (4.5)$$

In (4.5), the effect of product-market competition is captured by two coefficients, β_6^7 and β_7^7. More specifically, the significance of coefficient β_7^7 on the squared term of competition measure will tell us whether the competition-R&D investment relationship is non-linear. Concerning the sign of this coefficient, the negative and significant β_7^7 indicates an inverted-

U relationship, whereas the significantly positive β_7^7 postulates a U-shape for the effect of competition on firm R&D investment.

Similar to the two previous models, the role of expectations about future profitability and capacity need are reflected by the estimated coefficients β_3^7 and β_4^7, respectively. The significance of these coefficients will verify the role of expectations in the augmented model.

Equation (4.5) also controls for past investments through the first two lags of R&D intensity and for internal finance through the lagged value of cash flow ratio.

One remark that should be noted here is that only the country and time fixed effects are captured in (4.5). Since the measure of product-market competition is constructed at the two-digit SIC industry level, I do not control for further industry fixed effects in the model.

4.2.2. Small and medium-sized versus large firms

Another issue concerns the impact of firm size, as it is reasonable to consider that small and large firms might react differently in their investment decisions to any change in the environment (Acs and Audretsch, 1988; Van Dijk et al., 1997). Hence, it is necessary to examine whether the effects of my explanatory variables on firm R&D investment vary across firm size. To address this issue, I create a dummy variable SME_i, which equals 1 if the firm has fewer than 250 employees (small and medium-sized firms) and 0 otherwise, following the criterion from the European Union classification.[13] It should be noted that I combine small and medium-sized firms into one group, as they both consist of small portions of my whole sample. To avoid any firm that appears in both sub-samples (moving from small to large in some years, or vice versa), I restrict the large firm sample to those with no observation of fewer than 250 employees.

In order to test specifically whether the effect of expected profitability on firm R&D investment varies across firm size, I add into my model the interaction term between the dummy variable SME_i and the growth rate of Tobin's Q:

[13] According to the European Union classification's updated version in 2003, firms are classified as 'micro' (fewer than 10 employees or a turnover of less than €2 million), 'small' (fewer than 50 employees or a turnover of less than €10 million), or 'medium' (fewer than 250 employees or a turnover of less than €50 million), and the rest are in the 'large' category.

$$R\&D_{i,t} = \alpha_i^{7.1} + \beta_1^{7.1} R\&D_{i,t-1} + \beta_2^{7.1} R\&D_{i,t-2} + \beta_3^{7.1} \Delta Q_{i,t-1}$$
$$+\beta_4^{7.1} \Delta S_{i,t-1} + \beta_5^{7.1} CF_{i,t-1} + \beta_6^{7.1} PMC_{k,t-1} + \beta_7^{7.1} PMC_{k,t-1}^2$$
$$+\beta_8^{7.1} SME_i * \Delta Q_{i,t-1} + \beta_9^{7.1} SME_i + \varepsilon_{i,t}^{7.1} \quad (4.6)$$

The estimated coefficient $\beta_8^{7.1}$ will indicate whether the effect of the growth rate of Tobin's average Q on R&D investment varies across firm size. I expect the estimated coefficient of $\beta_8^{7.1}$ to be significant and positive, which means that the effect of market signal for expected profitability is stronger on the R&D investment decisions of small and medium-sized firms than those of large firms. This expectation is based on the fact that small and medium-sized firms are often more flexible in adjusting their R&D investments than larger firms, and therefore their investment decisions might be more sensitive to stock market reactions.

4.2.3. Low versus high R&D-intensity firms

For the second heterogeneity check, I test whether my results vary with high and low R&D-intensive firms. In order to address this, I create a dummy variable INT_i, which receives the value of 1 if the firm has no observation with R&D intensity higher than the average R&D intensity of its two-digit SIC industry over the 2005-2013 period. These are categorized as low R&D-intensive firms in my sample.

Then, equation (4.5) is augmented with both the dummy and its interaction with the growth rate of Tobin's average Q:

$$R\&D_{i,t} = \alpha_i^{7.2} + \beta_1^{7.2} R\&D_{i,t-1} + \beta_2^{7.2} R\&D_{i,t-2} + \beta_3^{7.2} \Delta Q_{i,t-1}$$
$$+\beta_4^{7.2} \Delta S_{i,t-1} + \beta_5^{7.2} CF_{i,t-1} + \beta_6^{7.2} PMC_{k,t-1} + \beta_7^{7.2} PMC_{k,t-1}^2$$
$$+\beta_8^{7.2} INT_i * \Delta Q_{i,t-1} + \beta_9^{7.2} INT_i + \varepsilon_{i,t}^{7.2} \quad (4.7)$$

In (4.7), with the presence of the interaction term between the dummy variable INT_i and the growth rate of Tobin's Q, the actual effect of stock market movements on low R&D-intensive firms is the sum of the estimated coefficients ($\beta_3^{7.2} + \beta_8^{7.2}$), while it is only $\beta_3^{7.2}$ for high R&D-intensive firms. Since it is reasonable to believe that high R&D-intensive firms are more sensitive to market reactions and expectations, the coefficient $\beta_8^{7.2}$ is expected to be negative in the empirical results.

4.2.4. Estimation issues

My main method of estimation is the system generalised method of moments (GMM) estimator proposed by Arellano and Bond (1991) and developed by Arellano and Bover (1995) and Blundell and Bond (1998), due to the potential endogeneity problem of the growth rate of Tobin's average Q and several other explanatory variables in my models. The reason was well-expressed in Fischer and Merton (1984): "In the general equilibrium sense, all prices are endogenously determined, and therefore, changes in stock prices cannot be exogenous" (p.35).

In choosing the 'best' set of instruments, I rely on two main tests. The first is the common Hansen test for over-identification, which tests the validity of my instruments. The null hypothesis of this test is that my set of instruments is valid. Secondly, the Arellano-Bond test for serial autocorrelation is examined under the null hypothesis of no existing serial correlation between the first difference of the error term and its lags. With this specific test, one should note that it is acceptable to have serial correlations for AR(1), because both the difference in the error term and its first lag contain the same component, $\varepsilon_{i,t-1}$. However, the serial correlation in the second order will eliminate the validity of recent lags as instruments; or, in other words, we must use deeper lags of variables as instruments (Roodman, 2009).

The 'best' results from GMM estimator are provided after several trials. I first use all the possible instruments (from lag 1 onwards for predetermined variables and from lag 2 onwards for endogenous variables). Then, following Roodman (2009), I apply the *collapse* option to reduce the duplication of instruments, and the *orthogonal* option to cope with the problem of missing data, as my data set is unbalanced. Also, I rely on the difference-in-Hansen test to set the specific number of instruments for each of my variables.

In order to compare the results, I present also the estimates obtained by using the ordinary lest squares (OLS) and fixed effect (FE) estimators. The econometrics package used is Stata 14.

4.3. Empirical results

Table 4. 1: Pairwise correlation (of main variables)

	R&D intensity	Growth rate of Q	Product-market competition	Cash flow ratio	Growth rate of sales
R&D intensity	1				
Growth rate of Q	0.0501	1			
Competition (*PMC*)	-0.2486	-0.0872	1		
Cash flow ratio	-0.4057	0.0435	0.1177	1	
Growth rate of sales	0.0082	-0.0910	-0.0105	0.0533	1

Table 4.1 provides the Pairwise correlation among my main variables. The highest correlations are from product-market competition and the cash flow ratio with the dependent variable - R&D intensity. This can be considered as the signal for the necessity of controlling for these two additional factors in the R&D investment model. Besides, surprisingly, the correlations between R&D intensity and the cash flow ratio has an unexpected negative sign. However, what is more important is that the correlations between the growth rate of Tobin's average Q and the other explanatory variables: product-market competition, the cash flow ratio and growth rate of sales, are considerably low (less than 0.1). This reduces the potential impact of multicollinearity problem on my empirical results.

Table 4.2 provides the empirical results of my baseline model, which reflects the effect of expectation about future profitability and capacity need on firm R&D investment decisions.

Table 4. 2: Results of the baseline model (4.1)

Model	OLS	FE	GMM
R&D intensity (lag 1)	0.7009***	0.2834***	0.4617***
	(0.0307)	(0.0401)	(0.0797)
R&D intensity (lag 2)	0.1858***	-0.0205	0.0253
	(0.0268)	(0.0319)	(0.0307)
Growth rate of average Q (lag 1)	0.0202***	0.0160***	0.0245***
	(0.0019)	(0.0019)	(0.0085)
Growth rate of sales (lag 1)	-0.0120***	-0.0082***	0.0180
	(0.0026)	(0.0026)	(0.0113)
Industry effects	Yes	No	Yes
Country effects	Yes	No	Yes
Year effects	Yes	Yes	Yes
Number of observations	23017	23017	23017
Number of firms	3624	3624	3624
Number of instruments			60
AR(1)			0.000
AR(2)			0.388
Hansen test (P-value)			0.639
Difference-in-Hansen test (level equation)			0.308

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, I use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity and lag 3 onwards of the growth rate of Q and sales for the difference equations, and the second lagged difference of R&D intensity and the third lagged differences of both the growth rate of Q and sales for level equations.

The first column of Table 4.2 reports OLS estimates, while results from the FE and system GMM estimators are presented in the second and third columns, respectively. The one-period-ahead growth rate of Tobin's average Q, my measure of expected profitability, appears to have a positive and significant effect on contemporary R&D intensity through all three estimations. In more detail, for the system GMM estimate (column 3), a 1% increase (decrease) in the one-period-ahead growth rate of Tobin's average Q leads to a 2.45% increase (decrease) in the contemporary value of R&D intensity. The associated 95% confidence interval is [0.78%, 4.12%].

Besides, the growth rate of sales, my measure of expected capacity need, has a positive but insignificant effect in system GMM estimation. This result is in line with my expectation about the less relevant role of capacity need on R&D investment, which has also been reported recently by two studies (Aghion et al., 2012; Guney et al., 2017). This is due to the fact that R&D investment is often carried out with the aim of improving the quality of products, hence it might be less influenced by a change in capacity need as in the case of physical capital investment.

On the other hand, the persistence of firm R&D investment is also documented in the results in Table 4.2, where the first lag of R&D intensity has a significantly positive effect on contemporaneous value. However, the second lag of R&D intensity is only significant in the OLS estimation, while it turns out to be insignificant in column 3 of Table 4.2 where the system GMM estimator is applied.

Concerning econometric issues, the results differ considerably in columns 1 and 2 of Table 4.2 where the methods of estimation are the popular pooled-OLS and FE treatment for panel data. Consistent with previous studies, I find that my system GMM estimates of lagged R&D intensity (the lagged values of the dependent variable) are in between its estimated coefficients from the OLS and FE estimates. In other words, these are supportive of the well-known downward bias of FE and upward bias of OLS estimators with regard to the dynamic panel model (Nickell, 1981; Bond, 2002).

Also, another important issue with OLS and FE estimators is that neither takes into account the potential endogeneity problem. In this case, the one-period-ahead growth rate of Q and past investments might not be totally exogenous. This is confirmed in the system GMM estimation, where these variables demonstrate the necessity of being instrumented. The 'best' set of instruments is specified after several trials, including lag 2 onwards of R&D intensity and the growth rate of Q and sales.

There are two main tests for the reliability of GMM estimates. First, the Hansen test indicates that the null hypothesis of valid instruments cannot be rejected (the P-value of 0.639 is much higher than 0.05). Secondly, concerning the Arellano-Bond tests for serial correlation (AR(1) and AR(2)), my results document the acceptable serial correlation at first level (where the P-value of the AR(1) test is 0.000), but confirm the null hypothesis of no serial correlation at the second order of the difference in error term (where the P-value of AR(2) is 0.388). This absence of higher-order serial correlation justifies my chosen set of instruments. In addition, the result of the difference-in-Hansen test also confirms the necessity of the set of instruments for level equations, which in turn supports my use of system GMM over the difference GMM estimator.

Then, Table 4.3 presents the results of my baseline model with the control for internal finance through the first lag of cash flow ratio, a well-known source of friction in the literature on Tobin's Q theory of investment.

Table 4. 3: Results of model (4.2) with control for lagged cash flow ratio

Model	OLS	FE	GMM
R&D intensity (lag 1)	0.6840***	0.2682***	0.4036***
	(0.0315)	(0.0402)	(0.0785)
R&D intensity (lag 2)	0.1795***	-0.0217	0.0492
	(0.0275)	(0.0317)	(0.0347)
Growth rate of average Q (lag 1)	0.0196***	0.0155***	0.0308***
	(0.0019)	(0.0018)	(0.0105)
Growth rate of sales (lag 1)	-0.0092***	0.0033***	0.0197
	(0.0026)	(0.0026)	(0.0127)
Cash flow ratio (lag 1)	-0.0396***	-0.0729***	0.1093**
	(0.0067)	(0.0122)	(0.0452)
Industry effects	Yes	No	Yes
Country effects	Yes	No	Yes
Year effects	Yes	Yes	Yes
Number of observations	22809	22809	22809
Number of firms	3621	3621	3621
Number of instruments			67
AR(1)			0.000
AR(2)			0.478
Hansen test (P-value)			0.872
Difference-in-Hansen test (level equation)			0.892

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, I use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, lag 3 onwards of the growth rate of Q and sales and cash flow ratio for the difference equations, the second lagged difference of R&D intensity, and the third lagged differences of the growth rate of Q and sales and cash flow ratio for the level equations.

Overall, table 4.3 indicates the necessity of controlling for internal finance through the lagged cash flow ratio in the firm's investment model. Similar to previous studies (Blundell et al., 1992; Guney et al., 2017), the system GMM results confirm that the first lag of cash flow ratio is not exogenous in the investment model, and it should be instrumented using its own lags. The GMM estimates in column 3 of Table 4.3 show that, in contrast to the insignificant effect of the growth rate of sales, the estimated coefficient of the lagged cash flow ratio (in the system GMM estimation) is positive and highly significant at the 5% level. It is in line with the findings from Himmelberg and Petersen (1994), where the change in sales is not significant in the R&D regression, but the cash flow ratio is.

Besides, all these other covariates show consistent results in comparison with Table 4.2. While the growth rate of Q is positive and statistically significant, the growth rate of sales remains positive but insignificant even at the 10% level. The dynamic model of R&D investment shows its appropriateness, as the first lag of R&D intensity documents a positive and statistically significant coefficient. The persistence of R&D data is confirmed with the much higher estimated coefficient of lagged R&D intensity in comparison with other factors in my model.

Similar to the results from Table 4.2, the GMM estimates in column 3 of Table 4.3 show noticeable differences in comparison to the OLS and FE estimates reported in the first two columns. Not only are the upward bias of the OLS estimator and the downwards bias of FE results are revealed in the estimated coefficients of the lagged R&D intensity, the negative cash flow coefficients in the first two columns exemplify the issue when the estimation is not controlled for endogeneity.

Another main purpose of this chapter is to check whether product-market competition can be a significant additional factor in the Tobin's Q model of firm R&D investment. To address this issue, equation (4.3) contains $PMC_{k,t-1}$, the measure of product-market competition at two-digit SIC industry-level. In line with the recent strand of literature that postulates the Schumpeter-Aghion non-linear relationship between competition and innovation, equation (4.3) also includes the squared term of $PMC_{k,t-1}$. The significance of the estimated coefficient of this squared term will indicate whether the relationship between product-market competition and firm R&D investment in this case is linear or non-linear. Results are presented in Table 4.4.

Table 4. 4: Results of model (4.5) with the presence of product-market competition

Model	OLS	FE	GMM
R&D intensity (lag 1)	0.6847***	0.2650***	0.3708***
	(0.0327)	(0.0414)	(0.0796)
R&D intensity (lag 2)	0.1792***	-0.0180	0.0435
	(0.0282)	(0.0325)	(0.0356)
Growth rate of average Q (lag 1)	0.0198***	0.0156***	0.0377***
	(0.0019)	(0.0019)	(0.0114)
PMC (lag 1)	1.2044***	0.5094	2.6934***
	(0.1879)	(0.6721)	(0.8960)
PMC-squared (lag 1)	-0.7097***	-0.2815	-1.6634***
	(0.1061)	(0.3594)	(0.5100)
Cash flow ratio (lag 1)	-0.0397***	-0.0705***	0.1073**
	(0.0068)	(0.0125)	(0.0497)
Growth rate of sales (lag 1)	-0.0089**	-0.0031	0.0256*

	(0.0027)	(0.0026)	(0.0139)
Country effects	Yes	No	Yes
Year effects	Yes	Yes	Yes
Number of observations	22407	22407	22407
Number of firms	3615	3615	3615
Number of instruments			50
AR(1)			0.000
AR(2)			0.415
Hansen test (P-value)			0.802
Difference-in-Hansen test (level equation)			0.972

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, I use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, lag 3 onwards of the growth rate of Q and sales and cash flow ratio for the difference equations, the second lagged difference of R&D intensity, and the third lagged differences of the growth rate of Q and sales and cash flow ratio for the level equations.

In Table 4.4, product-market competition appears to have a significantly non-linear effect on firm R&D investment. This is documented by the negative and statistically significant estimated coefficient of the squared term of $PMC_{k,t-1}$ (for GMM estimation in column 3, the coefficient is -1.6634).

The implied optimal competition level (calculated as $-\beta_6^7/2\beta_7^7$) is 0.8096, which means that the point where the effect of a change of competition turns from positive to negative is within the range of values of the competition measure in my sample. However, by more careful consideration, I discover that only 0.23% of the observations in the estimation sample are on the positive slope. In other words, the turning point of the inverted-U shape is found at the very beginning of my data set. This can be attributable to the fact that my ‘globalised’ approach concerning 15 developed countries as a single market reflects a higher level of competition (the lowest value of the $PMC_{k,t-1}$ measure is 0.6403). Hence, the empirical results can be interpreted as supportive of the negative Schumpeter effect of competition on R&D investment. This is in line with the explanation from Peneder (2012), in which the author indicates that the negative Schumpeter effect is based on the consideration of high initial levels of competition.

However, what is more important in the results in Table 4.4 is that the new control for product-market competition does not eliminate the role of expectations in determining the optimal level of firm R&D investment. The one-period-ahead growth rate of Tobin’s average Q remains positive and highly significant in the GMM estimation. The magnitude of its estimated coefficient is 0.0377, which is within the 95% confidence interval of the results before the model is controlled for competition. It shows the consistency of my results with regard to the role of expectation about future profitability. Besides, the effect of expectation about capacity need, surprisingly, turns out to be significant, but only at a 10% level in the GMM results in Table 4.4.

There is no other significant change in the effect of other covariates. While the first lag of R&D intensity and cash flow ratio positively and significantly impact firm R&D investment decisions, the second lag of R&D intensity has a small, positive but insignificant documented effect. The reliability of system GMM estimates is also confirmed by the diagnosis check results provided at the end of column 3 of Table 4.4.

Heterogeneity check

Table 4.5 displays the results of two heterogeneity checks with regard to firm size and the level of R&D intensity. The method of estimation is system GMM.[14]

First, column 1 of Table 4.5 presents the results with the control for firm size. In the literature, large firms are often considered to have more advantages in taking investment opportunities, due to their existing capacity of research labs, R&D personnel and the ability to issue their own bonds to attract external finance. Whereas, smaller firms are likely to be more sensitive to any change in the market, which signifies whether their investment might be profitable in the future. Hence, I expect the revision of expected profitability to be more important to small (and medium-sized) firms. In order to test this hypothesis, both the dummy SME_i and its interaction term with the growth rate of Tobin's average Q are added into my model.

Table 4. 5: Heterogeneity checks

Model	(1)	(2)
R&D intensity (lag 1)	0.4489***	0.4619***
	(0.0704)	(0.0725)
R&D intensity (lag 2)	0.0404	0.0497
	(0.0352)	(0.0352)
Growth rate of average Q	0.0254***	0.0264***

[14] The system GMM estimator keeps its superiority in comparison with OLS and FE methods. The full results of these two other estimators are presented in Tables A4.2 and A4.3 in the Appendix.

	(0.0074)	(0.0075)
PMC (lag 1)	1.7648**	3.1866***
	(0.7057)	(0.9216)
PMC-squared (lag 1)	-1.1038***	-1.9440***
	(0.4012)	(0.5311)
Cash flow (lag 1)	0.0854**	0.0097
	(0.0411)	(0.0340)
Growth rate of sales	-0.0022	-0.0055
	(0.0051)	(0.0036)
SME_i	0.0340***	
	(0.0062)	
SME_i * Growth rate of average Q	0.0172*	
	(0.0088)	
INT_i		-0.0366***
		(.0065)
INT_i* Growth rate of average Q		-0.0250***
		(0.0065)
Lincom effect	0.0426***	0.0014
	(0.0110)	(0.0051)
Country effects	Yes	Yes
Year effects	Yes	Yes
Number of observations	22279	22407
Number of firms	3583	3615
Number of instruments	57	57
AR(1)	0.000	0.000
AR(2)	0.328	0.450
Hansen test (P-value)	0.485	0.229
Difference-in-Hansen test (level equation)	0.919	0.753

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, we use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, lag 3 onwards of the growth rate of Q and sales and cash flow ratio for the difference equations, the second lagged difference of R&D intensity, and the third lagged differences of the growth rate of Q and sales and cash flow ratio for the level equations. The *lincom* effect is calculated from the estimated coefficients of the growth rate of Tobin's Q on itself and its interaction term with other variable. (1) is with the control for small or large firms, (2) is with the control for high/low R&D-intensive firms.

Column 1 of Table 4.5 shows that controlling for firm size indicates some interesting results. First, the dummy variable SME_i, on its own, is positive and highly significant, which indicates that, on average, the R&D intensity of small and medium-sized firms is higher than that of larger firms.

However, more important are the estimated coefficients of $\beta_3^{7.1}$ and $\beta_8^{7.1}$ on the growth rate of Tobin's Q and its interaction term with SME_i. When the dummy variable SME_i receives the value of 1 (small or medium-sized firms), the estimated effect of the change in average Q is 0.0426 (the sum of $\beta_3^{7.1}$ and $\beta_8^{7.1}$ in equation 4.6), significantly higher than that on large firms (the estimated coefficient $\beta_3^{7.1}$ is 0.0254). This result is supportive of my expectation that the R&D investment decisions of small and medium-sized firms are more sensitive to any change in stock market valuation than those of larger firms. It can be also explained by the fact that larger firms often engage in long-term R&D projects, and therefore their R&D investment budgets are more persistent and do not vary much with recent market movements. On the other hand, small and medium-sized firms often do not have sufficient internal finance and they must rely on expectations about future profitability to plan their investment budgets.

As a second heterogeneity check, I test how sensitive my findings are with regard to high/low R&D-intensive firms. Using a similar approach to firm size, I create a dummy variable INT_i and its interaction term with the growth rate of Q. The dummy INT_i equals 1 if the firm's R&D intensity over the 2005-2013 period is lower than the average R&D intensity of the SIC two-digit industry it belongs to (low R&D-intensive firm). In contrast, it equals 0 for all other firms with R&D intensity higher than the average R&D intensity of the SIC two-digit industry (high R&D-intensity firms).

Table 4. 6: Summary statistics of high and low R&D intensive samples

Variable	High R&D-intensive		Low R&D-intensive	
	Obs.	*Mean*	*Obs.*	*Mean*
Rd_intensity	12739	0.1309	18440	0.0186
Average Q	12302	1.7635	18400	0.9993
Growth rate of Q	9229	-0.0468	14053	-0.0372
PMC	12643	0.9111	18209	0.9086
Cash flow ratio	12494	-0.0118	18365	0.0800
Growth rate of sales	9591	0.0636	14078	0.0533

In Table 4.6, besides the obvious difference in the level of R&D intensity between these two sub-samples, the high R&D-intensive firms also have a much lower mean value of cash flow ratio (-0.0118, while it is 0.0800 for the sample of low R&D-intensive firms). This is an interesting statistic, which is opposite to the common notion that internal finance is often the main source for firm R&D investment. However, this common notion might not be true for my sample, which contains listed firms in developed countries only, as these firms do not really face any difficulty in accessing and attracting external finance. Besides, there seems to be no difference between the statistics of the growth rate of Tobin's average Q and sales.

Then, column 2 of Table 4.5 provides the regression results of model (4.7) with the presence of the dummy variable INT_i and its interaction term with the growth rate of Tobin's average Q. Similar to the control for firm size, it indicates the sensitivity of my results with regard to the level of the firm's R&D intensity. The estimated coefficient of the interaction term is negative and highly significant at the 1% level. In magnitude, it is almost the same as the estimated coefficient of the growth rate of Q on its own, and the linear combined effect (calculated using the *lincom* command in Stata) shows that the traction in Tobin's average Q has no significant effect on R&D investment among low R&D-intensive firms.

4.4. Sensitivity check

Table 4.7 presents the results from a sensitivity check based on an alternative measure of product-market competition: the Herfindahl-Hirschman index (HHI). The HHI measure is calculated as the sum of the squared market shares of all firms in each two-digit SIC industry. Fundamentally, the HHI measures the level of concentration, which can be considered as opposite to the level of competition. Hence, my results are consistent if the U-shape can be found for the new HHI measure.

Table 4. 7: Results with HHI measure of concentration

Model	OLS	FE	GMM
R&D intensity (lag 1)	0.6874***	0.2682***	0.4004***
	(0.0315)	(0.0402)	(0.0780)
R&D intensity (lag 2)	0.1823***	-0.0217	0.0509
	(0.0276)	(0.0317)	(0.0346)
Growth rate of average Q	0.0195***	0.0155***	0.0320***
	(0.0019)	(0.0018)	(0.0104)
HHI (lag 1)	-0.0839***	0.0011	-0.3227***
	(0.0101)	(0.0338)	(0.0604)
HHI-squared (lag 1)	0.1323***	-0.0024	0.5390***
	(0.0199)	(0.0435)	(0.1090)
Cash flow (lag 1)	-0.0390***	-0.0729***	0.1122**
	(0.0067)	(0.0122)	(0.0451)
Growth rate of sales	-0.0093***	-0.0033	0.0205
	(0.0026)	(0.0026)	(0.0127)
Country effects	Yes	No	Yes
Year effects	Yes	Yes	Yes
Number of observations	22809	22809	22375
Number of firms	3621	3621	3625

Number of instruments	50
AR(1)	0.000
AR(2)	0.493
Hansen test (P-value)	0.883
Difference-in-Hansen test (level equation)	0.898

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, I use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, lag 3 onwards of the growth rate of Q and sales and cash flow ratio for the difference equations, the second lagged difference of R&D intensity, and the third lagged differences of the growth rate of Q and sales and cash flow ratio for the level equations.

Table 4.7 indicates the consistency of my results when the HHI index is used to measure market concentration. There is no difference in the estimated coefficients of past investments, the one-period-ahead growth rate of Tobin's Q and sales and the lagged cash flow ratio. With regard to the HHI index, the positive and statistically significant coefficient of the squared term of the HHI index confirms that there is a non-linear relationship between competition and R&D investment. As expected, with the HHI index as a measure of concentration, this relationship follows a U-shape.

4.5. Conclusions

This chapter has provided empirical results on the augmented Tobin's Q model with the presence of product-market competition. The main method of estimation is system GMM, proposed by Arellano and Bond (1991) and developed by Arellano and Bover (1995) and Blundell and Bond (1998). System GMM is known to provide an effective treatment for potential endogeneity in dynamic panel models and has been widely used in the literature on firm investment (Cincera, 2003; Blundell et al., 1992; O'Connor and Rafferty, 2012). My sample contains 3,718 manufacturing firms from 15 OECD countries over the 2005-2013 period.

First, the results show that the one-period-ahead growth rate of Tobin's average Q, my measure of expected profitability that shapes expectations formation, has a positive and statistically significant effect on firm R&D investment. This evidence supports the long-term argument that expectations matter in determining firm investment, which can be dated back to Keynes (1936). The traditional Tobin's Q theory has focused on this expression;

however, with the failure of Tobin's average Q in the empirical literature, I believe that the role of expectation in determining the optimal level of firm investment has not been fully appreciated yet. By proposing a new measure of the one-period-ahead growth rate of Tobin's average Q, not only do I demonstrate how one can bring back Tobin's Q theory to the empirical work on R&D investment, I also provide additional evidential support for the role of expectations in modelling and estimating R&D investment.

However, the findings also indicate that the traction in Tobin's average Q is not the sole determinant of R&D investment as posited by neo-classical theory. Indeed, there are factors that cause divergence from the perfect competition assumption in neo-classical theory. One of these factors is capital-market imperfections, which either make external finance difficult to obtain or increase its cost when it is available. This issue induces managers to take into account the level of internal finance in their investment decisions. My results provide support for this notion, as the lagged cash flow ratio appears to have a positive and significant effect on the optimal level of R&D investment.

Moreover, to check for further deviation from the perfect competition assumption empirically, I augment the model with the level of product-market competition. The results indicate that product-market competition appears to have a significant effect on firm R&D investment, even though it does not eliminate the role of expectation in the model. The empirical evidence provides support to an inverted-U shape competition-innovation relationship proposed by Aghion et al. (2005). This result is also consistent through different measures of competition as well as methods of estimation.

A third innovation in this chapter is to provide some evidence on observable sources of heterogeneity in the relationship between the traction in Tobin's average Q and firm R&D investment. My findings indicate that the effect of the one-period-ahead growth rate of Tobin's average Q is stronger when firms are small or medium-sized, but it is weaker (and in fact insignificant) when the firm's R&D intensity is lower than the average R&D intensity of its two-digit SIC industries.

Overall, the chapter provides evidence to support my argument on the augmented Tobin's Q model. Hence, the next chapter continues to develop the nested models, where the second additional factor, the level of R&D spillovers, is added to the model in addition to cash flow ratio and product-market competition.

CHAPTER 5: THE ROLE OF KNOWLEDGE SPILLOVERS IN THE AUGMENTED TOBIN'S Q MODEL OF FIRM R&D INVESTMENT

5.1. Introduction

Chapter 4 provides support for my augmented Tobin's Q model of firm R&D investment, in which the expectations about future profitability and capacity need are considered together with the level of product-market competition in explaining the managerial incentives for R&D investment. Instead of using average Q as in the common but unsuccessful approach to the traditional Tobin's Q theory, I propose using the one-period-ahead growth rate of Tobin's average Q as a measure of expected profitability, which has been shown to be a significant determinant of R&D investment. A novel finding in Chapter 4 is that product-market competition has a significant effect on the managerial incentives for R&D activities in the augmented model. In fact, it does not eliminate the role of expectations, but contributes explanatory power to the model in general.

This chapter aims to expand the augmented Tobin's Q model with a second additional factor: the level of knowledge spillovers in the market. The issue of knowledge spillovers has been raised together with the importance of R&D investment in the 'endogenous growth model' (Romer, 1986, 1990; Grossman and Helpman, 1991). "Since knowledge is inherently a public good, the existence of technologically related research efforts of other firms may allow a given firm to achieve results with less research effort than otherwise" (Jaffe, 1986, p.984). A voluminous literature has been dedicated to the relationship between R&D spillovers and productivity (see Hall et al., 2010 for a survey), whereas its effect on firm R&D investment decisions, I believe, has not gained its deserved importance yet. There are few theoretical justifications for this relationship. On the one hand, it is commonly thought that the level of knowledge spillovers is negatively related to the optimal level of R&D investment, since the high level of the spillover pool outside can be a source of knowledge that spillover-recipient firms can emulate, from that avoiding the cost of duplicated research and therefore lowering the level of their R&D investment. On the other hand, the high level of spillovers might induce firms to engage more in their own investment, due to the threat of the creative destruction effect that their own knowledge and technology might become obsolete because of new inventions from their competitors. In addition, the hope of overtaking existing leaders and stealing their market shares by successful investment, the so-called ‘market-stealing’ effect, might encourage firms to accept uncertainty and invest more in R&D activities (Bloom et al., 2013).

Overall, even though it is inconclusive whether the effect of knowledge spillovers on the firm’s research effort is negative or positive, it must not be overlooked by any model on the determinants of firm investment. The empirical work from Harhoff (2000), Jaffe (1988), Capron and Cincera (2001) and Nieto and Quevedo (2005) have provided some initial empirical evidence to support this notion.

Therefore, failure to control for the effect of knowledge spillovers in an R&D investment model is highly likely to boil down to model mis-specification and omitted variable bias. Hence, I expand the augmented Tobin’s Q model with the new control of knowledge spillovers (together with the existing product-market competition) in this chapter. Empirically, three measures of the knowledge spillover pool are applied: the unweighted measures of intra- and inter-industry spillovers and the patent-weighted measure of inter-industry spillovers, based on the number of patent citations between the two-digit SIC industries.

The empirical work on the same data set of 3,718 firms from 15 OECD countries in the 2005-2013 period reports several findings. First, the control for knowledge spillovers does not affect the role of expectation about future profitability as well as product-market competition in my model. While the one-period-ahead growth rate of Tobin’s average Q retains its positive and significant effect, the inverted-U shape is confirmed for the competition-R&D investment relationship. In addition, similar to product-market competition, the level of both intra- and inter-industry spillovers have significant impacts on firm R&D investment. However, the empirical results seem to be more complicated than what has been discovered so far in the literature. The more common notion of a negative impact of spillovers on the firm’s incentives for investment can be found only for inter-industry spillovers, whereas the knowledge spilled over from other firms in the same industry tends to increase the firm’s research effort. In other words, my results support the perspective that the knowledge (spillover) pool from the main competitors is the source of creative destruction and/or ‘market-stealing’ effects which in turn might induce higher levels of R&D investment by the spillover-recipient firm.

The chapter is structured as follows. Section 5.2 presents the set of empirical models for checking the effect of technological spillovers in my augmented Tobin’s Q model. It also includes the data characteristics and the specific econometric issues that must be dealt with. Then, section 5.3 provides my empirical results, following by a set of robustness tests in section 5.4. Finally, section 5.5 concludes the chapter.

5.2. Model specifications and data

5.2.1. Empirical models

The main model of this chapter is the expanded version of the augmented Tobin's Q model from Chapter 4, in which the growth rate of Tobin's average Q and sales, my measure of the manager's expectations about future profitability and capacity need, are considered together with product-market competition in explaining the R&D investment decision-making process at firm-level. What is different in model (5.1) is the presence of the two measures of knowledge spillovers at intra- and inter-industry levels:

$$R\&D_{i,t} = \alpha_i^8 + \beta_1^8 R\&D_{i,t-1} + \beta_2^8 R\&D_{i,t-2} + \beta_3^8 \Delta Q_{i,t-1}$$

$$+\beta_4^8 \Delta S_{i,t-1} + \beta_5^8 CF_{i,t-1} + \beta_6^8 PMC_{k,t-1} + \beta_7^8 PMC_{k,t-1}^2$$

$$+\beta_8^8 S_{intra,t-1} + \beta_9^8 S_{inter,t-1} + \varepsilon_{i,t}^8 \qquad (5.1)$$

Where:

$RD_{i,t}$:	R&D expenditure at year *t* over total assets at the end of *t*-1
$\Delta Q_{i,t-1}$:	growth rate of Tobin's average Q
$CF_{i,t-1}$:	level of cash flow ratio at the end of *t*-1
$\Delta S_{i,t-1}$:	growth rate of sales
$PMC_{k,t-1}$:	level of product-market competition at the end of *t*-1
$S_{intra,t-1}$:	measures of intra-industry spillovers at the end of *t*-1
$S_{inter,t-1}$:	measures of inter-industry spillovers at the end of *t*-1
$\varepsilon_{i,t}^8$:	the composite error term as defined in equation (3.12b).

Equation (5.1) is a dynamic version of the R&D investment model, where the first two lags of R&D intensity are controlled for the persistence of R&D data.

The effect of knowledge spillovers is captured by the two coefficients β_8^8 and β_9^8. A positive and significant estimated β_8^8 suggests that firms are motivated to do more innovative activities if there is a high level of knowledge spillovers from other firms in the same industry, whereas a negative one will indicate that the high level of spillovers inside the industry may reduce the firm's incentive for R&D investment. Similarly, the estimated coefficient β_9^8 provides information about the effect of inter-industry spillovers, to the extent of whether the knowledge spilled over from other industries has a significant effect on firm R&D investment.

Again, another coefficient to pay attention to is β_3^8 on the growth rate of Tobin's average Q. Its estimate indicates whether the significant effect of expected profitability on firm R&D investment remains after the model is controlled for the level of knowledge spillovers. Besides, the growth rate of sales reflects the effect of expected capacity need on firm investment.

Equation (5.1) also takes into account the effect of internal finance through the first lag of cash flow ratio. Internal finance is a major source of friction in the traditional Tobin's Q theory, due to the fact that it could limit the firm's investment if that firm is constrained from raising as much external finance to utilize its full investment opportunity as it wishes.

In (5.1), two sets of dummy variables are used for the control of country and time fixed effects. Since my measures of knowledge spillovers and product-market competition are at industry-level, I do not control for further industry fixed effects.

Similar to Chapter 4, I test the sensitivity of my results regarding to the different sources of firm heterogeneity. The two dummies SME_i and INT_i are used to reflect the differences in firm size and the level of firm R&D intensity. In order to test the robustness of the growth rate of Tobin's average Q, my measure of expected profitability, I also add into the models its interaction with the dummy.

5.2.2. Spillover measurement

From the seminal contributions of Arrow (1962) and Griliches (1979, 1992), the issue of R&D spillovers and its effect has been one of the main topics of interest in the literature on the industrial organisation. In line with this development, several measures of spillovers have been proposed.

First, the simplistic way is to construct the effect of outside R&D investment with no weighting scheme. In other words, this measure of knowledge spillovers treats all the sources of external knowledge equally, no matter whether it is at firm or industry level. Evidence of this approach can be found in Wakelin (2001), Antonelli (1994) and others.

However, it is considered more coherent to give different weights to different sources of knowledge, especially at the inter-industry level. The example from Mohnen (1996) is worth recalling here, in which an aircraft manufacturer is more likely to benefit from R&D in 'precision instruments' than from research in the wood industry. Several options have been suggested for the weight itself. Mohnen (1996) synthesizes these options into two distinct kinds of weights. In the first set, the weight is measured on the basis of inter-firm or inter-industry flows of goods and services. The intuition behind this kind of spillover is that the more firm *i* purchases intermediate inputs or capital goods from firm *j*, the more it is technologically close to *j*. This is defined as rent spillovers in Griliches (1979, 1992).

Concerning the second type of spillover, the idea is originated by Griliches (1979) and developed by Jaffe (1986). According to this approach, the technological knowledge developed by a firm can be utilized to the greatest extent by other firms with the closest 'distance' from it. The distance is measured either by the level of R&D input each firm specifies for each technological class, or by the level of patent citations exchanged between firms or industries.

In this thesis, I apply three measures of knowledge spillovers, in order to test their effects in my augmented Tobin's Q model. The first two are the simple unweighted measures of intra- and inter-industry spillovers, in which all other firms in the same industry or all other industries are treated equally as the sources of externalities spill over to the investigated firm. The third measure is patent-weighted inter-industry spillovers, which is constructed based on the patent citations data. It should be noted that knowledge spillover is a much broader concept than is captured by patent citations. However, the fact that patent citations reveal the 'prior knowledge' that the inventor has learned from makes them a potential measure of knowledge spillovers from past inventions to the current invention (Deng, 2005). Also, Roach and Cohen (2013) conclude that despite several sources of measurement error (reported knowledge flows with no corresponding citations, or observed citations with no corresponding reported knowledge flows), patent citations do contain important information about knowledge spillovers.

To be more specific, the 'technological distance' is calculated for each pair of two-digit SIC industries using the number of patent citations collected from the European Patent Office (EPO) through the EPO Worldwide Patent Statistical Database (*Patstat*). To be consistent with my approach that the firm considers its investment budget for period *t* at the end of the previous period *t*-1, all three measures of knowledge spillovers will be lagged by one period.

Suppose the investigated firm *i* is from industry *k*. These three measure of intra- and inter-industry spillovers for firm *i* are specified as follows:

$$S_{intra,t-1} = \log(\sum_{j \neq i} RD_{j,t-1}) \tag{5.4}$$

Where:

$RD_{j,t-1}$: R&D expenditure of all firms *j* in the same industry *k* with the investigated firm *i* at period *t*-1.

$$S^{1}_{inter,t-1} = \log(\sum_{l \neq k} RD_{l,t-1}) \tag{5.5}$$

Where:

$RD_{l,t-1}$: total R&D expenditure of all other industries *l* except the industry *k* of the investigated firm *i* at period *t*-1.

The second measure of inter-industry spillovers is constructed with the patent citation weight as follows:

$$S^{2}_{inter,t-1} = \log(\sum_{l \neq k} RD_{l,t-1} * \frac{p_{kl}}{p_k}) \tag{5.6}$$

Where:

p_{kl}: number of patent citations from industry *k* to industry *l*

p_k: total number of patent citations from industry *k*.

One remark should be noted here is that in the literature, the measure of knowledge spillovers is often constructed based on R&D stock, while here what I use is the R&D investment flow. This is due to two main reasons. First, different from the effect of knowledge spillovers on productivity, which is often considered to rely on time lags, I argue that spillovers' influence on the firm's research effort is more immediate. It is due to the fact that the speed of knowledge dissemination is quite fast, and therefore the R&D investment flow is more relevant than the stock value. Second, the use of R&D investment flow avoids the measurement error in calculating R&D stock values. In fact, several papers have used R&D expenditure in constructing a measure of knowledge spillovers' measure (Acharya and Keller, 2009; Adam and Jaffe, 1996; Hanel, 2000).

While calculating the first two unweighted measures of knowledge spillovers, $S_{intra,t-1}$ and $S^1_{inter,t-1}$, is straight-forward, the task of constructing the third measure using a patent citation matrix between 20 two-digit SIC industries in my sample contains several steps. First, it is attributable to an issue of different industry codes between financial and patent databases. Like other financial databases, *Worldscope* and *Datastream* mainly use the Standard Industry Classification (SIC) code, whereas most of the patent databases apply the International Patent Classification (IPC) code. Hence, an IPC-SIC concordance is required. Second, to be consistent with my approach in Chapter 4 above, I aggregate the patent citations data to two-digit SIC industry-level. After building the patent spillover matrix, I merge it with my data set using the same variable, *sic_2digit*. More details of the patent citation database and the IPC-SIC concordance are presented below.

IPC-SIC concordance from Silverman

The concordance that links the IPC system to the SIC system at the four-digit level was developed by Brian Silverman. This concordance has been widely used by scholars (Silverman, 1999; McGahan and Silverman, 2001; Mowery and Ziedonis, 2001). The concordance and a detailed explanation on how it was constructed are available online at www.rotman.utoronto.ca/silverman. Here, it is important to keep in mind that the IPC-SIC code correspondence is not one to one. Silverman's concordance assigns multiple IPCs to each SIC and vice versa. In addition, congruent with my empirical approach, I aim to construct the matrix of patent citations at the two-digit SIC industry-level. Therefore, this issue is even more severe after data aggregation. To deal with it, I utilize the variable *usefreq* (from the same concordance file), with the aim of selecting the most important SIC code for each IPC. This variable reflects the frequency with which patents assigned to one IPC are also assigned to a specific SIC in use. I restrict the value of the *usefreq* variable to be bigger than 10%, and drop all the IPC-SIC observations which cannot satisfy this condition. These arrangements are likely to introduce some measurement errors for my measure. Overall, Table 5.1 shows the number of IPCs for each two-digit SIC manufacturing industry:

Table 5. 1: Silverman's IPC-SIC concordance with at least 10% *usefreq* restriction

Two-digit SIC	Industry name	Number of IPCs from Silverman's concordance
20	Food and Kindred Products	19
21	Tobacco Products	5
22	Textile Mill Products	15
23	Apparel and Other Finished Products Made from Fabrics and Similar Materials	5
24	Lumber and Wood Products, Except Furniture	12
25	Furniture and Fixtures	3
26	Paper and Allied Products	20
27	Printing, Publishing, and Allied Industries	12
28	Chemicals and Allied Products	45
29	Petroleum Refining and Related Industries	7
30	Rubber and Miscellaneous Plastics Products	18
31	Leather and Leather Products	8
32	Stone, Clay, Glass, and Concrete Products	6
33	Primary Metal Industries	12
34	Fabricated Metal Products, Except Machinery and Transportation Equipment	29
35	Industrial and Commercial Machinery and Computer Equipment	81
36	Electronic and Other Electrical Equipment and Components, Except Computer Equipment	77
37	Transportation Equipment	75
38	Measuring, Analysing, and Controlling Instruments	12
39	Miscellaneous Manufacturing Industries	7

From Table 5.1, the two-digit SIC industries with the highest number of IPC equivalents are Industrial and Commercial Machinery and Computer Equipment (SIC 35); Electronic and Other Electrical Equipment and Components (SIC 36); and Transportation Equipment (SIC 37). The industries with the lowest number of IPC equivalents are Furniture and Fixtures (SIC 25); Tobacco Products (SIC 21); and Apparel and Other Finished Products Made from Fabrics and Similar Materials (SIC 23).

Patent citation data from *Patstat*

Since I aim to develop a the patent citation matrix for 15 OECD countries, the best option for a patent database is the Worldwide Patent Statistical Database (*Patstat*), which is maintained and distributed by the EPO. *Patstat* offers broad patent characteristics (including information on the title and abstract of a patent application, filing and publication dates of the application, names and origin of the inventors and applicants, and the technological domain of the application according to the IPC) and citations of around 74 million records from more than 100 patent offices all over the world (Benz et al., 2015; De Rassenfosse et al., 2014). The data was collected from *Patstat* Online, Autumn 2017 version.

In order to download data from *Patstat*, Structured Query Language (SQL) is applied.[15] Following Branstetter (2001), I assume that an industry's position in the technology space is effectively fixed in the short term. Therefore, I collect a single number of patent citations for each pair of two-digit SIC industries in my sample for the whole 2005-2013 period of investigation. Also, similar to the treatment of product-market competition, I consider all the 15 OECD developed countries as a single market, due to the fact that most of the firms in my sample are multinational corporations and it seems to be implausible to limit their activities to inside a specific country.

One more remark that should be made here is that I compute patent citations at the family level. This is the way the *Patstat* database resolves issues over patent family members and allows researchers to distinguish between multiple applications for the same inventions in several patent offices (Karvonen and Kassi, 2013). More specifically, I use the *DOCDB* patent family provided by the *Patstat* database, which groups all applications with exactly the same priorities (Paris Convention or technical relation or others). I also exclude self-citations.

After a few steps of manipulation, the final spillover matrix based on patent citations data for 20 two-digit SIC manufacturing industries is presented in Table 5.2.

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[15] Several introductory courses to SQL are freely available online, including one on the EPO website. Specifically, my learning of SQL coding was taught and supported by Dr Geert Boedt from EPO. I deeply appreciate his help in the task.

Table 5. 2: Knowledge spillovers – Patent citations Matrix

Sic_2digit	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
20		0.01883	0.01138	0.00163	0.01851	0.00061	0.02721	0.00485	0.43958	0.01335	0.13814	0.00519	0.01349	0.00550	0.03324	0.14215	0.07818	0.03210	0.00190	0.01414
21	0.10660		0.06242	0.00159	0.01837	0.00092	0.16750	0.00403	0.20472	0.01373	0.10007	0.01605	0.00653	0.00470	0.03808	0.08335	0.09415	0.03869	0.00598	0.03252
22	0.00350	0.00485		0.00688	0.01475	0.01281	0.06607	0.00582	0.16892	0.00552	0.33838	0.01654	0.03923	0.00362	0.04788	0.04203	0.13491	0.06414	0.00110	0.02306
23	0.00256	0.00062	0.02675		0.09063	0.03891	0.00351	0.00177	0.01502	0.00203	0.05925	0.00827	0.01788	0.00302	0.06814	0.10829	0.18323	0.29280	0.00085	0.07647
24	0.00784	0.00170	0.01680	0.02408		0.05894	0.01919	0.00392	0.07313	0.00374	0.07702	0.01499	0.00862	0.00207	0.08179	0.23080	0.21896	0.11161	0.00122	0.04358
25	0.00082	0.00034	0.02678	0.01758	0.07144		0.00239	0.00109	0.00808	0.00078	0.05820	0.02341	0.00218	0.00095	0.01565	0.07237	0.07349	0.58090	0.00092	0.04266
26	0.01672	0.03648	0.10443	0.00223	0.02428	0.00242		0.02189	0.22089	0.01004	0.25466	0.00846	0.01939	0.00322	0.04758	0.06518	0.08945	0.02875	0.00104	0.04289
27	0.00038	0.00006	0.00171	0.00013	0.00050	0.00009	0.00262		0.15671	0.00102	0.10298	0.00029	0.01281	0.00125	0.03460	0.08730	0.58069	0.00560	0.00232	0.00895
28	0.02398	0.00237	0.02260	0.00048	0.00991	0.00056	0.02192	0.05774		0.07903	0.31036	0.00295	0.02180	0.01133	0.07476	0.05280	0.25889	0.02927	0.00786	0.01139
29	0.00979	0.00154	0.00458	0.00038	0.00413	0.00015	0.01202	0.00239	0.60448		0.08721	0.00042	0.00750	0.02053	0.05379	0.06898	0.05837	0.06153	0.00072	0.00149
30	0.00698	0.00120	0.04655	0.00160	0.00997	0.00372	0.02296	0.03985	0.31969	0.01192		0.00835	0.03197	0.00778	0.05301	0.08933	0.23146	0.07465	0.01157	0.02743
31	0.00457	0.00264	0.06527	0.00832	0.02760	0.02965	0.00907	0.00318	0.06291	0.00221	0.18622		0.00451	0.00150	0.04403	0.11733	0.15441	0.09822	0.02426	0.15411
32	0.00506	0.00035	0.02395	0.00250	0.00565	0.00070	0.01011	0.03524	0.10677	0.00442	0.18545	0.00147		0.01161	0.09005	0.08396	0.36636	0.04132	0.00592	0.01913
33	0.00258	0.00058	0.00494	0.00154	0.00278	0.00087	0.00502	0.00698	0.16357	0.03462	0.10795	0.00069	0.02643		0.23055	0.11817	0.16525	0.11777	0.00179	0.00794
34	0.00264	0.00132	0.01564	0.00240	0.00942	0.00155	0.00877	0.02266	0.12602	0.00988	0.10118	0.00276	0.02759	0.01720		0.13907	0.41785	0.07577	0.00370	0.01459
35	0.00234	0.00034	0.00189	0.00127	0.00661	0.00146	0.00177	0.01187	0.01642	0.00287	0.02108	0.00187	0.00432	0.00224	0.02997		0.74899	0.09983	0.00435	0.04051
36	0.00095	0.00034	0.00476	0.00163	0.00561	0.00108	0.00203	0.04384	0.06310	0.00195	0.05504	0.00185	0.01678	0.00261	0.07765	0.58466		0.07235	0.00760	0.05616
37	0.00177	0.00052	0.01028	0.01324	0.01073	0.04790	0.00245	0.00304	0.03682	0.00957	0.09512	0.00558	0.00880	0.00872	0.08080	0.30895	0.32329		0.00217	0.03025
38	0.00073	0.00052	0.00155	0.00032	0.00214	0.00082	0.00122	0.01310	0.11056	0.00115	0.14031	0.00938	0.01233	0.00137	0.02680	0.20508	0.41686	0.02148		0.03429
39	0.00145	0.00082	0.00816	0.00820	0.01132	0.00947	0.00709	0.00613	0.02841	0.00048	0.07505	0.01825	0.00587	0.00152	0.01848	0.30777	0.41924	0.06500	0.00731	

(Source: the *Patstat* database)

Each element in the matrix refers to the proportion of citations from one two-digit SIC industry to another. For instance, the first value in the second row is 0.1066, which means that 10.66% of the total number of citations from industry 21 is to industry 20.

Using this matrix for a weighting system on industry relationships, the third measure of knowledge spillovers at an inter-industry level is constructed. Table 5.3 provides the summary statistics of my main variables in this chapter.

Table 5. 3: Summary statistics of main variables in this chapter

Variable	*Obs.*	*Mean*	*Std.Dev.*	*Min*	*Max*
Rd_intensity	31179	0.0645	0.1311	0	1.2958
Growth rate of average Q	23282	-0.0410	0.3658	-1.7775	2
Competition (*PMC*)	30852	0.9096	0.0321	0.6403	0.9675
Cash flow ratio	30859	0.0428	0.2407	-2.8029	0.3605
Growth rate of sales	23669	0.0575	0.3783	-2	2
Intra-ind SPO	31493	17.0870	1.6935	7.9266	18.7919
Unweighted inter-ind SPO	31493	19.6238	0.1893	19.2302	19.9647
Patent-weighted inter-ind SPO	31493	17.7092	0.3623	16.9916	18.4598
Small or medium-sized *(SME)*	31209	0.3549	0.4785	0	1
Low R&D-intensive *(INT)*	31493	0.5858	0.4926	0	1

From Table 5.3, it can be seen that the patent-weighted measure of inter-industry spillovers (inter-ind SPO) has a wider range of values than the unweighted measure.

5.2.3. Estimation issues

The main method of estimation is still the system generalize method of moments (system GMM), in order to cope with the potential endogeneity problem of the growth rate of Tobin's average Q and several other explanatory variables in my models. It is an updated version of the GMM estimator proposed by Arellano and Bover (1995) and Blundell and Bond (1998), which aims at exploiting all available information from both difference and level sets of equations, and therefore is considered to be more efficient than either the difference or level estimator (O'Connor and Rafferty, 2012).

My measures of knowledge spillovers, both intra-industry and inter-industry, are constructed at the two-digit SIC industry-level and therefore are treated as exogenous variables. The 'best' set of instruments is selected based on the results of two tests: the common Hansen test for over-identification and the Arellano-Bond test for serial correlation. The former tests the null hypothesis that the set of instruments is valid, while the latter checks whether there is a serial correlation of the difference in error term and its lags, which causes the invalidity of recent lags as instruments. To be more specific, if this test result confirms that there is a serial correlation at the second order, the second lags cannot be used as instruments for endogenous variables, and researcher must use deeper lags instead (Roodman, 2009).

The most reliable estimates are chosen after several trials. I first use all the possible instruments (from lag 1 for predetermined variables and from lag 2 onwards for endogenous variables). Then, following Roodman (2009), I apply the *collapse* option to reduce the unnecessary duplication of instruments, and the *orthogonal* option to cope with the problem of missing data, as I am using an unbalanced panel. Also, I rely on the difference-in-Hansen test to choose the specific number of instruments for each of my variables. The set of instruments for each estimation will be stated in the note to each table of results. The econometrics package used is Stata 14.

5.3. Empirical results

Table 5.4 provides the Pairwise correlation among my main variables.

Table 5. 4: Pairwise correlation

	1	2	3	4	5	6	7	8
1.R&D intensity	1							
2.Growth rate of Q	0.0501	1						
3.Competition (*PMC)*	-0.2486	-0.0872	1					
4.Cash flow ratio	-0.4057	0.0435	0.1177	1				
5.Growth rate of sales	0.0082	-0.0910	-0.0105	0.0533	1			
6.Intra-ind SPO	0.2275	-0.0069	-0.4725	-0.0687	0.0280	1		
7.Unweighted inter-ind SPO	-0.1751	0.0408	0.4843	0.0507	0.0080	0.5308	1	
8.Patent-weighted inter-ind SPO	-0.1848	0.0152	0.5075	0.0727	0.0020	-0.3842	0.8053	1

Table 5.4 shows that there is a high level of correlation between my variables at industry-level: product-market competition and R&D spillovers. The highest correlation is found for the unweighted and patent-weighted measures of inter-industry spillovers; however, the correlation coefficients between these two measures and the unweighted intra-industry spillovers are noticeably different (0.5308 and -0.3842, respectively). In addition, the correlations between intra- and inter-industry spillovers with R&D intensity seem to be in opposite signs. More specifically, while the correlation

is positive for the former, both measures of inter-industry spillovers document negative correlation coefficients.

Table 5.5 provides empirical results of model (5.1) with the presence of R&D spillovers, both at intra- and inter-industry levels. The first column in Table 5.5 presents results with the unweighted inter-industry spillovers, in which all other industries are treated the same in their relationship with the investigated firm's industry. However, it is argued that a more appropriate approach is to apply a weighting system, as not all other industries have the same technological distance from each other. Hence, column 2 of Table 5.5 replaces the unweighted measure of inter-industry spillovers by the patent-weighted one, where the weight is constructed on the number of patent citations from industry *k* to industry *l* over total citations from industry *k* (backward citations). This patent citation weighting scheme has been widely used in the literature (Verspagen, 1997b; Fung and Chow, 2002).

Both estimations are controlled for country and time-invariant effects.[16]

Table 5. 5: Results of model (5.1) with knowledge spillovers

Model	(1)	(2)
R&D intensity (lag 1)	0.3611***	0.3592***
	(0.0811)	(0.0813)
R&D intensity (lag 2)	0.0408	0.0403
	(0.0357)	(0.0357)
Growth rate of average Q (lag 1)	0.0366***	0.0364***
	(0.0114)	(0.0114)
PMC (lag 1)	1.6333***	1.6249**
	(0.6098)	(0.6692)
PMC-squared (lag 1)	-0.9774***	-0.9774***
	(0.3467)	(0.3789)
Intra-industry spillovers (lag 1)	0.0015	0.0038***
	(0.0010)	(0.0007)
Unweighted inter-industry spillovers (lag 1)	-0.0543***	
	(0.0177)	
Patent-weighted inter-industry spillovers (lag 1)		-0.0143***
		(0.0036)
Cash flow (lag 1)	0.1102**	0.1104**
	(0.0502)	(0.0502)
Growth rate of sales (lag 1)	0.0260*	0.0258*
	(0.0139)	(0.0139)
Country effects	Yes	No
Year effects	Yes	Yes
Number of observations	22407	22407

[16] Because of space limits, only the results of my main method of estimation – system GMM - are presented here. The full OLS and FE estimates can be found in Tables A5.1 and A5.2 in the Appendix.

Number of firms	3615	3615
Number of instruments	52	52
AR(1)	0.000	0.000
AR(2)	0.390	0.391
Hansen test (P-value)	0.830	0.830
Difference-in-Hansen test (level equation)	0.978	0.977

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, I use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, lag 3 onwards of the growth rate of Q and sales and cash flow ratio for the difference equations, the second lagged difference of R&D intensity, and the third lagged differences of the growth rate of Q and sales and cash flow ratio for the level equations.

The findings from Table 5.5 indicate that knowledge spillovers, both at intra- and inter-industry levels, contribute significantly to the augmented Tobin's Q model. However, the relationship seems to be more complicated than what has been assumed in the theoretical literature. The more common notion of the negative impact of knowledge spillovers is, according to my results, only derived from inter-industry spillovers. It is documented by the negative and highly significant estimated coefficients of either the unweighted or patent citations-weighted measure of inter-industry spillovers.

There are several differences in results between column 1 and 2 of Table 5.5. First, the unweighted measure seems to exaggerate the effect of inter-industry spillovers, with its estimated coefficient almost four times higher than the estimated coefficient of the patent-weighted measure (-0.0543 and -0.0143, respectively). Second, it also impacts the effect of intra-industry spillovers, which is insignificant in column 1 but turns out to be significant in the column 2 where the patent citations-weighted measure is used to reflect the inter-industry spillovers effect. Overall, these findings provide support for the claim that not all industries in the economy have the same technological distance from each other, and it is necessary to apply a weighting system to quantify their connections (Wakelin, 2001; Biatour et al., 2011).

On the other hand, interestingly, I find that the effect of intra-industry spillovers is significantly positive in column 2 of Table 5.5. This result is consistent with the finding of Capron and Cincera (2001), where the authors confirm that the firms in their sample react aggressively to an increase in R&D outlays by competitors. It can be attributable to the fact that the knowledge (spillover) pool from major competitors might, in fact, be the source of creative destruction or 'market-stealing' effects rather than the source of knowledge to be emulated. In more detail, the increase in R&D investment of major competitors might raise the threat of creative destruction when the investigated firm's knowledge and technologies become obsolete. In addition, the hope of overtaking existing leaders and stealing their market share might encourage managers to increase their firm's R&D investment. Overall, larger knowledge (spillover) pool from close competitors might, indeed, induce the spillover-recipient firm to engage more in its own R&D investment.

My results are also in line with Bernstein (1988), who estimates the effects of spillovers on the receiving firms operating in seven Canadian industries and concludes that inter-industry spillovers reduce unit costs noticeably more than intra-industry R&D spillovers do.

These findings are truly important, because they address the problem at the heart of the literature on knowledge spillovers, in which there are two distinct types of spillover effects on the firm's research effort. On the one hand, the knowledge (spillover) pool from the R&D investment of other firms plays a role as a source of knowledge to be emulated, and hence it reduces the cost of investment for the spillover-recipient firm, for instance by avoiding any duplicated research. Hence, even though a large knowledge pool might appear to increase the firm's productivity, it might in fact decrease the level of the firm's R&D investment. On the other hand, the knowledge (spillover) pool might be a source of creative destruction and/or 'market-stealing' effects, in which either the spillover-recipient firm's own knowledge and technologies become obsolete, or its desire to overcome the existing leaders and steal their market share might induce its managers to engage in R&D activities, or both. If that is the case, the spillover-recipient firm might actually increase its R&D investment as a response to any increase in the knowledge (spillover) pool from the R&D investment of others. Despite the fact that the presence of knowledge spillovers has been confirmed by a number of studies, there has been little work on such a debate.

In this thesis, by documenting the opposite effects of intra- and inter-industry spillovers, I indicate that the solution to this debate does indeed lie in the consideration of different types of spillovers. The positive relationship between knowledge spillovers and the firm's research effort, as a result of either creative destruction and/or 'market-stealing' effects, is found to be dominated by intra-industry spillovers, the type of knowledge spilled over from direct competitors of the spillover-recipient firm, whereas with regard to the knowledge spilled over from outside the industry of the spillover-recipient firm, the negative externality (emulation) effects seem to outweigh the creative destruction and/or 'market-stealing' effects.

Another important result is that the additional control for knowledge spillovers does not eliminate the role of expectations in explaining firm investment decisions. The estimated coefficient of the one-period-ahead growth rate of Tobin's Q remains positive and highly significant in both estimations with either the weighted or unweighted measure of inter-industry spillovers. In addition, product-market competition also remains in a non-linear relationship with firm R&D investment. The squared term of PMC, my measure of product-market competition, is negative and highly significant at the 1% level. However, the tipping point is found at the very beginning value of the $PMC_{k,t-1}$ measure (the value of $PMC_{k,t-1}$ is 0.8312, and only 0.23% of total observations have a lower value of $PMC_{k,t-1}$ than that); or, in other words, there seems to be more evidence of a negative impact of competition on firm R&D investment in my sample. This, again, is attributable to the fact that my approach considers all 15 OECD countries as a single market, which could reflect a truer but also a higher level of competition for companies. The actual lowest value of the $PMC_{k,t-1}$ measure in my sample is already 0.6403, and therefore it is more in line with the Schumpeterian perspective that competition might negatively impact the firm's research effort if the initial level of competition is already high (Schumpeter, 1942; Peneder, 2012).

With regard to other covariates, the first lag of R&D intensity and the cash flow ratio, together with the growth rate of sales, all have a positive and statistically significant effect on firm R&D investment.

The results of diagnostic checks again indicate the appropriateness of the system GMM estimator. The null hypothesis of a valid set of instruments cannot be rejected in the Hansen test for both estimations (with a P-value of approximately 0.83 for both estimations). The chosen instruments are supported by no serial correlation at the second level of the difference in error term, and the difference-in-Hansen test confirms the usefulness of the instruments for level equations.

5.3.1. *Small and medium-sized versus large firms*

In order to test whether the empirical results vary across firm size, I re-estimate my model with the presence of a dummy variable, SME_i, and its interaction with the growth rate of Tobin's average Q. The latter aims at verifying whether the effect of expected profitability is different with regard to firm size, after the model is controlled for the effect of R&D spillovers. The dummy SME_i receives the value of unity if the firm has fewer than 250 employees (small or medium-sized firm) and 0 otherwise, following the criteria from the European Union classification. The results are presented in Table 5.6.

Table 5. 6: Model with control for firm size

Model	(1)	(2)
R&D intensity (lag 1)	0.4441***	0.4424***
	(0.0710)	(0.0713)
R&D intensity (lag 2)	0.0374	0.0373
	(0.0352)	(0.0352)
Growth rate of Q (lag 1)	0.0238***	0.0236***
	(0.0074)	(0.0074)
SME_i * Growth rate of Q (lag 1)	0.0186**	0.0187**
	(0.0087)	(0.0087)
PMC (lag 1)	0.8517*	0.9375*
	(0.4937)	(0.5198)
PMC-squared (lag 1)	-0.5242*	-0.5724*
	(0.2791)	(0.2936)
Intra-industry spillovers (lag 1)	0.0013	0.0028***
	(0.0009)	(0.0006)
Unweighted inter-industry spillovers (lag 1)	-0.0377***	
	(0.0143)	
Patent-weighted inter-industry spillovers (lag 1)		-0.0114***
		(0.0030)
Cash flow (lag 1)	0.0861*	0.0862**
	(0.0413)	(0.0413)
Growth rate of sales (lag 1)	-0.0022	-0.0023
	(0.0050)	(0.0050)
SME_i	0.0338***	0.0339***
	(0.0062)	(0.0062)
Lincom effect	0.0424***	0.0424***
	(0.0110)	(0.0109)
Country effects	Yes	Yes
Year effects	Yes	Yes
Number of observations	22279	22279
Number of firms	3583	3583
Number of instruments	59	59
AR(1)	0.000	0.000
AR(2)	0.311	0.313
Hansen test (P-value)	0.524	0.520
Difference-in-Hansen test (level equation)	0.949	0.943

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, we use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al (2016). It includes lag 2 onwards of R&D intensity, lag 3 onwards of the growth rate of Q and sales and cash flow ratio for the difference equations, the second lagged difference of R&D intensity, and the third lagged differences of the growth rate of Q and sales and cash flow ratio for the level equations.

Similar to Table 5.5, column 1 of Table 5.6 provides results with the unweighted measure of inter-industry spillovers, while the patent-weighted measure is used in the results of column 2.

From Table 5.6, it can be seen that there are noticeable differences in the results with regard to firm size. First, similar to the results in Chapter 4, the dummy variable SME_i, on its own, is positive and highly significant, which means that small and medium-sized firms seem to be more engaged in R&D investment than larger firms in my data set.

In addition, the interaction term between the dummy SME_i and the growth rate of Tobin's Q is also statistically significant at the 5% level in both estimations. With the same positive sign as the estimated coefficient of the growth rate of Q on its own, this finding supports the notion that small and medium-sized firms are more sensitive to the expectation about future profitability than larger firms. This can be explained by the fact that small and medium-sized firms often do not have sufficient internal finance, hence the expected profitability might influence their investment decisions more than those of larger firms, where the long-term R&D investment is often well prepared and more persistent over time.

Moreover, the estimated coefficients of other covariates are consistent with previous results, except that the effect of the growth rate of sales turns out to be insignificant. Once again, this shows the inconsistent and less significant effect of expected capacity need on firm R&D investment decisions, a special kind of firm investment that often aims at improving the quality of products and therefore is less reliant on whether the capacity need is expected to expand or not.

The results of the diagnostic tests also support the use of the system GMM estimator in dealing with the potential endogeneity issue with regard to the dynamic model of R&D investment.

5.3.2. Low versus high R&D-intensity firms

Next, I control for another firm characteristic: whether the firm is categorized as high or low R&D-intensive. The debate about whether high or low R&D-intensive firms receive stronger effects from knowledge spillovers remains inconclusive. On the one hand, it is reasonable to consider that high-tech, R&D-intensive firms are more likely to exploit knowledge spilled over from externalities, because of their existing 'absorptive capacity' from their own R&D investment (Cohen and Levinthal, 1989; Moen, 2005). Klette (1994) also suggests that technologically advanced firms seem to experience a predominantly positive spillover effect. On the other hand, some researchers argue that because of the high level of R&D spillovers from both inside and outside the industry, the significant reduction in the cost of investment helps firms to lower their research efforts. In other words, there is a negative correlation between the level of R&D intensity and the level of externalities the firm is facing.

Hence, in order to test whether there are differences in my results with regard to the firm's R&D intensity level, I re-use the dummy variable INT_i from Chapter 4. This dummy receives the value of 1 if the firm's R&D intensity is lower than the average R&D intensity of its two-digit SIC industry over the whole period of investigation 2005-2013 (low R&D-intensive firms), and 0 otherwise. In more detail, 2,175 firms are categorized as low R&D-intensive in my sample, whereas 1,543 firms are in the high R&D-intensive category. Similar to the test above for firm size, the interaction terms between the dummy INT_i and the growth rate of Tobin's Q are included in my model. The results of two specifications with unweighted and patent-weighted measures of inter-industry spillovers are in Table 5.7.

Table 5. 7: Model with control for high/low R&D-intensive firms

Model	(1)	(2)
R&D intensity (lag 1)	0.4575***	0.4594***
	(0.0736)	(0.0744)
R&D intensity (lag 2)	0.0480	0.0489
	(0.0353)	(0.0354)
Growth rate of Q (lag 1)	0.0269***	0.0271***
	(0.0075)	(0.0075)
INT_i * Growth rate of Q (lag 1)	-0.0263***	-0.0265***
	(0.0064)	(0.0064)
PMC (lag 1)	1.7938***	1.9325**
	(0.6731)	(0.7024)
PMC-squared (lag 1)	-1.0895***	-1.1633***
	(0.3836)	(0.4006)
Intra-industry spillovers (lag 1)	0.0026***	0.0037***
	(0.0009)	(0.0007)
Unweighted inter-industry spillovers (lag 1)	-0.0300**	
	(0.0136)	
Patent-weighted inter-industry spillovers (lag 1)		-0.0567***
		(0.0087)
Cash flow (lag 1)	0.0141	0.0140
	(0.0342)	(0.0343)
Growth rate of sales (lag 1)	-0.0052	-0.0053
	(0.0036)	(0.0036)
INT_i	-0.0378***	-0.0377***
	(0.0067)	(0.0068)
Lincom effect	0.0006	0.0006
	(0.0051)	(0.0051)

Country effects	Yes	Yes
Year effects	Yes	Yes
Number of observations	22407	22407
Number of firms	3615	3615
Number of instruments	59	59
AR(1)	0.000	0.000
AR(2)	0.428	0.433
Hansen test (P-value)	0.255	0.238
Difference-in-Hansen test (level equation)	0.594	0.642

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, we use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al (2016). It includes lag 2 onwards of R&D intensity, lag 3 onwards of the growth rate of Q and sales and cash flow ratio for the difference equations, the second lagged difference of R&D intensity, and the third lagged differences of the growth rate of Q and sales and cash flow ratio for the level equations.

Table 5.7 documents several differences in the results for high and low R&D-intensive firms. Besides the obvious result of the negative and highly significant INT_i on its own, what is more important is the opposite estimated coefficients of Tobin's average Q on its own and its interaction term with the dummy variable INT_i. With approximately the same magnitude, these two coefficients indicate that the effect of expected profitability (the traction in Tobin's average Q) on R&D investment seems to be neutral with regard to low R&D-intensive firms. In other words, only high R&D-intensive firms are sensitive to the expectation about future profitability.

Furthermore, another difference in the results in Table 5.7 is for the effect of the lagged cash flow ratio. It turns out to be insignificant after the model is controlled for whether the firm is categorized as high or low R&D-intensive.

The results of the diagnostic tests again indicate the appropriateness of my system GMM estimator, with strong rejections of the over-identification problem and the second serial correlation of the difference in error term. In addition, the difference-in-Hansen test confirms that the additional instruments for level equation are valid, which means that the system GMM is superior to the difference GMM estimator.

5.4. Sensitivity check

Table 5.8 presents my results from the model with R&D spillovers, however using *HHI* index as another measure of product-market competition. The *HHI* measure is calculated as the sum of the squared market shares of all firms at the two-digit SIC industry-level. Fundamentally, the *HHI* index measures the level of market concentration, and therefore I expect its relationship with R&D investment to be opposite to the effect of the $PMC_{k,t-1}$ measure. In other words, a U-shape relationship is expected from the results in Table 5.8.

Table 5. 8: Results with HHI measure of product-market competition

Model	(1)	(2)
R&D intensity (lag 1)	0.4033***	0.3996***
	(0.0781)	(0.0787)
R&D intensity (lag 2)	0.0502	0.0493
	(0.0346)	(0.0346)
Growth rate of average Q (lag 1)	0.0313***	0.0311***
	(0.0079)	(0.0079)
HHI (lag 1)	-0.0527**	-0.0221
	(0.0266)	(0.0256)
HHI-squared (lag 1)	0.1069**	0.0778*
	(0.0460)	(0.0440)
Intra-industry spillovers (lag 1)	0.0012	0.0045***
	(0.0010)	(0.0009)
Unweighted inter-industry spillovers (lag 1)	-0.0638***	
	(0.0180)	
Patent-weighted inter-industry spillovers (lag 1)		-0.0161***
		(0.0038)
Cash flow (lag 1)	0.1107**	0.1111**
	(0.0451)	(0.0452)
Growth rate of sales (lag 1)	0.0204	0.0203
	(0.0128)	(0.0127)
Country effects	Yes	Yes
Year effects	Yes	Yes
Number of observations	22809	22809
Number of firms	3621	3621
Number of instruments	52	52
AR(1)	0.000	0.000
AR(2)	0.483	0.481
Hansen test (P-value)	0.882	0.882
Difference-in-Hansen test (level equation)	0.921	0.917

Note: standard errors are in parentheses. ***, ** and * indicate the level of significant at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, we use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al (2016). It includes lag 2 onwards of R&D intensity, lag 3 onwards of the growth rate of Q and sales and cash flow ratio for the difference equations, the second lagged difference of R&D intensity, and the third lagged differences of the growth rate of Q and sales and cash flow ratio for the level equations. (1) is with the unweighted measure of inter-industry spillovers, while (2) is with the patent-weighted one.

Table 5.8 shows no difference in my results with regard to the *HHI* as a measure of market concentration. First, the estimated coefficient of the growth rate of Tobin's average Q, my measure of expectation about future profitability, is positive and highly significant at the 1% level in both estimations. Second, the other covariates retain their consistent impact in the model. While the first lag of R&D intensity and cash flow ratio have a positive effect, the second lag of R&D intensity and the growth rate of sales document no significant influence on the contemporaneous value of firm R&D investment. Besides, the opposite relations of intra- and inter-industry spillovers to the firm's incentives for R&D investment are confirmed.

With regard to the *HHI* index, a measure of market concentration, the results in Table 5.8 confirm that it has a non-linear relationship with firm R&D investment by documenting the statistically significant effect of the squared term of the *HHI* index at the 10% level. As expected, the concentration-R&D investment relationship follows a U-shape, as the level of concentration is often opposite to the level of market competition.

5.5. Conclusions

This chapter has studied the effect of R&D spillovers in the augmented Tobin's Q model of firm R&D investment. The level of externalities has recently been linked to the optimal level of R&D investment at firm-level (Nieto and Quevedo, 2005; Bloom et al., 2013), due mainly to its influence as the source of knowledge externalities that spillover-recipient firms might be able to emulate, hence lowering their R&D investment budget. On the other hand, some researchers argue that R&D spillovers induce more incentives for overinvestment, since not only might the higher spillover pool from close competitors (other firms in the same industry) increase the threat of creative destruction, but also the spillover-recipient firm might engage more in investment with the hope of overcoming the incumbent leaders by its successful investments, the so-called 'market-stealing' effect. With the increasing level of applied technologies and knowledge spillovers nowadays, ignoring its effect could be a problem for any model of firm investment in general or investment in R&D activities in particular.

To address this issue, I test the effect of both intra- and inter-industry spillovers in the augmented Tobin's Q model. The former specifies the level of knowledge spillovers inside the industry, or, in other words, from the firm's direct competitors. Since these firms share the same line of products, their technologies are strongly related and highly relevant to each other. The latter reflects the effect of knowledge spilled over from outside the industry. Empirically, I apply three measures of knowledge spillovers: unweighted intra- and inter-industry spillovers and the patent-weighted inter-industry spillovers based on the data on patent citations from the *Patstat* database.

Using the same data set of 3,718 manufacturing firms from 15 OECD countries over the 2005-2013 period, the chapter reports some valuable findings. First, it re-affirms that the one-period-ahead growth rate of Tobin's average Q, my proposed measure of expected profitability that shapes expectations formation, has a positive and significant effect on firm R&D investment. However, similar to Chapter 4, my results show that other factors can contribute significantly to the augmented Tobin's Q model. In this case, the consideration of both intra- and inter-industry spillovers in the R&D investment model illustrates a more complicated relation between knowledge spillovers and firm R&D investment than is commonly expected. On the one hand, the intra-industry spillover pool of R&D investment is associated with a positive effect on the firm's R&D investment intensity. This is because the creative destruction and/or market-stealing effects of the intra-industry R&D pool outweigh the positive externality (emulation) effects. On the other hand, the bigger inter-industry pool of R&D investment is associated with a negative effect on the firm's R&D investment intensity. This is because the positive externality (emulation) effects outweigh the creative destruction and/or market-stealing effects with regard to the knowledge (spillover) pool from other industries. This is a novel finding that not only contributes to the debate on the extent to which knowledge spillovers exist, but also indicates that the effect of spillovers on the incentive of the firm to invest in R&D activities depends on the specific type of spillovers.

Moreover, other results remain consistent with regard to the new control for R&D spillovers in the model. The competition-R&D investment relationship remains non-linear and follows the proposed inverted-U shape from Aghion et al. (2005). The dynamic model is confirmed to be suitable by the positive and highly significant effect of lagged R&D intensity. Furthermore, while the growth rate of sales, my measure of expected capacity need, has an insignificant effect, the lagged cash flow ratio keeps proving that it is a more relevant measure of the role of internal finance, with its positive and statistically significant effect being documented across different specifications.

The heterogeneity checks for the relationship between the one-period-ahead growth rate of Tobin's average Q and R&D investment confirm that it is stronger when firms are small or medium-sized, but weaker when firms' R&D intensity is lower than the average R&D intensity in their two-digit industries. This is consistent with the findings from Chapter 4.

CHAPTER 6: THE ROLE OF GOVERNANCE QUALITY IN THE AUGMENTED TOBIN'S Q MODEL OF FIRM R&D INVESTMENT

6.1. Introduction

Similar to product-market competition, corporate governance quality possibly affects the managerial incentives for firm R&D investment. The intuition derives from 'agency theory', in which any existing conflict between managers and stockholders might influence the managers' decision-making process at firm-level (Jensen and Meckling, 1976). In more detail, stockholders are more likely to engage in R&D investment because of their anticipation about its positive effect on performance, and they can also reduce its inherent risk by keeping diversified investment portfolios. On the other hand, managers might be reluctant to invest in long-term R&D projects because innovative projects have a high level of uncertainty and often do not yield short-term returns (Baysinger et al., 1991). The significant relationship between corporate governance quality and firm R&D investment is confirmed by several studies (Hill and Snell, 1988; Mahoney et al., 1997; Bushee, 1998).

With regard to my augmented Tobin's Q model, the failure to control for the effect of corporate governance quality is highly likely to boil down to model mis-specification and omitted variable bias. Therefore, in this chapter, I continue my set of nested empirical models with the additional control for corporate governance quality. Again, the first purpose is to test whether the expectations, especially about future profitability (reflected by the one-period-ahead growth rate of Tobin's average Q), retains its positive and significant effect on firm R&D investment. The second aim is to verify whether corporate governance quality should be controlled for in the augmented Tobin's Q model, together with product-market competition and knowledge spillovers, in order to explain better the investment decision-making process at firm-level.

The main issue of this chapter concerns corporate governance data. A number of studies have confirmed that corporate governance quality at firm-level affects the firm's investment decisions (see Belloc, 2012 for a survey). However, most of them rely on US firm-level data, and there seems to be no available corporate governance database at firm-level that allows for multi-nation comparisons.[17]

[17] As far as I know, only the *ASSET4 ESG* database, an affiliate of Thomson Reuter, provides this kind of governance data. However, the sample that can be collected and merged with my financial data shows clearly its poor quality and strong bias towards large firms (722 over 741 firms are categorized as large firms in this sample). Hence, I do not use it here, but hope to explore the effect of governance quality at firm-level in a further study.

However, there is scope for using country-level governance indicators to indirectly reflect the effect of corporate governance quality on the firm's strategic decisions. This is due to the fact that several studies have suggested that firm-level corporate governance quality can be reflected partly by country-level governance indicators. For instance, Doidge et al. (2007) find that country fixed effects explain approximately 70% of the variation in firm-level corporate governance ratings. Similarly, Griffin et al. (2017) claim that firm-level corporate governance practices vary primarily at the country level. Moreover, Seifert and Gonenc (2012) confirm that the level of creditor rights at country-level discourages firms' research efforts. Hence, in this chapter, following this idea, I apply several governance indicators at country-level to examine whether governance quality can be another additional factor in my augmented Tobin's Q model of firm R&D investment, and whether the effects of the existing covariates change with this new control.

Using the system-GMM estimator on the data set of 3,718 manufacturing firms from 15 OECD countries over the 2005-2013 period, my empirical results confirm the importance of controlling for country-level governance characteristics in my model. Both the different legal origin systems and the other two governance indicators, the creditor rights and rule of law indexes, have significant effects in the augmented Tobin's Q model. In more detail, while there is a clear difference in the average level of R&D intensity between firms located in English-common law origin countries and others, the significant effect of the one-period-ahead growth rate of Tobin's average Q, my measure of expected profitability that shapes expectations formation, on firm R&D investment does not vary across different legal origin systems. Besides, while a stronger level of creditor rights in a country's governance system leads to a lower level of firm R&D intensity inside that country, the higher legal enforcement tends to encourage managers to invest more in R&D investment. Overall, all three measures of country-level governance quality contribute significantly to the augmented Tobin's Q model.

With regard to the existing covariates, the new control of corporate governance does not eliminate the important role of expected profitability, as the one-period-ahead growth rate of Tobin's average Q retains its positive and significant effect on firm R&D investment in all estimations. Similarly, both product-market competition and knowledge spillovers keep their significant contributions of explanatory power to the model. While there is an inverted-U shape for the effect of competition, the effect of positive intra-industry spillovers and negative inter-industry spillovers are also maintained. Overall, my results strongly support the possibility of an augmented Tobin's Q model, in which several different but not mutually exclusive theories can be considered together in explaining R&D investment decisions at firm-level.

The rest of the chapter is structured as follows. Section 6.2 presents my empirical approach for the new control of corporate governance quality, including the model specifications, data and methods of estimation. Section 6.3 provides empirical results, followed by section 6.4 containing several robustness tests. Finally, section 6.5 concludes the chapter.

6.2. Model specifications, data and methods of estimation

This section presents my empirical approach to the augmented Tobin's Q model of firm R&D investment with the new control of country-level governance quality, including model specifications and the characteristics of my rich data set of 3,718 companies from 15 developed countries. It also specifies the potential econometric issues and how they are dealt with by suitable methods of estimation.

6.2.1. Model specifications

The first aspect of corporate governance I consider here is about the different legal origin systems. For several decades, the questions of why firms in the US or UK have enormous equity markets in comparison with firms in Russia, or why Germany and Japan have such easily accessed banking systems, have been of interest for economists. La Porta et al. (1997, 1998) trace these issues to the core differences in legal origin systems. While the English common law is made by judges and subsequently incorporated into legislation, the German, French and Scandinavian civil law is part of the scholar and legislator-made civil law tradition, which dates back to Roman law (David and Brierley, 1985).

Hence, to address the influence of these different legal origin systems in my model, I create a dummy variable LOS_i, which equals 1 if the firm is located in a country with an English-common law origin (there are 4 countries in this category: Australia, Canada, the UK and the US) and 0 otherwise (the other 11 countries in the sample). Also, in order to test the variation in the effect of expected profitability on firm investment decisions across countries with different legal origins, I add the interaction term between the dummy LOS_i and the growth rate of Tobin's Q to my model:

$$R\&D_{i,t} = \alpha_i^9 + \beta_1^9 R\&D_{i,t-1} + \beta_2^9 R\&D_{i,t-2} + \beta_3^9 \Delta Q_{i,t-1} + \beta_4^9 \Delta S_{i,t-1}$$

$$+\beta_5^9 CF_{i,t-1} + \beta_6^9 PMC_{k,t-1} + \beta_7^9 PMC_{k,t-1}^2$$

$$+\beta_8^9 S_{intra,t-1} + \beta_9^9 S_{inter,t-1}$$

$$+\beta_{10}^9 LOS_i * \Delta Q_{i,t-1} + \beta_{11}^9 LOS_i + \varepsilon_{i,t}^9 \qquad (6.1)$$

Where:

RD_{it}:	R&D expenditure at year *t* over total assets at year *t*-1
$\Delta Q_{i,t-1}$:	growth rate of Tobin's average Q
$CF_{i,t-1}$:	level of cash flow ratio at the end of year *t*-1
$\Delta S_{i,t-1}$:	growth rate of sales
$PMC_{k,t-1}$:	level of product-market competition of industry *k* at the end of year *t*-1
$S_{intra,t-1}$:	measures of intra-industry spillovers at period *t*-1
$S_{inter,t-1}$:	measures of inter-industry spillovers at period *t*-1
LOS_i:	dummy variable for legal origin
$\varepsilon_{i,t}^9$:	the composite error term as defined in equation (3.12b).

Equation (6.1) is a dynamic version of the R&D investment model at firm level, in which the first two lags of R&D intensity are controlled for the past investment effect on contemporaneous value.[18] Two other covariates are the growth rate of Tobin's Q and sales, my measures of expectations about future profitability and capacity need, following the accelerator model from Mairesse and Siu (1984). Model (6.1) is also controlled for internal finance through the lagged cash flow ratio, and other

[18] Following the results of the Autoregressive Distributed Lags model (ARDL), presented in Table A4.1 in the Appendix.

additional factors that have proved to contribute significantly to the augmented Tobin's Q model in the last two empirical chapters: product-market competition and the level of R&D spillovers.

Equation (6.1) also contains the set of time dummies. Since both R&D spillovers and product-market competition are measured at industry-level and the dummy LOS_i is at country-level, I do not control for further industry and country fixed effects.

For the new control of legal origins, what to pay attention to is the coefficient β_{10}^{9} of the interaction term between the dummy variable LOS_i and the growth rate of Tobin's average Q. Its estimated coefficient illustrates whether the different legal origins change the slope of the relationship between R&D investment and the traction in Tobin's Q as my measure of expected profitability that shapes expectations formation. The common belief states that more developed stock markets in countries with an English-common law origin might have a stronger influence on the firm's investment strategy, due to its greater access to external finance to exploit investment opportunities. If this hypothesis is true, the estimated coefficient $\sigma_{1,10}$ is expected to be positive and significant.

In addition, prior studies have shown that other country-level governance indicators, including creditor rights, shareholder rights and the legal environment, might also influence the firm's investment decisions. For instance, Hillier et al. (2011) confirm that several country-level governance indicators have a strong effect on R&D investment-cash flow sensitivity at firm-level. Similarly, Munari et al. (2010) and Tylecote and Ramirez (2006) also indicate that a different country-level governance quality might affect firms' research efforts.

In this thesis, I apply two other measures of corporate governance at country-level: the creditor rights and rule of law indexes. There are two main reasons for my use of the creditor rights index instead of the common shareholder rights index in the literature. First, it is due to the high correlation between the dummy LOS_i for legal origins and the shareholder rights index.[19] Second, Brockman and Unlu (2009) suggest that cross-country variations in creditor rights have even more explanatory power than cross-country variations in shareholder rights with regard to the firm's strategy, although regarding dividend payments. Hence, this creditor rights index, taken from Brockman and Unlu (2009), is the first measure that will be added in model (6.2).

[19] The shareholder rights index is taken from Spamann (2010). The high correlation coefficient (-0.8025) between the dummy Los_i and this index is in line with previous findings (La Porta et al., 1997, 1998).

The second measure is the rule of law index taken from John et al. (2008). This index assesses the law and order tradition in a country on a scale from 1 to 10; the lower the index, the less a tradition there is of law and order in that country.

$$
\begin{aligned}
R\&D_{i,t} = \alpha_i^{9.1} &+ \beta_1^{9.1} R\&D_{i,t-1} + \beta_2^{9.1} R\&D_{i,t-2} + \beta_3^{9.1} \Delta Q_{i,t-1} + \beta_4^{9.1} \Delta S_{i,t-1} \\
&+ \beta_5^{9.1} CF_{i,t-1} + \beta_6^{9.1} PMC_{k,t-1} + \beta_7^{9.1} PMC_{k,t-1}^2 \\
&+ \beta_8^{9.1} S_{intra,t-1} + \beta_9^{9.1} S_{inter,t-1} \\
&+ \beta_{10}^{9.1} LOS_i + \beta_{11}^{9.1} CR_i + \beta_{12}^{9.1} RL_i + \varepsilon_{i,t}^{9.1} \qquad (6.2)
\end{aligned}
$$

Where:

CR_i: the creditor rights index

RL_i: the rule of law index.

In (6.2), together with the different legal origin systems, two indexes CR_i and RL_i reflect more the effects of country-level governance quality on firm investment decisions. Since the stronger the level of creditor rights in a country's governance system, the less power the managers have in taking long-term risks, I expect the estimated coefficient $\beta_{11}^{9.1}$ to be negative. However, the opposite sign should be expected for the estimate of coefficient $\beta_{12}^{9.1}$ of the rule of law index, since the important part of legal enforcement is about intellectual property rights that strengthen the firm's profitability for any new invention. Hence, a stronger rule of law index should induce more R&D investment at firm-level.

Again, I test the sensitivity of my results regarding to the different sources of firm heterogeneity. The two dummies SME_i and INT_i are used to reflect the differences in firm size and the level of firm R&D intensity. In order to test the robustness of the growth rate of Tobin's average Q, my measure of expected profitability, I also add into the models its interaction with the dummy.

6.2.2. Measure of corporate governance quality

The first governance indicator is the different legal origin systems. The idea dates back to the seminal La Porta et al. (1997, 1998), where the authors show that laws vary a lot across countries due to differences in legal origins. There are four main legal origins: English-common, French-, German- and Scandinavian-civil law. The latter three originally developed from Roman civil law, while the former includes the common law of England and the colonies to which it spread, including Australia, Canada and the US.

The other two measures of corporate governance at country-level are the creditor rights and rule of law indexes. The former is obtained from Djankov et al. (2007, 2008), two studies that revise and update the indicators from La Porta et al. (1998). More specifically, Djankov et al. (2007) state that: "the creditor rights index measures four powers of secured lenders in bankruptcy: (1) whether there are restrictions, such as creditor consent, when a debtor files for reorganisation; (2) whether secured creditors are able to seize their collateral after the petition for reorganisation is approved, that is, whether there is no automatic stay or asset freeze imposed by the court; (3) whether secured creditors are paid first out of the proceeds of liquidating a bankrupt firm; and (4) whether an administrator, and not management, is responsible for running the business during the reorganisation" (p.302). The higher the creditor rights index, the more secure lenders are in lending their money to firms.

The second governance indicator is the rule of law index taken from John et al. (2008). It reflects the assessment of the law and order tradition of the country. Its scale is from 0 to 10, with the lower the index, the less tradition of law and order in each country.

6.2.3. Estimation issues

Similar to the two previous empirical chapters, my main method of estimation is the system generalised method of moments (system GMM) estimator, in order to deal with the potential endogeneity problem in a dynamic investment model. It is a developed version of the original GMM estimator through two main studies of Arellano and Bover (1995) and Blundell and Bond (1998), with the improvement of a joint estimation in both differences and levels. The main advantage of system GMM estimation is that all variables including lagged and differenced variables are potentially valid instruments as long as they are not correlated with the contemporaneous error term (Greene, 2008).

With regard to the new control for country-level governance quality, I treat all governance indicators as exogenous variables, since they are unlikely to be affected by the firm-specific error terms. The reliability of system GMM estimates depend on the results of several tests, including the Hansen test for over-identification, the Arellano-Bond test for serial correlation at a higher level of the difference in error term, and the difference-in-Hansen test on the instruments used in the level equations that indicates whether system GMM is superior to difference GMM. The best set of instruments is chosen after several trials. I first use all the possible instruments (from lag 1 for predetermined variables and from lag 2 onwards for endogenous variables). Then, following Roodman (2009), I cope with the problem of too many instruments by using the *collapse* option to reduce the duplication of instruments and the *orthogonal* option to cope with the problem of missing data, as I am using an unbalanced panel. The number of instruments for each covariate then is then decided to satisfy its specific difference-in-Hansen test. The chosen set of instruments for each estimation will be stated in the note to each table of results.

In order to compare the results, I also present the estimates obtained by using the OLS and FE estimators. The econometrics package used is Stata 14.

6.3. Empirical results

Table 6.1 provides empirical results of my augmented Tobin's Q model with the new control for different legal origin systems. After confirming in previous chapters that product-market competition and R&D spillovers have strong effects on firm R&D investment, I keep these two factors in the model. However, since the patent citations-weighted measure of inter-industry spillovers proves to reflect better the relationship between industries, I provide only results with this measure here.[20] The first column of Table 6.1 reports OLS estimates, while results from the FE and system GMM estimators are presented in the second and third columns, respectively.

[20] The results for the unweighted measure of inter-industry spillovers are available from the author upon request.

Table 6. 1: Results of model (6.1) with control for legal origin

Model	(1)	(2)	(3)
R&D intensity (lag 1)	0.6830***	0.2648***	0.4190***
	(0.0325)	(0.0412)	(0.0724)
R&D intensity (lag 2)	0.1812***	-0.0159	0.0412
	(0.0282)	(0.0323)	(0.0345)
Growth rate of average Q (lag 1)	0.0083***	0.0065***	0.0245***
	(0.0013)	(0.0015)	(0.0088)
LOS_i * Growth rate of average Q (lag 1)	0.0214***	0.0170***	0.0088
	(0.0031)	(0.0032)	(0.0090)
PMC (lag 1)	0.6284***	0.3738	1.7957***
	(0.1785)	(0.6492)	(0.6112)
PMC-squared (lag 1)	-0.3664***	-0.1990	-1.0679***
	(0.1025)	(0.3473)	(0.3477)
Intra-industry spillovers (lag 1)	0.0012***	-0.0011	0.0036***
	(0.0002)	(0.0032)	(0.0007)
Patent-weighted inter-industry spillovers (lag 1)	-0.0011	0.0318*	-0.0112***
	(0.0009)	(0.0142)	(0.0030)
Cash flow (lag 1)	-0.0388***	-0.0690***	0.0795**
	(0.0068)	(0.0125)	(0.0390)
Growth rate of sales (lag 1)	-0.0097***	-0.0038	0.0009
	(0.0027)	(0.0026)	(0.0051)
LOS_i	0.0073***		0.0344***
	(0.0008)		(0.0056)
Lincom effect			0.0332***
			(0.0087)
Country effects	No	No	No
Year effects	Yes	Yes	Yes
Number of observations	22407	22407	22407
Number of firms	3615	3615	3615
Number of instruments			45
AR(1)			0.000
AR(2)			0.394
Hansen test (P-value)			0.673
Difference-in-Hansen test (level equation)			0.960

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, I use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, lag 3 onwards of the growth rate of Q and sales and cash flow ratio for the difference equations, the second lagged difference of R&D intensity, and the third lagged differences of the growth rate of Q and sales and cash flow ratio for the level equations. The *lincom* effect is calculated from the estimated coefficients of the growth rate of Tobin's Q on itself and its interaction term with other variable.

Table 6.1 indicates the consistency of my previous results after different legal origin systems between countries are controlled for.

Concerning the new control of legal origins, my results indicate that there is a noticeable difference in average R&D intensity between firms in countries with English-common law and firms in countries with Roman-civil law origins. It is shown by the positive and significant estimated coefficient of the dummy variable LOS_i, which means that on average firms in countries with an English-common law origin seem to be more engaged in R&D activities than firms in Roman-civil law countries. On the other hand, the insignificant estimated coefficient of the interaction term between LOS_i and the growth rate of Q shows that the effect of expected profitability on firm R&D investment does not vary across countries with different legal origins. In other words, even though countries with an English-common law origin (the UK, the US, Canada, Australia) are often considered to have more developed stock markets, there seems to be no difference in the effect of stock market movements as the revision of expected profitability on firm R&D investment in these countries compared to the others.

Once again, system GMM proves to be superior to both OLS and FE estimators in controlling for the endogeneity issue in a dynamic panel model. The estimated coefficient of the interaction term between LOS_i and the growth rate of Tobin's Q turns to be insignificant after it is instrumented, due to the fact that one of its components, the growth rate of Q, is not completely exogenous. The reliability of GMM estimates is also supported by the diagnostic test' results. First, the null hypothesis of a valid set of instruments cannot be rejected in the Hansen test of over-identification. Second, the Arellano-Bond test confirms that there is serial correlation at the first order of the difference in error term, which is acceptable. However, what is more important is that there is no higher order of serial correlation, which means that there is no adjustment required for using deeper lags as instruments. Third, the P-value of 0.960 shows that the specific set of instruments for the level equations is valid, and therefore that system GMM is superior to the difference GMM estimator. Overall, system GMM is proven suitable to cope with the potential endogeneity issue in my model.

The model, then, is augmented with two other governance indicators at country-level: the creditor rights and rule of law indexes. The results are presented in Table 6.2.

Table 6. 2: Results of model (6.2) with more control for governance indicators

Model	(1)	(2)	(3)
R&D intensity (lag 1)	0.6835***	0.2650***	0.3617***
	(0.0327)	(0.0414)	(0.0809)
R&D intensity (lag 2)	0.1785***	-0.0181	0.0414
	(0.0282)	(0.0325)	(0.0356)
Growth rate of average Q (lag 1)	0.0200***	0.0157***	0.0362***
	(0.0019)	(0.0019)	(0.0114)
PMC (lag 1)	0.6506***	0.4483	1.7091***
	(0.1785)	(0.6502)	(0.6548)
PMC-squared (lag 1)	-0.3791***	-0.2448	-1.0239***
	(0.1026)	(0.3478)	(0.3715)
Intra-industry spillovers (lag 1)	0.0012***	-0.0008	0.0039***
	(0.0002)	(0.0033)	(0.0007)
Patent-weighted inter-industry spillovers (lag 1)	-0.0014	0.0305**	-0.0149***
	(0.0009)	(0.0142)	(0.0036)
Cash flow (lag 1)	-0.0395***	-0.0705***	0.1107**
	(0.0068)	(0.0125)	(0.0502)
Growth rate of sales (lag 1)	-0.0089***	-0.0031	0.0257*
	(0.0027)	(0.0026)	(0.0139)
LOS_i	0.0053***		0.0324***
	(0.0007)		(0.0058)
CR_i	-0.0009*		-0.0050***
	(0.0005)		(0.0016)
RL_i	0.0007*		0.0035***
	(0.0003)		(0.0010)
Country effects	No	No	No
Year effects	Yes	Yes	Yes
Number of observations	22407	22407	22407
Number of firms	3615	3615	3615
Number of instruments			41
AR(1)			0.000
AR(2)			0.399
Hansen test (P-value)			0.815
Difference-in-Hansen test (level equation)			0.950

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, I use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, lag 3 onwards of the growth rate of Q and sales and cash flow ratio for the difference equations, the second lagged difference of R&D intensity, and the third lagged differences of the growth rate of Q and sales and cash flow ratio for the level equations.

The results in table 6.2 provides further support for our augmented Tobin’s Q model of firm R&D investment. First, the expected profitability, reflected by the one-period-ahead growth rate of Tobin’s average Q, retains its positive and significant effect on firm R&D investment. In terms of magnitude (for system GMM estimation in column 3 of Table 6.2), 1% increase (decrease) in the one-period-ahead growth rate of average Q leads to an approximately 2.45% increase (decrease) in the level of the firm's R&D intensity. Besides, while the first lag of R&D intensity and cash flow positively affects contemporaneous value, the second lag of R&D intensity and the growth rate of sales do not contribute significantly to explain firm investment decisions. With regard to the additional covariates, while product-market competition confirms its non-linear relationship (following an inverted-U shape) with innovative effort at firm-level, the effects of positive intra-industry spillovers and negative inter-industry spillovers are also documented.,

Table 6.2 also confirms the necessity of controlling for further corporate governance quality at country-level. However, even though both the creditor rights and rule of law indexes have a statistically significant effect on R&D investment at firm-level, their influences are in opposite directions. On the one hand, the creditor rights index has a negative and statistically significant effect on firm R&D investment. It is in line with the finding from Seifert and Gonenc (2012), the first paper that examines the linkage between country-level creditor rights and firm R&D intensity. Their results show that managers in countries with strong creditor rights might have more incentives to avoid cash flow risk and therefore reduce their incentives for R&D investment more than managers of firms located in countries with weaker creditor rights.

On the other hand, the higher the rule of law index, the higher the R&D intensity that can be found for my sample. This positive relationship might be attributable to the fact that legal enforcement concerns mainly intellectual property rights, which support innovators in protecting their inventions. Hence, the stronger level of legal enforcement might indeed induce managers to increase their investment plans. The same positive relationship between the quality of the judicial system and R&D intensity, although at an industry-level, can be found in the recent paper by Seitz and Watzinger (2017). Additionally, research shows that stronger intellectual property rights lead to more R&D intensity (Lin et al., 2010, Chen, 2017).

However, in terms of magnitude, the estimated coefficient of rule of law is much lower than the coefficient of creditor rights (0.0035 and 0.0050, respectively). This means that the protection of creditor rights seems to be more important to firm investment decisions than the level of legal enforcement in the country.

Again, the results of all diagnostic tests confirm the appropriateness of system GMM as my main method of estimation, with no higher serial correlation in the difference of error terms, no over-identification problem and a valid set of instruments for level equation (which means that system GMM is preferable to the difference GMM estimator).

6.3.1. Heterogeneity check

Table 6.3 provides the results of my heterogeneity tests, first with firm size in column 1, and second with the level of firm R&D intensity in column 2.[21]

Table 6. 3: Results of heterogeneity check

Model	(1)	(2)
R&D intensity (lag 1)	0.4458***	0.4582***
	(0.0709)	(0.0740)
R&D intensity (lag 2)	0.0386	0.0499
	(0.0352)	(0.0354)
Growth rate of average Q (lag 1)	0.0238***	0.0273***
	(0.0074)	(0.0075)
SME_i* Growth rate of average Q (lag 1)	0.0186**	
	(0.0087)	
INT_i* Growth rate of average Q (lag 1)		-0.0263***
		(0.0064)
PMC (lag 1)	0.9360*	1.9589***
	(0.5113)	(0.6982)
PMC-squared (lag 1)	-0.5709**	-1.1789***
	(0.2890)	(0.3984)
Intra-industry spillovers (lag 1)	0.0029***	0.0038***
	(0.0006)	(0.0007)
Patent-weighted inter-industry spillovers (lag 1)	-0.0115***	-0.0108***
	(0.0030)	(0.0030)
Cash flow (lag 1)	0.0877**	0.0188
	(0.0411)	(0.0336)
Growth rate of sales (lag 1)	-0.0024	-0.0054
	(0.0049)	(0.0036)
LOS_i	0.0180***	0.0153***
	(0.0034)	(0.0035)
CR_i	-0.0041***	-0.0027**
	(0.0013)	(0.0012)
RL_i	0.0086***	0.0010
	(0.0016)	(0.0007)
SME_i	0.0343***	
	(0.0062)	
INT_i		-0.0380***

[21] Because of space limits, I present only system GMM results here. The full OLS and FE estimates are in table A6.1 and A6.2 in the Appendix.

		(0.0068)
Lincom effect	0.0424***	0.0010
	(0.0109)	(0.0051)
Country effects	No	No
Year effects	Yes	Yes
Number of observations	22279	22407
Number of firms	3583	3615
Number of instruments	48	48
AR(1)	0.000	0.000
AR(2)	0.318	0.439
Hansen test (P-value)	0.473	0.233
Difference-in-Hansen test (level equation)	0.877	0.609

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, I use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, lag 3 onwards of the growth rate of Q and sales and cash flow ratio for the difference equations, the second lagged difference of R&D intensity, and the third lagged differences of the growth rate of Q and sales and cash flow ratio for the level equations. The *lincom* effect is calculated from the estimated coefficients of the growth rate of Tobin's Q on itself and its interaction term with other variable. (1) is with the control for small or large firms, (2) is with the control for high/low R&D-intensive firms.

Table 6.3 indicates that my findings are sensitive with regard to the different firm characteristics. This is documented mainly by the significant estimated coefficients of both the dummy SME_i or INT_i on itself and the interaction terms between each and the growth rate of Tobin's average Q in these two estimations.

More specifically, in column 1 of Table 6.3, where the model is controlled for firm size, the estimated coefficient of the interaction term is positive and statistically significant at the 5% level. This means that the effect of the growth rate of Tobin's average Q, my measure of expected profitability that shapes expectations formation, is stronger on small or medium-sized firms than on larger firms. On the other hand, the estimated coefficient of the interaction term in column 2 is negative and also highly significant, which means that the growth rate of Tobin's Q is weaker for low R&D-intensive firms. In fact, with an almost similar magnitude to the estimated coefficient of the growth rate of Tobin's Q on its own, the results in column 2 show that there seems to be no effect from the expectation about future profitability on firm R&D investment decisions if the firm is categorized as low R&D-intensive.

The results of several diagnostic tests confirm the reliability of my system GMM estimates. There is no second-order serial correlation between the difference of error terms, no over-identification problem and system GMM is proven to be better than difference GMM with the valid subset of instruments for level equation by the difference-in-Hansen test.

6.3.2. Model selection criteria

Finally, I apply the model and moment selection criteria (MMSC) developed by Andrew and Lu (2001) for my set of nested models. The specific MMSC-BIC criterion resembles the well-known BIC model selection criterion for the GMM framework, by including 'bonus terms that reward the use of more moment conditions for a given number of parameters and the use of less parameters for a given number of moment conditions' (Andrews and Lu, 2001, p.125).[22]

Table 6.4 provides the results of the specific MMSC-BIC criterion for 5 models: (i) the baseline model where the main determinants of R&D investment are the growth rate of Tobin's average Q and sales, (ii) the augmented version of model (i) with the lagged cash flow ratio, (iii) the extended model (ii) with also product-market competition, (iv) where the model (iii) is controlled for knowledge spillovers as well, and (v) is where the country-level governance indicators are added into model (iv).

Table 6. 4: Results of model and moment selection criteria (MMSC-BIC)

Model	(i)	(ii)	(iii)	(iv)	(v)
MMSC-BIC	-119.76403	-165.14661	-163.96019	-164.54188	-197.45089

Similar to the assessment of the common BIC model selection criterion, lower values of MMSC-BIC indicate a better fit and so the model with the lowest MMSC-BIC is the best fitting model in the set of comparable ones (Kass and Raftery, 1995; Andrew and Lu, 2001). From table 6.4, it can be seen that all the augmented Tobin's Q models perform better than the original one, where only the one-period-ahead growth rate of Tobin's average Q and sales are considered to be the main determinants of firm R&D investment. Moreover, the lowest MMSC-BIC value is reported for the final model in column 5 of Table 6.4, where all three factors (product-market competition, the level of R&D

[22] The MMSC-BIC value for each model is constructed by the formula (3.16) in Chapter 3.

spillovers and governance quality) are controlled. This indicates its appropriateness as the 'best' model in this case to explain the R&D investment decision-making process at firm-level.

6.4. Sensitivity check

Similar to previous two chapters, I test the robustness of my results with another measure of product-market competition: the Herfindahl-Hirschman index (*HHI*). The index reflects the level of market concentration, which is usually opposite to the level of competition. Hence, my previous results are robust if the U-shape can be found for the *HHI* index-R&D investment relationship, while the other covariates retain their effects on firm R&D investment. The results are presented in Table 6.5.

Table 6. 5: Results with HHI measure of product-market competition

Model	(1)	(2)	(3)
R&D intensity (lag 1)	0.6861***	0.2682***	0.4017***
	(0.0315)	(0.0401)	(0.0782)
R&D intensity (lag 2)	0.1809***	-0.0219	0.0505
	(0.0275)	(0.0317)	(0.0345)
Growth rate of average Q (lag 1)	0.0197***	0.0155***	0.0306**
	(0.0019)	(0.0018)	(0.0104)
HHI (lag 1)	-0.0074	0.0017	-0.0219
	(0.0088)	(0.0378)	(0.0247)
HHI-squared (lag 1)	0.0150	-0.0024	0.0759*
	(0.0163)	(0.0474)	(0.0429)
Intra-industry spillovers (lag 1)	0.0014***	-0.0015	0.0046***
	(0.0002)	(0.0036)	(0.0009)
Patent-weighted inter-industry spillovers (lag 1)	-0.0019**	0.0348***	-0.0167***
	(0.0009)	(0.0131)	(0.0039)
Cash flow (lag 1)	-0.0386***	-0.0730***	0.1103**
	(0.0067)	(0.0122)	(0.0452)
Growth rate of sales (lag 1)	-0.0093***	-0.0033	0.0200
	(0.0026)	(0.0026)	(0.0047)
LOS_i	0.0054***		0.0313***
	(0.0007)		(0.0057)
CR_i	-0.0008		-0.0047***
	(0.0005)		(0.0015)
RL_i	0.0007*		0.0033***
	(0.0003)		(0.0009)
Country effects	No	No	No
Year effects	Yes	Yes	Yes
Number of observations	22809	22809	22809
Number of firms	3621	3621	3621
Number of instruments			41
AR(1)			0.000
AR(2)			0.489
Hansen test (P-value)			0.868

Difference-in-Hansen test (level equation)	0.869

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, I use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, lag 3 onwards of the growth rate of Q and sales and cash flow ratio for the difference equations, the second lagged difference of R&D intensity, and the third lagged differences of the growth rate of Q and sales and cash flow ratio for the level equations.

Table 6.5 indicates that my findings are robust with regard to different measure of product-market competition. With the *HHI* measure of market concentration, its effect is found to be non-linear and to follow a U-shape by the positive and slightly significant coefficient of the squared term of the *HHI* index. The effects of other covariates remain consistent with previous findings, in which the positive effects are confirmed for the one-period-ahead growth rate of Tobin's average Q as a measure of expected profitability that shapes expectations formation, the lagged R&D intensity, cash flow ratio and intra-industry spillovers, while inter-industry spillovers keep their negative impact on firm R&D investment. With regard to the additional control of governance quality at country-level, on the one hand, the firm seems to be more engaged in R&D investment if it is located in a country with an English-common law origin or with a high level of legal enforcement (reflected by the rule of law index). On the other hand, the higher the level of creditor rights in a country, the less research incentive is found for firms inside that country. This might be attributable to the fact that if creditor rights are strongly protected, managers might experience less power in choosing R&D investments over the short-term but more profitable projects.

The next sensitivity check is about the impact of the recent financial crisis 2008-2010. To address this issue, I create the dummy variable FC, which equals 1 for the 3 years 2008, 2009 and 2010. In order to test this financial crisis's effect on the role of expected profitability in forming firm R&D investment decisions, I add both the dummy FC on its own and its interaction with the growth rate of Tobin's average Q into my model. Results are presented in table 6.6 below.

Table 6. 6: Results with the new control for financial crisis 2008-2009

Model	(1)	(2)	(3)
R&D intensity (lag 1)	0.6836***	0.2651***	0.4428***
	(0.0327)	(0.0415)	(0.0735)
R&D intensity (lag 2)	0.1785***	-0.0179	0.0672**
	(0.0282)	(0.0325)	(0.0332)
Growth rate of average Q (lag 1)	0.0215***	0.0179***	0.0560***
	(0.0028)	(0.0026)	(0.0176)
PMC (lag 1)	0.6454***	0.4217	1.5732***

	(0.1785)	(0.6496)	(0.5738)
PMC-squared (lag 1)	-0.3759***	-0.2292	-0.9226***
	(0.1025)	(0.3475)	(0.3265)
Intra-industry spillovers (lag 1)	0.0012***	-0.0007	0.0034***
	(0.0002)	(0.0033)	(0.0006)
Patent-weighted inter-industry spillovers (lag 1)	-0.0014	0.0317***	-0.0111***
	(0.0009)	(0.0143)	(0.0032)
Cash flow (lag 1)	-0.0395***	-0.0705***	0.0284
	(0.0068)	(0.0125)	(0.0440)
Growth rate of sales (lag 1)	-0.0089***	-0.0031	-0.0007
	(0.0027)	(0.0026)	(0.0105)
LOS_i	0.0054***		0.0238***
	(0.0007)		(0.0049)
CR_i	-0.0009*		-0.0039***
	(0.0005)		(0.0014)
RL_i	0.0006*		0.0019***
	(0.0003)		(0.0009)
FC * Growth rate of average Q (lag 1)	-0.0027	-0.0041	-0.0432***
	(0.0038)	(0.0037)	(0.0218)
FC	0.0025	-0.0036	
	(0.0016)	(0.0031)	
Lincom effect			0.0128
			(0.0117)
Country effects	No	No	No
Year effects	Yes	Yes	Yes
Number of observations	22407	22407	22407
Number of firms	3615	3615	3615
Number of instruments			47
AR(1)			0.000
AR(2)			0.525
Hansen test (P-value)			0.343
Difference-in-Hansen test (level equation)			0.831

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, I use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, lag 3 onwards of the growth rate of Q and sales and cash flow ratio for the difference equations, the second lagged difference of R&D intensity, and the third lagged differences of the growth rate of Q and sales and cash flow ratio for the level equations. The *lincom* effect is calculated from the estimated coefficients of the growth rate of Tobin's Q on itself and its interaction term with other variable.

Table 6.6 shows that the financial crisis 2008-2010 significantly affects the consistency of my result with regard to the role of expectations on firm R&D investment decisions. The interaction term between the dummy FC and the growth rate of Tobin's average Q is negative and significant in GMM estimation. The linear combined effect is positive but insignificant, which means that during the crisis period 2008-2010, the revision of expected future profitability does not have strong influence on the managerial incentives for firm investment decisions. This is indeed a positive signal, since the reaction from the stock market might be pessimistic in the crisis period, and hence the ignorance of managers to these reactions can be crucial in maintaining the adequate level of R&D investment for sustainable growth.

Then, I compare the results with my proposed measure of expected profitability and investment opportunity, the growth rate of Tobin's average Q, with the commonly used Tobin's average Q. Results of model (6.2) using the system GMM method is presented in table 6.7 below:

Table 6. 7: Results with either growth rate of Tobin's Q or Tobin's average Q itself

Model	(1)	(2)
R&D intensity (lag 1)	0.3617***	0.4528***
	(0.0809)	(0.0658)
R&D intensity (lag 2)	0.0414	0.0216
	(0.0356)	(0.0380)
Growth rate of average Q (lag 1)	0.0362***	
	(0.0114)	
Average Q		0.0157***
		(0.0027)
PMC (lag 1)	1.7091***	2.4657***
	(0.6548)	(0.5225)
PMC-squared (lag 1)	-1.0239***	-1.3958***
	(0.3715)	(0.2987)
Intra-industry spillovers (lag 1)	0.0039***	0.0033***
	(0.0007)	(0.0006)
Patent-weighted inter-industry spillovers (lag 1)	-0.0149***	-0.0080***
	(0.0036)	(0.0027)
Cash flow (lag 1)	0.1107**	-0.1177**
	(0.0502)	(0.0517)
Growth rate of sales (lag 1)	0.0257*	-0.0484***
	(0.0139)	(0.0186)
LOS_i	0.0324***	0.0074
	(0.0058)	(0.0051)
CR_i	-0.0050***	-0.0020*
	(0.0016)	(0.0011)
RL_i	0.0035***	0.0024***
	(0.0010)	(0.0007)
Country effects	No	No
Year effects	Yes	Yes
Number of observations	22407	22518
Number of firms	3615	3626

Number of instruments	41	43
AR(1)	0.000	0.000
AR(2)	0.399	0.609
Hansen test (P-value)	0.815	0.015
Difference-in-Hansen test (level equation)	0.950	0.048

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. The instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, lag 3 onwards of the growth rate of Q and sales and cash flow ratio for the difference equations, the second lagged difference of R&D intensity, and the third lagged differences of the growth rate of Q and sales and cash flow ratio for the level equations.

Table 6.7 indicates that results are more reliable for the use of the growth rate of Tobin's average Q, my proposed measure of both expected profitability and investment opportunity, in comparison with the use of the traditional Tobin's average Q. In column (2) of table 6.7, even though the effect of Tobin's average Q is confirmed to be positive and highly significant, the use of Tobin's average Q affects the results of both the lagged cash flow and the growth rate of sales. Their estimates turn to be negative. Also, both Hansen test and the difference in Hansen test indicates that there is a problem with the set of instruments for the second estimation using Tobin's average Q.

Finally, I test the robustness of my results regarding to country heterogeneity. Table 6.8 below provides results of model (6.2) where in column (1) I exclude South Korea and re-run the regression with 14 countries, and column (2) where I apply the weight to control for the different number of observations between countries.

Table 6. 8: Robustness test for country heterogeneity

Model	(1)	(2)
R&D intensity (lag 1)	0.3646***	0.4241***
	(0.0831)	(0.1050)
R&D intensity (lag 2)	0.0389	0.1216***
	(0.0362)	(0.0375)
Growth rate of average Q (lag 1)	0.0346***	0.0070
	(0.0127)	(0.0092)
PMC (lag 1)	2.1388***	1.1870
	(0.0742)	(0.9375)
PMC-squared (lag 1)	-1.2823***	-0.6910
	(0.4216)	(0.5316)
Intra-industry spillovers (lag 1)	0.0045***	0.0041***
	(0.0008)	(0.0012)
Patent-weighted inter-industry spillovers (lag 1)	-0.0160***	-0.0051
	(0.0041)	(0.0045)
Cash flow (lag 1)	0.0944***	-0.0516

	(0.0514)	(0.0469)
Growth rate of sales (lag 1)	0.0192	-0.0060
	(0.0189)	(0.0139)
LOS_i	0.0272***	0.0123
	(0.0053)	(0.0077)
CR_i	-0.0032**	-0.0016
	(0.0014)	(0.0015)
RL_i	0.0165***	0.0064***
	(0.0044)	(0.0020)
Country effects	No	No
Year effects	Yes	Yes
Number of observations	18775	22407
Number of firms	3005	3615
Number of instruments	41	41
AR(1)	0.000	0.002
AR(2)	0.352	0.418
Hansen test (P-value)	0.763	0.036
Difference-in-Hansen test (level equation)	0.947	0.905

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. The instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, lag 3 onwards of the growth rate of Q and sales and cash flow ratio for the difference equations, the second lagged difference of R&D intensity, and the third lagged differences of the growth rate of Q and sales and cash flow ratio for the level equations.

It can be seen from table 6.8 that the exclusion of South Korea does not affect significantly my results, while adding the weight with respect to the number of observations does. Even though, most of the estimates remain its sign, only some turn to be insignificant, such as the effect of the growth rate of Tobin's Q or both the level and the squared term of *PMC,* my measure of product-market competition. In addition, the Hansen test p-value of 0.036 shows that this estimation faces the problem of over-identification, which might influence the estimates.

6.5. Conclusions

This chapter has tested the augmented Tobin's Q model of firm R&D investment with a third additional factor: the country-level governance quality. 'Agency theory' suggests that any existing conflict of interest between managers and shareholders might significantly affect firm investment decisions. This relationship is even more noticeable in the case of R&D investment, the kind of investment that often causes an information asymmetry problem.

To address the effect of governance quality, three indicators are applied. The first is the different legal origin systems between countries, either the English-common law or the Roman-civil law. Second, two other indexes reflecting the level of creditor rights and legal enforcement are employed. Utilizing the same system GMM estimator on the sample of 3,718 manufacturing firms from 15 OECD countries over the 2005-2013 period, I report several findings. The results first show that controlling for country-level governance quality is important, as the estimated coefficients of all three indicators are highly significant in all estimations. To be more specific, my findings confirm that firms in countries with an English-common law origin have, on average, a higher level of R&D intensity. However, the significant effect of expected profitability, reflected by the one-period-ahead growth rate of Tobin's average Q, is documented to be indifferent across the 15 countries in my sample. Besides, the level of creditor rights negatively affects firm R&D investment, while the higher rule of law index is in a country is associated with more R&D investment.

Moreover, the new controls for country-level governance quality does not affect previous findings. While the one-period-ahead growth rate of Tobin's average Q keeps its positive and significant effect on firm R&D investment, the competition-R&D investment relationship remains non-linear and follows the inverted-U shape proposed by the seminal Aghion et al. (2005) paper. With regard to the influence of knowledge spillovers, the results in this chapter show the consistency of both positive intra-industry spillovers and the negative effect of inter-industry spillovers. Overall, these results strongly support the augmented Tobin's Q model in explaining the R&D investment decision-making process at firm-level.

The chapter also provides evidence on several sources of heterogeneity in the relationship between the one-period-ahead growth rate of Tobin's average Q and firm R&D investment. The relationship is found to be stronger when the firm is categorized as either small or medium-sized, with regard to the European Union classification of the number of employees. This effect also turns out to be insignificant when the firm's R&D intensity level is lower than the average R&D intensity of its two-digit SIC industry. These results are consistent with findings in previous empirical chapters.

CHAPTER 7: CONCLUSION

The determinants of R&D investment at a firm level has been a topic of interest for economists for a long time. However, our knowledge of firm R&D investment behaviour remains somewhat fragmented. This thesis aims to build bridges between several different but not mutually exclusive theories on the managerial incentives for R&D investment. My approach is informed by the Tobin's Q theory of investment, which investigates the effect of expectations about the profitability of future investment on the firm's investment decisions. The relevant measure of the one-period-ahead growth rate of Tobin's average Q is used to address two main issues in the well-known Tobin's Q theory. First, it addresses the inappropriateness of the common but unsuccessful approach using average Q as a proxy for the unobservable marginal Q. Instead, I propose the one-period-ahead market rate of return weighted with one-period-ahead change in replacement cost of capital to reflect managers' revision of expected profitability. Second, using this measure allows for the removal of the strict assumption that marginal Q is the sole determinant of firm investment. I do this by proposing and testing an augmented Tobin's Q model with three factors relevant to the managerial incentives for R&D investment: product-market competition, the level of R&D spillovers and country-level governance quality.

The system GMM estimator is employed on the data set of 3,718 manufacturing firms from 15 OECD countries over the 2005-2013 period. Overall, my empirical results indicate the possibility of an augmented Tobin's Q model, in which these factors significantly contribute to explaining the R&D investment decision-making process at firm-level.

7.1. Main findings

The empirical results are discussed in three empirical chapters of this thesis.

Chapter 4 reports the results of my baseline model taken from Mairesse and Siu (1984) which examines the role of expectations about future profitability and capacity need in determining the optimal firm R&D investment. The findings confirm that the expected profitability, reflected by the one-period-ahead growth rate of Tobin's average Q, significantly influences R&D investment decisions, while the expected capacity need, reflected by the one-period-ahead growth rate of sales, does not contribute much explanatory power to the model. I attribute the latter result to the fact that

R&D investment is often carried out with the aim of improving the quality of products, and hence the expected capacity need might not be as important to R&D investment as it is in the case of physical capital investment. In addition, Chapter 4 also presents the results of the first augmented Tobin's Q model with the presence of product-market competition. The findings are supportive of the non-linear competition-innovation relationship from Aghion et al. (2005). In more detail, at a low levels of competition, the firm's research effort tends to increase as competition increases; but after a threshold it turns to decreasing with the higher level of competition. What is even more important here is that the presence of product-market competition does not influence the role of expectations, especially about future profitability, in the model. The one-period-ahead growth rate of Tobin's average Q remains positive and significant across different specifications and methods of estimation.

However, several heterogeneity checks at the end of Chapter 4 indicate that the effect of the one-period-ahead growth rate of Tobin's average Q on R&D investment is homogenous across firm types. Specifically, I find that the effect is stronger among small and medium-sized firms and high R&D-intensive firms. In contrast, the effect is smaller and sometimes insignificant with regard to large firms or low R&D-intensive firms.

Chapter 5 expands the augmented Tobin's Q model in Chapter 4 with another factor: the level of R&D spillovers. The empirical results on the same data set of 3,718 manufacturing firms first indicate the consistency of previous findings. While the one-period-ahead growth rate of Tobin's average Q, my measure of managers' revision of expected profitability, has a positive and significant effect on firm R&D investment. However, the effect of expected capacity need, reflected by the growth rate of sales, is insignificant. Nevertheless, the non-linear relationship between competition and R&D investment is confirmed by the negative and significant estimated coefficient of the squared term of competition measure.

With regard to the new control of R&D spillovers, the results in Chapter 5 document the significant effects of both intra- and inter-industry spillovers on the optimal level of firm R&D investment. My findings first show that the positive effect of intra-industry spillovers seems to be outweighed by the negative inter-industry spillovers effect, which is congruent with the commonly accepted notion that a high the level of spillovers tends to reduce the firm's research effort. Nevertheless, more careful consideration indicates that the actual relationship is more complicated than has been found, in the sense that the knowledge (spillover) pool inside the industry might actually be a source of creative destruction and/or ‘market-stealing’ effects, which in turn induce managers to invest more in R&D activities. Hence, the spillovers’ negative effect on managerial incentives for R&D investment is found only with inter-industry spillovers, where the knowledge (spillover) pool is rather a source of emulation than either a threat of creative destruction or a ‘market-stealing’ effect.

The heterogeneity checks for both firm size and the level of R&D intensity are also consistent with the previous chapter, in which small and medium-sized firms or high R&D-intensive firms are more sensitive to stock market reactions.

Chapter 6 carries out a similar procedure with the new control of corporate governance quality. Readers should notice that due to the lack of corporate governance data at firm-level, I use only country-level governance indicators with relevance for corporate governance (CG) quality. Three CG-related measures of governance quality are checked for: different legal origin systems, the level of protection for creditor rights and legal enforcement. Empirical results using the same system GMM estimator on 3,718 manufacturing firms indicate that both the different legal origins and other two other governance indicators have significant effects on firm R&D investment. First, with regard to the different legal origin systems, my findings show that on average the level of R&D investment is higher in countries with the English-common law origin. However, even though stock markets are more developed in countries with the English-common law origin, there seems to be no difference in the effect of expected profitability, reflected by the revision of stock market movements, on firm R&D investment between these countries and others. The interaction term between the dummy LOS_i and the growth rate of Tobin’s average Q is insignificant in all specifications. Second, both the level of protection for creditor rights and legal enforcement have significant effects on the firm R&D investment model, even though their influences go in opposite directions. Consistent with the results of Seifert and Gonenc (2012), I find that stronger protection of creditor rights in a country might cause managers to avoid risk in long-term investments like R&D activities. On the other hand, the stronger the country-level legal enforcement, the higher the level of R&D intensity can be found at firm-level.

However, the more important finding from Chapter 6 is that, similar to product-market competition and knowledge spillovers, the presence of governance indicators does not eliminate the role of expectation, especially about future profitability, in the R&D investment model. The effect of the one-period-ahead growth rate of Tobin’s average Q is always positive and highly significant across estimations. In addition, the non-linear competition-R&D investment relationship, the positive but small effect of intra-industry spillovers, and the impact of negative inter-industry spillovers remain significant in the model.

7.2. Contributions of the research

This thesis has made four contributions to the existing knowledge and evidence base concerning the determinants of firm R&D investment.

First, it re-emphasises the importance of expectations for firm investment decisions. The idea dates back to Keynes (1936) and is re-stated in Tobin's Q theory – a theoretical perspective that dominated investment modelling in the literature during the 1970s and 1980s. However, the unobservable nature of marginal Q and the lack of empirical support for Tobin's average Q as a proxy have led to fragmentation and somewhat *ad hoc* modelling in the empirical literature on R&D investment. Using the one-period-ahead growth rate of Tobin's average Q as a source of information for managerial expectation formation, I have been able to establish a significant relationship between expectations about future profitability and the firm's R&D investment on average.

Second, this study has built bridges between different but not mutually exclusive theories on the determinants of firm R&D investment. While product-market competition and corporate governance are often considered to affect the incentives for R&D investment through their disciplining effects on firms' managers, knowledge spillovers tend to discourage investment due to their incomplete appropriability of the returns to R&D investment. In addition, Eklund (2013) suggests that one of the main weaknesses in these approaches is, in fact, the lack of consideration of the role of managers' expectations about future profitability. The empirical results in this thesis support the presence of all three factors in an augmented Tobin's Q model, together with the one-period-ahead growth rate of Tobin's average Q, in explaining the R&D investment decision-making process at firm-level.

Third, the thesis provides consistent estimated based on the system GMM estimator and a rich data set of 3,718 manufacturing firms. The system GMM estimator is considered to be effective in dealing with the endogeneity issue in a dynamic panel model.

Finally, my rich data set allows for testing of whether the relationship between the one-period-ahead growth rate of Tobin's average Q, my measure of expected profitability that shapes expectations formation, and firm R&D investment is homogeneous or heterogeneous across different firm types, industry characteristics and legal traditions. The results demonstrate that the relationship is usually heterogeneous across firm/industry types, with exception of different legal origins.

7.3. Implications of the research

The results in this thesis have important implications for both firms' investment strategy and future research.

First, the findings of this thesis might be interpreted as an indication that most of previous approaches to the determinants of firm R&D investment are fragmented and they might suffer from omitted variable bias. The evidence I find in support of an augmented Tobin's Q model provides more insights into how managers form their investment decisions. In more detail, my findings confirm that the one-period-ahead rate of return on stock market valuation after taking into account the one-period-ahead change in replacement cost of capital is an important source of information for managers in their revision of expected future profitability, which, in turn, affects their incentives for firm R&D investment. However, it can only reflect one part of the information set that managers consider in forming their investment decisions, and the augmented model is proven to explain better the R&D investment decision-making process at firm-level.

A second important contribution from my findings relates to the more complicated effect of knowledge spillovers on the firm's research effort than the common notion of a negative relationship predicted by the neoclassical theory of knowledge externalities. In fact, the effect depends on different spillover types. With regard to intra-industry spillovers, the knowledge (spillover) pool from the R&D investment of direct competitors seems to be a source of creative destruction and/or 'market-stealing' effects, leading to an increase in R&D investment by the firm in the industry. This can be interpreted as escape-competition effect, which shows that firms increase their R&D investment in reaction to industry-level R&D investment in order to keep up with technological change or maintain market shares or both. The opposite effect is found for inter-industry spillovers. In this case, the knowledge (spillover) pool tends to be a source of knowledge to be emulated, and therefore induces firms to lower their R&D investment as they cannot appropriate all benefits of their R&D effort and can benefit from knowledge externalities created by the investment of other firms. These findings should be taken into consideration by policy makers in setting government R&D spending, since public support, either through R&D tax credits or R&D subsidies, might not deliver the desired effects on firm R&D investment if they ignore the differential effects of different spillover types.

The thesis also indicates different channels in which government policies can be implemented to stimulate private R&D investment. Acknowledging the high level of competition in the globalised market and the inverted-U shape relationship between competition and R&D investment, any attempt to induce firm R&D investment through increasing further the level of market competition might not be an ideal suggestion. Instead, policy makers may consider strengthening the stock market, in order to use the positive expected profitability signal to raise the managerial incentives for R&D investment. Similarly, a suitable set of governance indicators at institutional level is important in determining managers' perspective about R&D investment.

7.4. Limitations of the research

Despite my use of best practice in modelling, data collection and data analysis techniques, a few caveats are in order.

First, my sample consists of R&D-active and listed firms only. As such, the findings should not be generalised to the wider population of firms which may include non-R&D-active and non-listed companies. Also, data scarcity has prevented me from investigating the role of CG mechanisms measured at the firm-level. Given the increasing importance of corporate governance quality issue in the industrial organisation literature, I hope to address this issue in the future.

Second, as is common to quantitative research, the empirical results of this thesis suffer from a measurement issue. For instance, the one-period-ahead growth rate of Tobin's average Q, my measure of expected profitability, might suffer from the misleading valuations of the stock market. Stock prices might be high relative to its fundamental values simply because it is expected to increase, or low because it is expected to further decrease. This is common issue for any measure of Tobin's Q that relies on stock market valuation and expectation. However, one possible solution which is applied here is to consider an augmented model where the expected profitability and investment opportunity reflected by stock market valuation is not the sole determinant of managerial incentives for R&D investment. Besides, even the more precise measure of inter-industry spillovers that I have been using, the patent citations-weighting system, is not free of criticism. Even though it is considered to be a better measure of the external knowledge pool compared to the unweighted one, knowledge spillovers is a much broader concept than what is captured by patent citations. The reason is that for patent citations to take place, both the spillover-receiving and spillover-generating industries have to be actively engaged in R&D activities and they both must apply for patents. This leaves out a significant part of knowledge that may spill over in reality, which is highly likely to affect the empirical results.

Third, concerning other factors that might also affect the optimal level of firm R&D investment, government support is obviously a relevant factor. There are several form of support, such as R&D tax credits or R&D subsidies. However, whether that public support significantly impacts private R&D investment is still an open-ended topic. For instance, Becker (2015) indicates that recent studies often confirm a positive effect of direct subsidies on private R&D investment, while Dimos and Pugh (2016) provide a meta-analysis to show that there is no evidence of substantial additionality of private R&D with respect to the level of public subsidy. In this thesis, I do not control for the effect of government support, due to the lack of data for both R&D tax credits and R&D subsidies for the firms in my sample. Nevertheless, controlling for government spending might be another necessary check for the robustness and validity of the findings in future research.

7.5. Future research suggestions

The thesis has successfully brought back Tobin's Q theory, or, more precisely, the role of expectations in forming firm investment decisions. The consistent and positive effect of the profitability of future investment allows me to state several suggestions for further research.

First, future research might be interested in using a similar augmented Tobin's Q framework with the new measure of the one-period-ahead growth rate of average Q, in order to investigate other firms' strategies, for example, about physical capital investment, dividend payments or advertisement planning. In other words, I believe that the role of expectations is not limited to R&D investment decisions, and therefore the augmented Tobin's Q framework might be of great use for any research about the managerial decision-making process at firm-level in the future.

Another potential use of my proposed framework is to apply it to data from emerging markets. One of the main conclusions of this thesis is that the effect of stock market movements, reflected by the one-period-ahead growth rate of Tobin's average Q, does not vary across countries with different legal origin systems. However, the sample is limited to 15 OECD countries. Hence, a similar approach on data from emerging markets might provide fruitful insights, especially due to higher degree of variation in corporate governance indicators.

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APPENDIX

Table A3. 1: Variables' definitions

Variable	Definition
R&D intensity	Research and development expenses (WC01201) / Total assets at the end of *t*-1 (WC02999)
Tobin's average Q	Market value of equity (WC08001) + Preferred stock (WC03451) + Total debt (WC03255) / Total assets (WC02999)
Tobin's average Q 1	Market value of equity (WC08001) + Total assets (WC02999) – Book value of common equity (WC03501) / Total assets (WC02999)
Cash flow	Cash flow of the company (WC04201) + R&D (WC01201) / Total assets (WC02999)
Cash flow 1	Cash flow of the company (WC04201) + R&D (WC01201) / Total assets (WC02999)
Sales	Net sales or revenues (WC01001)
Employees	Number of employees (WC07011)
EBIT	Earnings before interest and taxes (WC18191)

Table A3. 2: Top 20 countries in Scoreboard World Top R&D Investor 2011-2013

	2011 Top 1400 R&D Investors	2012 Top 1500 R&D Investors	2013 Top 2000 R&D Investors
1	**Australia (17)**[23]	**Australia (18)**	**Australia (19)**
2	**Canada (19)**	**Canada (20)**	**Canada (17)**
3	**Denmark (10)**	**Denmark (13)**	**Denmark (14)**
4	**Finland (15)**	**Finland (17)**	**Finland (16)**
5	**France (5)**	**France (5)**	**France (7)**
6	**Germany (3)**	**Germany (3)**	**Germany (3)**
7	**Italy (11)**	**Italy (12)**	**Italy (13)**
8	**Japan (2)**	**Japan (2)**	**Japan (2)**
9	**South Korea (8)**	**South Korea (9)**	**South Korea (8)**
10	**Spain (16)**	**Spain (15)**	**Spain (18)**
11	**Sweden (9)**	**Sweden (10)**	**Sweden (11)**
12	**Switzerland (7)**	**Switzerland (8)**	**Switzerland (9)**
13	**The Netherland (12)**	**The Netherland (11)**	**The Netherland (12)**
14	**UK (4)**	**UK (4)**	**UK (4)**
15	**US (1)**	**US (1)**	**US (1)**
16	Belgium (18)	Belgium (19)	Cayman Islands (10)
17	Cayman Islands (20)	Cayman Islands (14)	China (5)
18	China (13)	China (6)	India (15)
19	India (14)	India (16)	Israel (20)
20	Taiwan (6)	Taiwan (7)	Taiwan (6)

(*Source: European Commission – World Top Corporate R&D Investors Scoreboard)*

[23] The number in bracket denotes the order of country in the top 20 countries with highest number of firms in the R&D *Scoreboard*. The smaller the country's order, the higher the number of firms in *Scoreboard*.

Table A4. 1: Results of the auto-regressive distributed lags (ARDL) model

Model	OLS	FE	GMM
R&D intensity (lag 1)	0.6462***	0.0617	0.6018***
	(0.0442)	(0.0563)	(0.0972)
R&D intensity (lag 2)	0.1491***	-0.1996***	0.1032
	(0.0513)	(0.0554)	(0.1028)
R&D intensity (lag 3)	-0.0010	-0.1997***	0.0370
	(0.0464)	(0.0683)	(0.0780)
R&D intensity (lag 4)	0.1027**	-0.0343	0.0219
	(0.0518)	(0.0581)	(0.0781)
R&D intensity (lag 5)	0.0462	-0.0594	-0.0078
	(0.0325)	(0.0378)	(0.0508)
Industry effects	Yes	No	Yes
Country effects	Yes	No	Yes
Year effects	Yes	Yes	Yes
Number of Observations	12598	12598	12598
Number of firms	3595	3595	3595
Number of instruments			45
AR(1)			0.000
AR(2)			0.298
Hansen test (P-value)			0.228
Difference-in-Hansen test (level equation)			0.750

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, I use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity for the difference equations, and its second lagged differences for level equations.

Table A4. 2: Full results of equation (4.6) for heterogeneity check with firm size

Model	(1)	(2)	(3)
R&D intensity (lag 1)	0.6818***	0.2676***	0.4489***
	(0.0334)	(0.0421)	(0.0704)
R&D intensity (lag 2)	0.1812***	-0.0198	0.0404
	(0.0290)	(0.0328)	(0.0352)
Growth rate of average Q (lag 1)	0.0062***	0.0051***	0.0254***
	(0.0010)	(0.0010)	(0.0074)
PMC (lag 1)	0.9940***	0.4312	1.7648**
	(0.1764)	(0.6570)	(0.7057)
PMC-squared (lag 1)	-0.5902***	-0.2374	-1.1038***
	(0.0996)	(0.3510)	(0.4012)
Cash flow (lag 1)	-0.0383***	-0.0696***	0.0854**
	(0.0073)	(0.0127)	(0.0411)
Growth rate of sales (lag 1)	-0.0099***	-0.0038	-0.0022
	(0.0027)	(0.0026)	(0.0051)
SME_i	0.0047***		0.0340***
	(0.0008)		(0.0062)
SME_i * Growth rate of average Q	0.0245***	0.0191***	0.0172*
	(0.0031)	(0.0031)	(0.0088)
Country effects	Yes	No	Yes
Year effects	Yes	Yes	Yes
Number of Observations	22279	22279	22279
Number of firms	3583	3583	3583
Number of instruments			57
AR(1)			0.000
AR(2)			0.328
Hansen test (P-value)			0.485
Difference-in-Hansen test (level equation)			0.919

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, we use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, the growth rate of Q and sales, and lag 3 onwards of cash flow ratio for the difference equations, the second lagged differences of R&D intensity, the growth rate of Q and sales and the third lagged difference of cash flow ratio for the level equations. (1) presents OLS estimates, (2) is for FE estimates, and (3) is for system GMM estimates.

Table A4. 3: Full results of equation (4.7) for heterogeneity check with the level of R&D intensity

Model	(1)	(2)	(3)
R&D intensity (lag 1)	0.6671***	0.2685***	0.4619***
	(0.0327)	(0.0409)	(0.0725)
R&D intensity (lag 2)	0.1671***	-0.0153	0.0497
	(0.0278)	(0.0322)	(0.0352)
Growth rate of average Q (lag 1)	0.0332***	0.0258***	0.0264***
	(0.0031)	(0.0030)	(0.0075)
PMC (lag 1)	1.6425***	0.4117	3.1866***
	(0.2148)	(0.6648)	(0.9216)
PMC-squared (lag 1)	-0.9794***	-0.2298	-1.9440***
	(0.1231)	(0.3554)	(0.5311)
Cash flow (lag 1)	-0.0404***	-0.0694***	0.0097
	(0.0067)	(0.0124)	(0.0340)
Growth rate of sales (lag 1)	-0.0094***	-0.0037	-0.0055
	(0.0026)	(0.0026)	(0.0036)
INT_i	-0.0131***		-0.0366***
	(0.0011)		(.0065)
INT_i * Growth rate of average Q (lag 1)	-0.0309***	-0.0236***	-0.0250***
	(0.0028)	(0.0028)	(0.0065)
Country effects	Yes	No	Yes
Year effects	Yes	Yes	Yes
Number of Observations	22407	22407	22407
Number of firms	3615	3615	3615
Number of instruments			57
AR(1)			0.000
AR(2)			0.450
Hansen test (P-value)			0.229
Difference-in-Hansen test (level equation)			0.753

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, we use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, the growth rate of Q and sales, and lag 3 onwards of cash flow ratio for the difference equations, the second lagged differences of R&D intensity, the growth rate of Q and sales and the third lagged difference of cash flow ratio for the level equations. (1) presents OLS estimates, (2) is for FE estimates, and (3) is for system GMM estimates.

Table A5. 1: Full results of equation (5.1) with the unweighted measure of inter-industry spillovers

Model	(1)	(2)	(3)
R&D intensity (lag 1)	0.6829***	0.2650***	0.3611***
	(0.0327)	(0.0414)	(0.0811)
R&D intensity (lag 2)	0.1780***	-0.0180	0.0408
	(0.0282)	(0.0325)	(0.0357)
Growth rate of average Q (lag 1)	0.0199***	0.0156***	0.0366***
	(0.0019)	(0.0019)	(0.0114)
PMC (lag 1)	0.6216***	0.2928	1.6333***
	(0.1650)	(0.5665)	(0.6098)
PMC-squared (lag 1)	-0.3633***	-0.1674	-0.9774***
	(0.0960)	(0.3063)	(0.3467)
Intra-industry spillovers (lag 1)	0.0010***	0.0017	0.0015
	(0.0003)	(0.0021)	(0.0010)
Unweighted inter-industry spilovers (lag 1)	-0.0034	0.0381	-0.0543***
	(0.0046)	(0.0548)	(0.0177)
Cash flow (lag 1)	-0.0404***	-0.0705***	0.1102**
	(0.0068)	(0.0125)	(0.0502)
Growth rate of sales (lag 1)	-0.0089***	-0.0031	0.0260*
	(0.0027)	(0.0026)	(0.0139)
Country effects	Yes	No	Yes
Year effects	Yes	Yes	Yes
Number of Observations	22407	22407	22407
Number of firms	3615	3615	3615
Number of instruments			52
AR(1)			0.000
AR(2)			0.390
Hansen test (P-value)			0.830
Difference-in-Hansen test (level equation)			0.978

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, we use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, the growth rate of Q and sales, and lag 3 onwards of cash flow ratio for the difference equations, the second lagged differences of R&D intensity, the growth rate of Q and sales and the third lagged difference of cash flow ratio for the level equations. (1) presents OLS estimates, (2) is for FE estimates, and (3) is for system GMM estimates.

Table A5. 2: Full results of equation (5.1) with the patent citation weighted inter-industry spillovers

Model	(1)	(2)	(3)
R&D intensity (lag 1)	0.6827***	0.2650***	0.3592***
	(0.0327)	(0.0414)	(0.0813)
R&D intensity (lag 2)	0.1779***	-0.0181	0.0403
	(0.0282)	(0.0325)	(0.0357)
Growth rate of average Q (lag 1)	0.0199***	0.0157***	0.0364***
	(0.0019)	(0.0019)	(0.0114)
PMC (lag 1)	0.6583***	0.4483	1.6249***
	(0.1805)	(0.6502)	(0.6692)
PMC-squared (lag 1)	-0.3828***	-0.2448	-0.9774***
	(0.1037)	(0.3478)	(0.3789)
Intra-industry spillovers (lag 1)	0.0012***	-0.0008	0.0038***
	(0.0002)	(0.0033)	(0.0007)
Patent-weighted inter-industry spilovers (lag 1)	-0.0015*	0.0305	-0.0143***
	(0.0009)	(0.0142)	(0.0036)
Cash flow (lag 1)	-0.0404***	-0.0705***	0.1104**
	(0.0068)	(0.0125)	(0.0502)
Growth rate of sales (lag 1)	-0.0089***	-0.0031	0.0258*
	(0.0027)	(0.0026)	(0.0139)
Country effects	Yes	No	Yes
Year effects	Yes	Yes	Yes
Number of Observations	22407	22407	22407
Number of firms	3615	3615	3615
Number of instruments			52
AR(1)			0.000
AR(2)			0.391
Hansen test (P-value)			0.830
Difference-in-Hansen test (level equation)			0.977

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, we use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, the growth rate of Q and sales, and lag 3 onwards of cash flow ratio for the difference equations, the second lagged differences of R&D intensity, the growth rate of Q and sales and the third lagged difference of cash flow ratio for the level equations. (1) presents OLS estimates, (2) is for FE estimates, and (3) is for system GMM estimates.

Table A5. 3: Full results of equation (5.1) with HHI measure of market concentration and the unweighted measure of inter-industry spillovers

Model	(1)	(2)	(3)
R&D intensity (lag 1)	0.6855***	0.2681***	0.4033***
	(0.0315)	(0.0401)	(0.0781)
R&D intensity (lag 2)	0.1806***	-0.0218	0.0502
	(0.0275)	(0.0316)	(0.0346)
Growth rate of average Q (lag 1)	0.0195***	0.0155***	0.0313***
	(0.0019)	(0.0018)	(0.0105)
HHI (lag 1)	-0.0108	-0.0031	-0.0527**
	(0.0088)	(0.0373)	(0.0266)
HHI-squared (lag 1)	0.0193	0.0026	0.1069**
	(0.0172)	(0.0468)	(0.0460)
Intra-industry spillovers (lag 1)	0.0011***	0.0011	0.0012
	(0.0003)	(0.0028)	(0.0010)
Unweighted inter-industry spilovers (lag 1)	-0.0064	0.0379	-0.0638***
	(0.0049)	(0.0624)	(0.0180)
Cash flow (lag 1)	-0.0394***	-0.0729***	0.1107**
	(0.0067)	(0.0122)	(0.0451)
Growth rate of sales (lag 1)	-0.0093***	-0.0033	0.0204
	(0.0026)	(0.0026)	(0.0128)
Country effects	Yes	No	Yes
Year effects	Yes	Yes	Yes
Number of Observations	22809	22809	22809
Number of firms	3621	3621	3621
Number of instruments			52
AR(1)			0.000
AR(2)			0.483
Hansen test (P-value)			0.882
Difference-in-Hansen test (level equation)			0.921

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, we use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, the growth rate of Q and sales, and lag 3 onwards of cash flow ratio for the difference equations, the second lagged differences of R&D intensity, the growth rate of Q and sales and the third lagged difference of cash flow ratio for the level equations. (1) presents OLS estimates, (2) is for FE estimates, and (3) is for system GMM estimates.

Table A5. 4: Full results of equation (5.1) with HHI measure of market concentration and the patent citation weighted inter-industry spillovers

Model	(1)	(2)	(3)
R&D intensity (lag 1)	0.6854***	0.2682***	0.3996***
	(0.0315)	(0.0402)	(0.0787)
R&D intensity (lag 2)	0.1806***	-0.0219	0.0493
	(0.0275)	(0.0317)	(0.0346)
Growth rate of average Q (lag 1)	0.0195***	0.0155***	0.0311***
	(0.0019)	(0.0018)	(0.0104)
HHI (lag 1)	-0.0064	0.0017	-0.0221
	(0.0089)	(0.0378)	(0.0256)
HHI-squared (lag 1)	0.0129	-0.0024	0.0778*
	(0.0165)	(0.0474)	(0.0440)
Intra-industry spillovers (lag 1)	0.0014***	-0.0015	0.0045***
	(0.0002)	(0.0036)	(0.0009)
Patent-weighted inter-industry spilovers (lag 1)	-0.0020**	0.0348***	-0.0161***
	(0.0009)	(0.0131)	(0.0038)
Cash flow (lag 1)	-0.0395***	-0.0730***	0.1111**
	(0.0067)	(0.0122)	(0.0452)
Growth rate of sales (lag 1)	-0.0093***	-0.0033	0.0203
	(0.0026)	(0.0026)	(0.0127)
Country effects	Yes	No	Yes
Year effects	Yes	Yes	Yes
Number of Observations	22809	22809	22809
Number of firms	3621	3621	3621
Number of instruments			52
AR(1)			0.000
AR(2)			0.481
Hansen test (P-value)			0.883
Difference-in-Hansen test (level equation)			0.917

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, we use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, the growth rate of Q and sales, and lag 3 onwards of cash flow ratio for the difference equations, the second lagged differences of R&D intensity, the growth rate of Q and sales and the third lagged difference of cash flow ratio for the level equations. (1) presents OLS estimates, (2) is for FE estimates, and (3) is for system GMM estimates.

Table A6. 1: Full results of equation (6.3) for heterogeneity check with firm size

Model	(1)	(2)	(3)
R&D intensity (lag 1)	0.6806***	0.2675***	0.4458***
	(0.0334)	(0.0421)	(0.0709)
R&D intensity (lag 2)	0.1806***	-0.0199	0.0386
	(0.0290)	(0.0328)	(0.0352)
Growth rate of average Q (lag 1)	0.0065***	0.0051***	0.0238***
	(0.0010)	(0.0010)	(0.0074)
SME_i * Growth rate of average Q (lag 1)	0.0244***	0.0191***	0.0186**
	(0.0031)	(0.0031)	(0.0087)
PMC (lag 1)	0.4741***	0.3389	0.9360*
	(0.1675)	(0.6325)	(0.5113)
PMC-squared (lag 1)	-0.2791***	-0.1833	-0.5709**
	(0.0964)	(0.3379)	(0.2890)
Intra-industry spillovers (lag 1)	0.0011***	-0.0030	0.0029***
	(0.0002)	(0.0032)	(0.0006)
Patent-weighted inter-industry spillovers (lag 1)	-0.0014*	0.0313**	-0.0115***
	(0.0009)	(0.0142)	(0.0030)
Cash flow (lag 1)	-0.0382***	-0.0696***	0.0877**
	(0.0073)	(0.0127)	(0.0411)
Growth rate of sales (lag 1)	-0.0098***	-0.0038	-0.0024
	(0.0027)	(0.0026)	(0.0049)
LOS_i	0.0048***		0.0180***
	(0.0006)		(0.0034)
CR_i	-0.0009*		-0.0041***
	(0.0005)		(0.0013)
RL_i	0.0013***		0.0086***
	(0.0004)		(0.0016)
SME_i	0.0047***		0.0343***
	(0.0008)		(0.0062)
Country effects	No	No	No
Year effects	Yes	Yes	Yes
Number of Observations	22279	22279	22279
Number of firms	3583	3583	3583
Number of instruments			48
AR(1)			0.000
AR(2)			0.318
Hansen test (P-value)			0.473
Difference-in-Hansen test (level equation)			0.877

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, I use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, the growth rate of Q and sales, and lag 3 onwards of cash flow ratio for the difference equations, the second lagged differences of R&D intensity, the growth rate of Q and sales and the third lagged difference of cash flow ratio for the level equations. (1) presents OLS estimates, (2) is for FE estimates, and (3) is for system GMM estimates.

Table A6. 2: Full results of equation (6.4) for heterogeneity check with the level of R&D intensity

Model	(1)	(2)	(3)
R&D intensity (lag 1)	0.6638***	0.2685***	0.4582***
	(0.0327)	(0.0409)	(0.0740)
R&D intensity (lag 2)	0.1648***	-0.0154	0.0499
	(0.0277)	(0.0322)	(0.0354)
Growth rate of average Q (lag 1)	0.0333***	0.0258***	0.0273***
	(0.0031)	(0.0030)	(0.0075)
INT_i * Growth rate of average Q (lag 1)	-0.0309***	-0.0236***	-0.0263***
	(0.0028)	(0.0028)	(0.0064)
PMC (lag 1)	0.9931***	0.3528	1.9589***
	(0.1926)	(0.6433)	(0.6982)
PMC-squared (lag 1)	-0.5897***	-0.1944	-1.1789***
	(0.1110)	(0.3441)	(0.3984)
Intra-industry spillovers (lag 1)	0.0015***	-0.0007	0.0038***
	(0.0002)	(0.0033)	(0.0007)
Patent-weighted inter-industry spillovers (lag 1)	-0.0023***	0.0302**	-0.0108***
	(0.0009)	(0.0143)	(0.0030)
Cash flow (lag 1)	-0.0406***	-0.0694***	0.0188
	(0.0067)	(0.0124)	(0.0336)
Growth rate of sales (lag 1)	-0.0094***	-0.0036	-0.0054
	(0.0026)	(0.0026)	(0.0036)
LOS_i	0.0043***		0.0153***
	(0.0006)		(0.0035)
CR_i	-0.0008*		-0.0027**
	(0.0005)		(0.0012)
RL_i	0.0002		0.0010
	(0.0003)		(0.0007)
INT_i	-0.0139***		-0.0380***
	(0.0012)		(0.0068)
Country effects	No	No	No
Year effects	Yes	Yes	Yes
Number of Observations	22407	22407	22407
Number of firms	3615	3615	3615
Number of instruments			48
AR(1)			0.000
AR(2)			0.439
Hansen test (P-value)			0.233
Difference-in-Hansen test (level equation)			0.609

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, I use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, the growth rate of Q and sales, and lag 3 onwards of cash flow ratio for the difference equations, the second lagged differences of R&D intensity, the growth rate of Q and sales and the third lagged difference of cash flow ratio for the level equations. (1) presents OLS estimates, (2) is for FE estimates, and (3) is for system GMM estimates.

Table A6. 3: Results with the measure of one-period-ahead ratio of Tobin's Q and sales

Model	(1)	(2)	(3)	(4)	(5)
R&D intensity (lag 1)	0.4576***	0.4405***	0.4160***	0.4068***	0.4079***
	(0.0652)	(0.0659)	(0.0694)	(0.0706)	(0.0701)
R&D intensity (lag 2)	0.0130	0.0272	0.0261	0.0215	0.0210
	(0.0310)	(0.0322)	(0.0336)	(0.0337)	(0.0338)
Growth rate of Q (lag 1)	0.0125***	0.0127***	0.0131***	0.0127***	0.0130***
	(0.0018)	(0.0020)	(0.0021)	(0.0021)	(0.0021)
Growth rate of sales (lag 1)	-0.0057	-0.0043	-0.0061	-0.0058	-0.0057
	(0.0060)	(0.0056)	(0.0056)	(0.0056)	(0.0056)
Cash flow (lag 1)		0.0257	0.0239	0.0255	0.0248
		(0.0347)	(0.0375)	(0.0376)	(0.0379)
PMC (lag 1)			2.7148***	1.5537***	1.5959***
			(0.6438)	(0.4437)	(0.4409)
PMC-squared (lag 1)			-1.6421***	-0.9138***	-0.9384***
			(0.3692)	(0.2528)	(0.2515)
Intra-industry spillovers (lag 1)				0.0037***	0.0038***
				(0.0006)	(0.0006)
Patent-weighted inter-industry spillovers (lag 1)				-0.0109***	-0.0112***
				(0.0026)	(0.0026)
LOS_i					0.0248***
					(0.0039)
CR_i					-0.0040***
					(0.0012)
RL_i					0.0028***
					(0.0008)
Industry effects	Yes	Yes	No	No	No
Country effects	Yes	Yes	Yes	Yes	No
Year effects	Yes	Yes	Yes	Yes	Yes
Number of Observations	22606	22422	22035	22035	22035
Number of firms	3612	3610	3604	3604	3604
Number of instruments	61	68	51	53	42
AR(1)	0.000	0.000	0.000	0.000	0.000
AR(2)	0.320	0.149	0.198	0.186	0.185
Hansen test (P-value)	0.394	0.424	0.195	0.239	0.231
Difference-in-Hansen test (level equation)	0.802	0.654	0.692	0.667	0.598

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). For column (1), it includes lag 2 onwards of R&D intensity and the growth rate of Q and lag 3 onwards of the growth rate of sales for the difference equations, and the second lagged differences of R&D intensity and the growth rate of Q and the third lagged differences of the growth rate of sales for level equations. For the other 4 columns, it includes lag 2 onwards of R&D intensity and the growth rate of Q, and lag 3 onwards of the growth rate of sales and cash flow ratio for the difference equations, the second lagged differences of R&D intensity and the growth rate of Q, and the third lagged differences of the growth rate of sales and cash flow ratio for the level equations.

Another measure of Tobin's average Q is stated in equation below. Using this measure, with the same restriction of no observation with the value of average Q bigger than 10, I re-estimate my main regressions and the results are presented in table A6.4 below.

$$Q'_t = \frac{MVS_t + TA_t - CE_t}{TA_t}$$

Where:

MVS_t: market value of outstanding shares, which is equal the product of a firm's share price and the number of common stock shares outstanding.

CE_t: book value of common equity

TA_t: book value of total assets

Table A6. 4: Main results with the one-period-ahead growth rate of Q' (another measure of Tobin's average Q)

Model	(1)	(2)	(3)	(4)	(5)
R&D intensity (lag 1)	0.4711***	0.4113***	0.3811***	0.3689***	0.3741***
	(0.0851)	(0.0834)	(0.0834)	(0.0853)	(0.0850)
R&D intensity (lag 2)	0.0400	0.0625*	0.0603*	0.0570*	0.0587*
	(0.0302)	(0.0330)	(0.0339)	(0.0339)	(0.0340)
Growth rate of average Q' (lag 1)	0.0335***	0.0370***	0.0449***	0.0438***	0.0435***
	(0.0103)	(0.0120)	(0.0128)	(0.0128)	(0.0128)
Growth rate of sales (lag 1)	0.0134	0.0104	0.0162	0.0166	0.0164
	(0.0106)	(0.0111)	(0.0118)	(0.0118)	(0.0118)
Cash flow (lag 1)		0.0960**	0.0960**	0.0987**	0.0978**
		(0.0423)	(0.0459)	(0.0461)	(0.0461)
PMC (lag 1)			2.6539***	1.6037***	1.6630***
			(0.8065)	(0.5913)	(0.5808)
PMC-squared (lag 1)			-1.6323***	-0.9615***	-0.9938***
			(0.4629)	(0.3370)	(0.3318)
Intra-industry spillovers (lag 1)				0.0037***	0.0037***
				(0.0007)	(0.0007)
Patent-weighted inter-industry spillovers (lag 1)				-0.0132***	-0.0136***
				(0.0035)	(0.0035)
LOS_i					0.0300***
					(0.0057)
CR_i					-0.0048***
					(0.0016)
RL_i					0.0031***
					(0.0009)
Industry effects	Yes	Yes	No	No	No
Country effects	Yes	Yes	Yes	Yes	No
Year effects	Yes	Yes	Yes	Yes	Yes
Number of Observations	22985	22783	22381	22381	22381
Number of firms	3616	3614	3607	3607	3607
Number of instruments	60	67	50	52	41
AR(1)	0.000	0.000	0.000	0.000	0.000
AR(2)	0.316	0.368	0.301	0.281	0.287
Hansen test (P-value)	0.609	0.780	0.699	0.732	0.702
Difference-in-Hansen test (level equation)	0.266	0.634	0.778	0.796	0.697

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). For column (1), it includes lag 2 onwards of R&D intensity and lag 3 onwards of the growth rate of Q and sales for the difference equations, and the second lagged difference of R&D intensity and the third lagged differences of both the growth rate of Q and sales for level equations. For the other 4 columns, it includes lag 2 onwards of R&D intensity, lag 3 onwards of the growth rate of Q and sales and cash flow ratio for the difference equations, the second lagged difference of R&D intensity, and the third lagged differences of the growth rate of Q and sales and cash flow ratio for the level equations.

Table A6. 5: Results of model (6.2) without second lag of R&D intensity

Model	(1)	(2)	(3)
R&D intensity (lag 1)	0.8228***	0.2523***	0.3475***
	(0.0181)	(0.0375)	(0.0816)
Growth rate of average Q (lag 1)	0.0195***	0.0157***	0.0368***
	(0.0020)	(0.0019)	(0.0112)
PMC (lag 1)	0.8467***	0.7567	1.9268***
	(0.1895)	(0.6840)	(0.6673)
PMC-squared (lag 1)	-0.4954***	-0.4075	-1.1534***
	(0.1090)	(0.3655)	(0.3771)
Intra-industry spillovers (lag 1)	0.0015***	-0.0017	0.0043***
	(0.0002)	(0.0034)	(0.0007)
Patent-weighted inter-industry spillovers (lag 1)	-0.0023***	0.0307**	-0.0169***
	(0.0009)	(0.0147)	(0.0036)
Cash flow (lag 1)	-0.0442***	-0.0697***	0.1150**
	(0.0070)	(0.0126)	(0.0486)
Growth rate of sales (lag 1)	-0.0104***	-0.0027	0.0251*
	(0.0027)	(0.0027)	(0.0135)
LOS_i	0.0074***		0.0361***
	(0.0008)		(0.0053)
CR_i	-0.0010*		-0.0052***
	(0.0005)		(0.0017)
RL_i	0.0009***		0.0038***
	(0.0003)		(0.0010)
Country effects	No	No	No
Year effects	Yes	Yes	Yes
Number of observations	22407	22407	22407
Number of firms	3615	3615	3615
Number of instruments			41
AR(1)			0.000
AR(2)			0.273
Hansen test (P-value)			0.652
Difference-in-Hansen test (level equation)			0.877

Note: standard errors are in parentheses. ***, ** and * indicate the level of significance at 1%, 5% and 10%, respectively. All regressions include a constant. For OLS estimation, I use robust standard errors. For system GMM estimation, the instrument selection process is based on Kiviet et al. (2016). It includes lag 2 onwards of R&D intensity, lag 3 onwards of the growth rate of Q and sales and cash flow ratio for the difference equations, the second lagged difference of R&D intensity, and the third lagged differences of the growth rate of Q and sales and cash flow ratio for the level equations.