The relationship between Research & Development expenditure and the firm's market share in the UK highly innovative industries

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Thesis Summary

In spite of the widely-held focus on innovation, on the one hand, and the popularity of market share-oriented strategy, on the other, in strategic management, there is a dearth for evidence about the relationship between in-house R&D and market share.
The research question is: 'Does an increase in a firm's R&D expenditures (relative to the industry's total or the firm's rivals) leads to an increase in the firm's market share?' It explores whether a firm could grab a larger market share at the expense of its competitors through a growth in the share of R&D expenditures in the industry. The sample of industries includes Pharmaceuticals and Biotechnology, Aerospace and Defence, Software and Computer services, Technology and Hardware equipment, Automobiles and Parts, which together account for more than a half of the UK1000 R&D activities. The methodology employs econometric estimates of production functions containing R&D variables. This research findings support the Sources of Growth theory: in short and medium terms, increasing conventional inputs such as capital, labour, human capital, and intermediate inputs increases market share of the top and middle end firms in the UK highly innovative industries. The research findings are also consistent with the 'first-mover advantage' theory: the lagged market share is significant and positive, showing that 'success breeds success', in line with Philips' (1966) arguments. However, although according to the economic growth theory innovation leads to economic growth at a macro-level, at the level of an individual firm this may not be so obvious in short and medium terms in regards to the growth in market share of the top and middle end firms in the UK highly innovative industries. In spite of the prevailing view that a growth of market share is the primary strategic objective firms seek to achieve at any cost, the findings of this research suggest that firms do not necessarily aim their in-house R&D at increasing a market share.

Key words: innovation, investment, spillovers, intra-industry, inter-industry

Declaration

I hereby declare that this thesis is my own work and effort and that it has not been submitted anywhere for any award. Where other sources of information have been used, they have been acknowledged. The work has been edited by my supervisors to whom I am grateful.

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List of Abbreviations

A&D	Aerospace and Defence
A&P	Automobiles and Parts
BERR	Business, Enterprise and Regulatory Reform
BIS	Department for Business, Innovation and Skills
BvD	Bureau van Dijk
DIUS	Department for Innovation, Universities and Skills
EU	European Union
GDP	Gross Domestic Product
ICB	Industry Classification Benchmark
IFRS	International Financial Reporting Standards
MS	Market Share
M&A	Mergers and Acquisitions
OECD	Organisation for Economic Co-operation and Development
P&B	Pharmaceutical and Biotechnology
R&D	Research and Development
ROE	Return on Equity
S&CS	Software and Computer Services
SCP	Structure-Conduct-Performance
T&HE	Technology and Hardware Equipment
UK	United Kingdom
US	United States (of America)

Chapter 1: Introduction

Employing a firm's market share as its performance indicator, this research aims to empirically explore its relationship with Research & Development (R&D) expenditure in highly innovative industries in the UK. The research is relevant to both academics and practitioners, asking the question: 'Does an increase in a firm's R&D expenditures (relative to the industry's total or the firm's rivals) leads to an increase in its market share?

This report is structured around five chapters. Chapter 1 introduces the research context and aims, addressing the research question, and providing justification for the study. It also discusses the choice of market share as a performance indicator. The research's contributions to knowledge, management practice, and to some extent, policy implications are also addressed. Chapter 2 contains a critical literature review of how the scientific knowledge on innovation and market structure has historically evolved in economics. It is followed by Chapter 3: research methodology - description and justification of the conceptual framework and method. Chapter 4 discusses the empirical findings. Finally, Chapter 5 concludes the report, summarizing the main themes.

1.1 Background

There is a general consensus that technical progress promotes economic growth at the macro-level and that significant part of technical progress derives from R&D activity of profit-seeking firms. Marx (1867/1919) argued that capitalists reinvest their profits in capital equipment not simply to expand or substitute exhausted production capacity, but also, to take advantage of technical progress and thus, to remain competitive. While classical and early neo-classical economists treat technical progress as exogenous, Schumpeter, (1942) argues that corporate hunt for profits drives the implementation of efficiency improvements coming from innovation; therefore, it is an important determinant of dynamic efficiency. This Schumpeterian view is incorporated into neo-classical frameworks of endogenous growth theory (Romer, 1986, 1990; Lucas, 1988) which link macro-economic growth to firms' R&D.

The creation of new knowledge at the firm level is seen as a major source of firms' competitive advantage and long-run superior performance (Barney, 1991; Drucker, 1995; Spender and Grant, 1996; Brown and Eisenhardt, 1997; Huggins and Izushi, 2006). Yet, company-financed R&D is associated with several interacting simultaneous market failures such as uncertainty, inappropriability, and indivisibility (Spence, 1984). R&D is often risky, and its output (i.e., knowledge) has a public-good quality, being subject to knowledge spillovers. Modern research (e.g. Huggins and Izushi, 2007) use the notion of 'knowledge communities' in explaining how knowledge is linked and transferred across organizations and economies. The firm costs of producing R&D output are also 'lumpy' (fixed costs), not infinitely divisible. Also, there are increasing returns to scale associated with the use of new technology (Oliveira *et al.*, 2006; List and Zhou, 2007).

Reflecting those market failures, existing theories of competitive advantage – resource-based, relational and industry-structure, provide different normative prescriptions as to innovation and R&D strategy (Dyer and Singh, 1998). Of the three, the resource-based theory stresses the importance of resource accumulation through innovation and R&D most strongly. In-house R&D is important as technical know-how is often 'sticky' due to its tacit, complex, and specific nature, which makes it hard to identify, and costly to transfer across organizations (Zander and Kogut, 1995; Szulanski, 1996; Galunic and Rodan, 1998; Rodan, 2005). The theory also suggests that firms should protect their high-value knowledge as their sustainable competitive advantage (Dierickx and Cool, 1989; Barney, 1991). By contrast, relational theory places less importance on capacity-building through in-house R&D, advocating that firms should share valuable know-how with their alliance members (Dyer and Singh, 1998). For industry-structure theorists, a firm's sustainable competitive advantage depends on its relative bargaining power based on the erection of entry barriers (Porter, 1980). The role of innovation and R&D is least featured in the industry-structure analysis.

In fact, a firm's ability to generate profitable innovations can take a number of other forms than in-house R&D, including 'out-sourcing' to capture the benefits of R&D

performed by other firms (Chesbrough, 2003) and through mergers and acquisitions (M&A). Firms acquire valuable knowledge also through reverse engineering, analyzing patent applications, scientific and trade publications, employing competitors' staff, attending trade shows and conferences, learning from suppliers, customers, and collaborators (Levin *et al.*, 1987; Appleyard, 1996), and illegal practices, e.g. bribes to obtain trade secrets (Carlton, 1992).

In assessing the contribution of in-house R&D at the firm level, an indicator of the firm performance has to be chosen. Various indicators exist for the measurement of firm performance, such as value added, profitability, productivity/sales growth, and market value. Among such indicators, market share is one of the most frequently used by managers and business analysts. A firm's market share generally relates to its long-run profitability, and it is also a growth performance indicator, both of which contribute to its popularity among practitioners, shareholders and general public. Market share enables measurement of firm's performance against its peers and direct competitors. Its main advantage is that it normalizes for factors largely outside the control of the firm, e.g., the effect of inflation or sector growth/decline caused by factors in other sectors or the general economy (industry-wide variables such as investment cycles, economic cycles and changes in taxation or interest rate). Also, it eradicates a potential problem where a time-lag between growth in market share and profits exist, especially when this time-lag differs between industries (Scherer, 1980). For example, if early sales are completed at low margin to 'build footprint' and subsequent contracts are higher margin (upgrading and maintenance are profitable after consumers are locked-in). Market share is more stable than other measures, for example, ROE.

Traditional strategic thinking argues that increased market share is better almost regardless of what the company has to do to achieve it. However, this is not always the most effective approach as the outcome of pursuing a market share varies considerably among industries and market situations (Jackson, 2007). Setting market-share goals has immense resource-allocation implications (Buzzel and Wiersema, 1981). It also depends on competitors' strengths, the resources available to support a strategy, and the willingness of management to forgo present earnings for future results. For instance, a small competitor selling frequently purchased, differentiated consumer products can achieve satisfactory results with a small market share, e.g., by having a higher rate of return than bigger firms. The smaller, more profitable company may avoid going head-to-head with larger, more powerful competitors, deploying its investments into segments where the dominant players do not compete. In essence, growth is not always good – in fact, some growth actually destroys value. This suggests that firms may not necessarily aim their in-house R&D at increasing a market share.

In spite of the widely-held focus on innovation, on the one hand, and the popularity of market share-oriented strategy, on the other, in strategic management, there is a dearth for evidence about the relationship between in-house R&D and market share. The literature shows that the relationship between market share and innovation depends on the industry characteristics, especially on the concentration level: whether it is perfect competition, oligopoly or monopoly. The literature is focused on the social aspects of welfare: market share is conceived in the context of monopoly/oligopoly and its impact upon firms' conduct within an industry (e.g. pricing). For managers at individual firms, the existing evidence concerning R&D expenditure at the level of an individual firm is scarce and inconclusive as to its contribution to the firm's growth in market share.

1.2 Research Aim and Research Questions

Against the background, this research aims to fill this gap, addressing both theoretical and practical issues, combining academic and experiential knowledge (March, 2006). The research question is: 'Does an increase in a firm's R&D expenditures (relative to the industry's total or the firm's rivals) leads to an increase in the firm's market share?' It explores whether a firm could grab a larger market share at the expense of its competitors through a growth in the share of R&D expenditures in the industry. Viewed differently, the research asks if firms aim their in-house R&D strategically at growing their market share. The research tests a hypothesis that an increase in the share of R&D expenditures in the industry feeds through, after a time-lag, to an increase in market share. The hypothesis is in levels, emphasizing the direction of the relationship, not the exact magnitude. It also takes into account that a race of increasing market share may grow the size of the industry's market by encouraging innovative activities.

The sample of industries examined includes Pharmaceuticals and Biotechnology (accounting for 36% of the UK1000 top investing in R&D companies total), Aerospace and Defence, Software and Computer services, Technology and Hardware equipment, and Automobiles and Parts sectors (each of them accounting for on average 6% of the UK1000 top investing in R&D companies total), which together account for more than a half of the UK1000 R&D activities (R&D Scoreboard, 2009). According to Ortega-Argiles *et al.,* (2008) classification of Industry Classification Benchmark (ICB) codes of industry and service sectors (used in other similar studies e.g. in Cincera and Ravet, 2011) to high-, medium- or low-tech sectors, the selected industries belong to the high-tech sectors.

1.3 Contribution to Knowledge and Skills

Nelson and Winter (1978) emphasize that market structure and innovation are endogenous with the flows between them heading both ways. However, in the economics literature on the relationship between market structure and innovation, many studies see the causation coming from structure to innovation (Nelson and Winter, 1982b). Market structure may affect the amount of innovative activity. Dominant firms may reinvest their returns on R&D and grow relative to their rivals. On the other hand, the successful innovation may produce supernormal profits and create entry barriers which protect those excess profits. Likewise, a successful 'fast-second' copy-cat player may monopolize the industry. It is surprising that scientific research based on Schumpeterian hypothesis has often ignored the reverse causal relationship, with some notable exceptions such as Phillips' (1971) research of the aircraft industry and Levin's (1978) exploratory empirical work. This research aims to provide a richer, more subtle interpretation on how innovation influences market structure. Due to data constraints, the parameters of the stochastic process (e.g., the level of technological risk, entry and entry barriers, efficiencies), which are likely to account for inter-firm differences in R&D intensity, are not accounted for, although inferences are made to some extent from the literature available and research findings.

The research findings will be also of interest to investors, managers, consultants, professional bodies, and government. The study offers insights to companies examining their R&D investment needs, and assistance to analysts and investors.

The research has a logico-scientific design: valid argument, empirical truth, and boundary conditions. It tests a theory that explains the causes and consequences of the relationship between R&D and firm's market share in its context. The idea is not novel but well articulated, structured, and linked in a way that suggests new bearings and strategies for practical applications (Rindova, 2008).

The rest of the study consists of a critical literature review (Chapter 2), followed by research methodology (Chapter 3), research findings and discussions (Chapter 4), and conclusion (Chapter 5).

Chapter 2 : Literature Review

This chapter critically reviews how the literature on innovation and industry structure has historically evolved in economics, identifying gaps in the literature and justifying the contribution of this study to it. Although the two-way causality between innovation and industry structure is generally accepted nowadays, its research did not take place in both directions at the same time. Studies of how different industry structures affect innovation are older and more extensive (e.g., Scherer; 1980; Kamien and Schwartz, 1982; Baldwin and Scott, 1987; Cohen and Levin, 1989). By contrast, the other direction of causality – how firms' innovative activities shape industry structure – is less researched (e.g. Scherer, 1980; Kamien and Schwartz, 1982; Geroski, 1991).

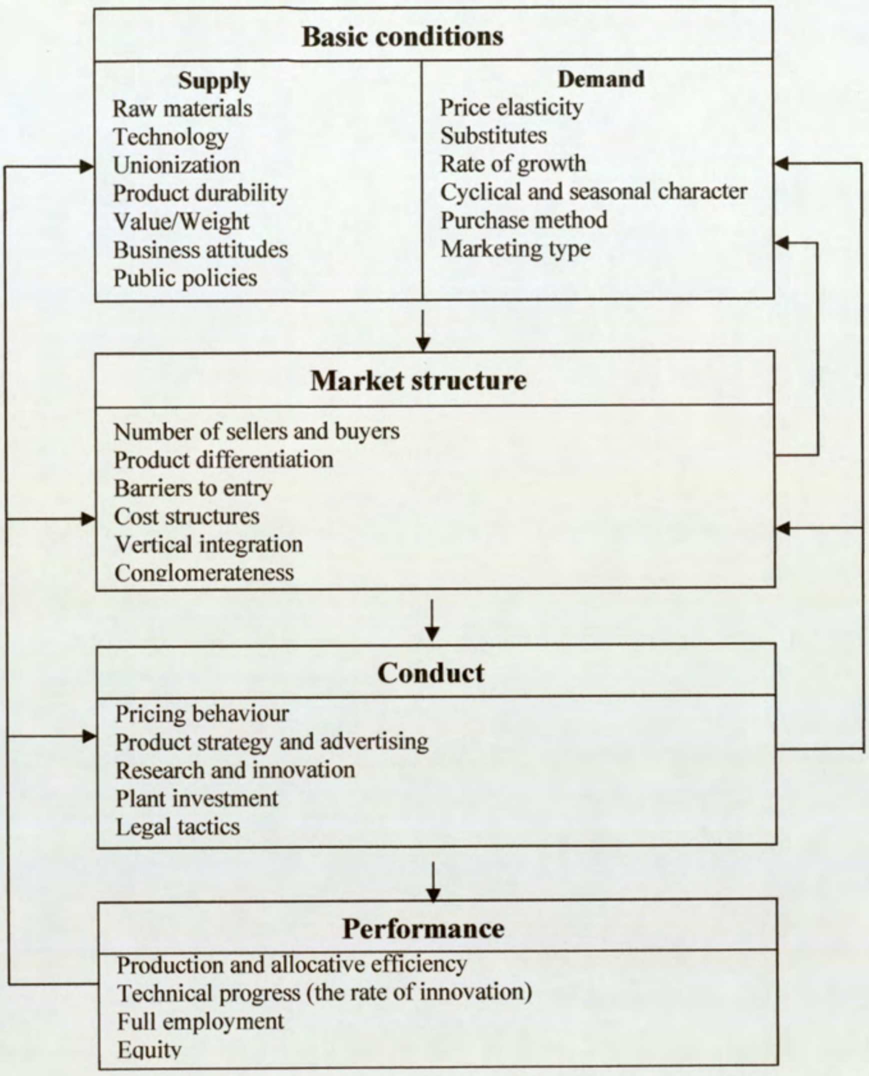
Given the early interest of industrial organisation economists in social welfare and anti-trust legislations, studies of the relationships were initially based on the Structure-Conduct-Performance (henceforth, SCP) framework that focused upon the impact of monopoly/oligopoly upon firms' conduct within an industry (e.g. pricing) (Section 2.1). Variables describing firm size and industry structure were highlighted and their impact upon innovation was examined. Although some studies show that market structure influences innovative activities, empirical evidence remains mixed and often inconclusive due to methodological issues (Section 2.2). Subsequent progress in research suggests that industry structure and innovation are endogenous. It is argued that they are both dependent on other industry characteristics such as customer preferences, technological opportunities, and appropriability conditions (Section 2.3). Theoretical studies also explore the other direction of the loop causality – the influence of innovation on industry structure. They show that innovation impacts industry structure through two mechanisms. One is the change in the optimal scale of production due to innovation. The other is the erection of technology-based entry barriers (Section 2.4). Recent theoretical research, such as the work of Geroski (1991), explores the dynamics of innovation and industry structure by focusing upon the role of entry in the industry dynamics. The research suggests that a cohort of innovative entrants displaces inefficient incumbents, leading to modifications in the nature of entry barriers and productivity growth (Section 2.5). Theoretical studies have gone to great lengths to reveal the complexity in relationships between innovation and industry structure and particularly the ways in which innovation affects industry structure. However, there is a dearth of empirical, firm-level evidence on the impact of R&D conducted by firms already operating in the industry upon their market shares.

2.1 Structure-Conduct-Performance (SCP) Framework

2.1.1 An overview of the SCP framework

The SCP framework depicts the influence of an industry's structure on the conduct of producers and the performance of both the industry and the producers. Industrial performance refers to how well industries operate to maximize economic welfare. According to the SCP framework (Mason, 1939; Bain, 1956), industrial performance depends on firms' conduct in the market (e.g., pricing behaviour, advertising, R&D, plant investment), which in turn depends on industry structure (e.g., the number of sellers and buyers, product differentiation, entry barriers) as shown in Figure 1.

Figure 1: The Structure-Conduct-Performance Model (Source: adapted from Scherer and Ross, 1990, p.5).



Industry structure often refers to the concentration of sellers, where perfect competition (i.e., no single firm can influence the price of the product sold) and monopoly are the extreme cases. Perfect competition is characterised by numerous price-taking firms, perfect information, homogeneous products, and low-entry barriers. Oligopoly refers to the dominance of a market by a few firms whose decision-making is based on mutual interdependence. Pure monopolists, oligopolists, and monopolistic competitors dictate to some extent market prices; each firm can sell more of its output, under certain demand conditions only by dropping the price of its output. An increasing number of suppliers decreases the price of outputs sold, ultimately to the competitive equilibrium price (Cournot, 1838).

Under the SCP framework, industry structure is determined by given supply and demand conditions. Generally, scale economies lead to market concentration since a few, relatively large companies produce and market their products at lower average cost per unit than other companies. The opportunity of scale economies tends to diminish over time as the size of market stabilises. Scale economies are observable in perfectly competitive markets (if each of the firms is large enough to enjoy all scale economies), naturally monopolistic structures (in which one firm enjoys all scale economies), or oligopolistic structure (in which a few firms enjoy all scale economies). Which industry structure will prevail depends on the relevant technology and industry size.

Market growth does not change the concentration level significantly although, without it, the market would become increasingly concentrated (Scherer, 1980). Industry structure is also shaped by M&A which increases concentration. Company diversification and vertical integration represent both the static dimension of industry structure and the dynamic one (the process of altering it). The static dimension illustrates the degree of firms' coverage of the whole process: raw materials, production, intermediaries, final product or/and service development, distribution, and customer relations (Scherer, 1980). Greater coverage means greater market power and potential for its abuse. Dynamically, firms seek to vertically integrate 'upstream' (backward) to gain control over the production of raw materials and intermediate inputs instead of purchasing them from suppliers. Firms also seek to 'downstream' (forward) to gain control over the development of the final product or/and service, distribution, and customer relation management.

Industry structure is also affected by politics, state/regional policies and international law within which industries work (e.g., patent, tariffs, anti-trust law, taxations/tax exempts, infant industries protection, government procurement), the prevailing socioeconomic values, and culture of the business society.

2.1.2 Critics of the SCP Framework

Critics argue that the SCP framework refers only to the causal one-way flow from structure to conduct and performance. It adheres to the constricted static allocative efficiency and unrealistic assumptions (e.g., consumer tastes and technology are constant; profit is generated when an industry is in long-run equilibrium). As opposed to static efficiency, dynamic efficiency is associated with the invention of new products and/or services, and the employment of innovative processes and techniques of production which lower costs and prices of firms' output. The two forms of efficiency are not always compatible as they refer to different notions of competition: perfect competition and competition through innovation.

The dynamic allocative efficiency, associated with 'Austrian' school of economics, promotes the view that competition through innovation is an ongoing process (Scumpeter, 1942). Firms conduct may influence both industry structure and its demand and supply conditions. For example, marketing (advertising, public relations) may create brand loyalty, product differentiation, and/or barriers to entry. Advertising may decrease price-elasticity of demand for the firm's products and/or services, permitting firms to elevate price and keep their loyal customers. Within an industry, the degree of product and/or service differentiation refers to the extent to which buyers distinguish between sellers' outputs. Products are perfectly homogenous when in the buyers' eyes products are perfect substitutes. Suppliers can elevate the price of differentiated product and/or services without sacrificing their entire output quantity. Intensified R&D may lead to a high rate of innovation and, hence, alterations of cost conditions and/or new products, which in turn help to erect barriers to entry (Scherer, 1980).

Critics also suggest the existence of stochastic determinants of industry structure, such as, luck, historical chance, managerial skills, and efficiency, which are incorporated in stochastic growth models (Scherer, 1980). A more sophisticated analysis of the determinants of industry structure may bring together the static, dynamic and stochastic elements.

2.2 Empirical Studies of Industry Structure-Innovation Relationships

Studies reviewed in this section test the following two hypotheses:

- Innovation increases more than proportionately with firm size;

- Innovation increases with the increase of market power.

The two hypotheses are not identical to each other. Monopoly power is not synonymous of large scale; even if a firm is of large size, it does not mean that the firm possesses monopoly power (Scherer, 1980; Kamien and Schwartz, 1982). This section also reviews other studies that involve different variables shedding lights on the subject.

2.2.1 Firm size and innovation, and other relevant relationships

Early empirical tests of the hypothesis that large firms are more than proportionately innovative than small ones were generally undertaken with a linear regression of inputs or/and outputs of firm R&D on a measure of size (the notable exceptions to which include Nelson *et al.*, 1967; Gellman Research Associates, 1976; Pavitt *et al.*, 1987). Their results gave rise to studies that further investigated the relationships of other corporate characteristics (e.g., diversification, vertical integration, financial capability) with size and innovation (Cohen and Levin, 1989). As discussed in Lee and Sung in their work: *'Schumpeter's Legacy: A New Perspective on the Relationship between Firm Size and R&D'* (2005), the empirical literature provides diverse results, however, they found that the relationship between R&D and size is likely to be stronger for industries with higher technological opportunities. Key findings from the studies on the subject are as follows:

- Larger firms may take more advantage of innovation than smaller ones. Such advantage includes higher R&D returns from large volumes and fixed R&D costs spread over larger sales volumes. Some recent US studies (e.g. Cannolly and Hirschey, 2005) find support for size advantages in the valuation effects of R&D expenditures.

- Large diversified firms may appropriate more benefits from innovation than smaller ones. A large firm with a brand name can more easily utilise unforeseen products or/and service penetrating new markets than non-diversified firms (Nelson, 1959). Scott and Pascoe (1987) find that R&D investment is path-dependent on firm's level of diversification into technologically-related industries. However, diversified R&D prevents firms from exploiting economies of scale and may also increase managerial costs (Asakawa, 2001; Cincera and Ravet, 2011).

- Large firms can support large, diversified R&D portfolios amplifying the probability of creating innovative product or/and service, hence, realising higher returns on R&D expenditure. There are economies of scope to R&D, particularly in vertically integrated industries, which vary over the life-cycle of the technology (Malerba, 1985).

- Large firms benefit from scale advantages in the R&D process; there are scale economies in the technology of R&D. Researchers are more productive when they have more colleagues with whom to interact and tap into each other's knowledge domains.

- Larger firms could finance their R&D as size confers an ability of generating internal funds. Large firms are also in a better position to borrow money for R&D: size confers stability and trust for creditors. Critics argue that liquidity and profitability are only a 'threshold factors' essential for R&D.

- Large firms are able to develop and bring to the market their innovative products and/or services faster, more effectively and efficiently than smaller firms. Their R&D processes are more productive thanks to the complementarities between R&D and other departments such as financial planning, manufacturing, and marketing.

However, some cast doubts as to such beneficial effects of firm size upon R&D and innovation.

- Critics argue that large firms can have less incentive to innovate. The study of innovation in transition economies found that innovation is driven by new firms (Aghion and Schaffer, 2002). Large firm structure may stifle innovation due to red-tape issues (Schumpeter, 1942; Baldwin and Gellatly, 2003). As firm size increases, R&D efficiency decreases as management control is diluted and the researchers' motivation declines as the returns on their efforts shrink (Oster, 1982). Small firms as a cohort, in some sectors, are responsible for higher percentages of innovations and employment growth than large firms (Acs and Audretsch 1988, 1991; Davidsson *et al.*, 1994; Audretsch, 2002). Small firms are more likely to produce radical innovation although larger firms may be better at commercialising them (Henderson, 1993).

- The relationship between firm size and innovation may depend on industry conditions, specifically on market structure. Acs and Audretsch (1987) suggest that large firms are disproportionately more innovative than small firms in concentrated industries with high entry barriers, whereas small firms are more innovative in an environment of low-concentrated, immature industries. Dorfman's (1987) study of electronics industries supported this.

Early research (e.g., Horowitz, 1962; Hamberg, 1964; Comanor, 1967) found a weak positive correlation between firm size and a measure of innovation. Mansfield (1964) and Grabowski (1968) showed that such relationship exists only in some industries, e.g. chemicals. Later research found that the relationship between size and R&D is positive and monotonic (Link, 1980; Loeb, 1983; Meisel and Lin, 1983). Pavitt (1983) found that the largest firms have highest ratio of significant innovations per employee.

Other studies present mixed results. Scherer (1965a, 1965b), Philips (1971), Malecki (1980), and Link (1981) find that the relationship between firm size and R&D is non-linear: R&D increases with firm size up to a threshold, then levels off, and declines in some industries while such relationships do not exist in others. By contrast, Bound *et al.* (1984) show that R&D intensity initially decreases and then increases with firm scale; firms on both ends of the size distribution were more R&D intensive than the firms in between. In a similar vein, Pavitt *et al.* (1987) find that the firms on both end of the size distribution were accountable for a disproportionate share of significant innovations.

These early studies used simple models and aggregated data, not always controlling for industry effects and distinguishing between firm size and unit size. Accounting for these, Cohen *et al.* (1987) find that neither of the size variables significantly influenced

R&D intensity. Scherer (1984b) provides evidence that the size effect does not appear in all industries.

Research on the relationship between R&D and market value (where market share has interaction effects with R&D upon market value) also sheds light on the subject. Hall and Vopel (1997) find that the market value of US firms during 1987–1991 is higher for firms with greater R&D expenditures, and the effect of R&D expenditures upon the market value is higher for a higher market share. Investigating whether the advantage to high share firms relies on a Schumpeterian rationale (i.e., large scale firms anticipate a lower cost of funding R&D) or it is due to the Gilbert-Newberry strategic pre-emption effect (i.e., the threat of new successful entrant with ability to drag industry profits down provides greater incentives for existing large-share firms to innovate), they supported the Schumpeterian reasoning. In a similar vein, Blundell *et al.* (1999) find that the effect of R&D on market value is greater for high market share firms although they attribute this to the Gilbert-Newberry effect: high market share firms are more incentivised to pre-emptively innovate than other firms.

Recent studies on firm's investment decisions during recessions (e.g., Srinivasan *et al.* 2010) found that, *all other things held equal*, in downturns, the higher the firm's market share, increases in R&D investment increases its profits. However, the higher the firm's market share, increases in marketing expenditures decreases its profits (but higher the firm's financial leverage, increases in marketing expenditures increases its profits).

Some contemporary studies (e.g., Duso *et al.* 2011) suggest that R&D may exert a negative effect on market share, but they found that this effect is weak and the results may not be conclusive.

Unlike the scale economies hypothesis, some argue that firm superiority, luck, and strategy lead to a firm's growth. According to the scale economies hypothesis, size confers an advantage. Against this, they suggest that it is the firm superiority (innovativeness, management) or efficiency (inputs allocation) in the past that leads to firm growth and excess profits (Eckard, 1995; Davies and Lyons, 1996). In their view, only after this growth process, statistically significant positive relationships between size and profitability are established (Scherer, 1980). Geroski (1999) and Lotti *et al.*

(2003) echo this, contending that smaller, risk-taking firms grow more rapidly than their larger rivals. Lucky firms undergo a virtuous circle in which re-investment of excess returns generates greater returns and further growth. Again, a statistical analysis will show a positive relationship between market share and profitability; however, its basis is not economies of scale but luck.

In conclusion, studies on the first hypothesis – innovation increases more than proportionately with firm size – remain statistically inconclusive (Cohen and Levin, 1989). With the exception of Bound *et al.* (1984) and Cohen *et al.* (1987), they use non-random samples, not accounting for selection biases. Not all the studies control for firm and industry characteristics other than firm size although the significance of firm and industry effects are recognised (Scott, 1984). Possible collinearity between firm and industry effects, and firm size was not always considered, either. Only a few studies recognise the existence of inter-industry differences in the relationship between firm size and innovative activities (Kamien and Schwartz, 1982). A few use separate regressions for each industry to control for industry effects (e.g., Mansfield, 1968; Scherer, 1984) while others employ fixed industry effects model (e.g. Bound *et al.*, 1984; Scott, 1984; Cohen *et al.*, 1987). There is an issue of the unit of analysis. Most large firms are conglomerates of many units operating in different industries, therefore, some of the arguments refer to firms (e.g. surmounting capital market imperfections), while others to business units (e.g. cost spreading). Scale economies in R&D may appear at the level of firm's activities in specific markets. In many studies, diversification is accounted for by the use of crude measures (e.g. the number of industries in which the firm operates).

2.2.2 Monopoly and innovation

As for the second hypothesis – innovation increases with the increase of market power – there is some evidence that monopolistic firms innovate more than other firms (Scherer, 1967a). However, it is open to debate whether this is a confirmation of the one-way causal effect of industry structure on innovation or it is a statistical artifact due to poor quality of data. Blundell *et al.* (1999) argue that dominant firms' large scale is due to greater R&D investment. Also, there is an issue of unobserved heterogeneity, e.g., firms anticipate different technological opportunities and appropriability conditions (Cohen and Levin, 1989). Different measures of innovation used are also problematic. Solow residuals, interrelated with market power by construction, in part represent the diffusion of innovative activities (Hall, 1988). R&D expenditures, a measure of innovation input, are sometimes undeclared in firms' accounts. Patents, a measure of innovation output, may be biased as not all inventions are patented and implemented.

For Schumpeter innovation is a means of generating monopoly profits and sustaining them (Kamien and Schwartz, 1982). This allows two contrasting interpretations. First, the prospect of monopoly and extraordinary profits through innovation incentivises firms to invest in R&D (Scherer, 1980). Here, innovation shapes industry structure, leading to concentration and monopoly, which will be discussed in Section 2.4. This hypothesis provides the foundation of the patent protection legislations. To generate extraordinary profits, a firm must exercise temporary monopoly power to prevent/retard imitation of its innovative product and/or services. This is achieved through government legislations (e.g., patents, trademarks, copyrights), trade secrets, illegal practices or erection of entry barriers. Second, ex-ante oligopolistic structure and ex-ante monopoly power provide greater incentives for dominant firms to innovate than other firms as dominant firms are more capable to undertake, deal with innovation process, and realise the rewards (Scherer, 1980). An oligopolistic structure facilitates more stable environment for the oligopolists by decreasing uncertainty linked with ferocious rivalry that undermine the incentive for innovation (Cohen and Levin, 1989). The power to exclude rivals by limiting or preventing copy-cats or/and erecting entry barriers are the methods of gaining and sustaining monopoly profits (Kamien and Schwartz, 1982). Here, industry structure (existent monopoly power) influences innovation. The empirical research tested directly the hypothesis about the effects of ex-ante industry structure on innovation, and only indirectly the hypothesis about the effects of ex-ante market power on innovation (Cohen and Levin, 1989), leading to several arguments:

- Monopolist is in a better position to finance its R&D both internally ('deep pockets') and externally (Bhattacharya and Ritter, 1983). However, in case of radical innovations in a one-shot game, the efficiency effect is insignificant and the challenger will invest more.

- As the total industry profits shrink when new entrants successfully enter the market, incumbents have greater strategic incentives to pre-emptively innovate. As a consequence, the industry evolution is described in terms of continual dominance (Gilbert and Newbery, 1982). The efficiency effect plays a significant role in this continual dominance in industry structures characterised by persistent duopoly, cycles of innovative activities, and uncertainty (Cohen and Levin, 1989).

- Dominant firm with monopoly power owed to its current product or/and services is in a better position to expand that power to its new products or/and services, e.g., through its supply chain management or brand name (Schmalensee, 1978; Shaked and Sutton, 1982; McCormick *et al*., 2006; Lynn, 2010).

- The threat that the dominant firm might strike back may prevent challengers to imitate the dominant firm's invention. Product exclusivity combined with the firm's ability to upgrade it when copy-cats appear depress imitative competitors (Kamien and Schwartz, 1972a)

- A dominant firm with monopoly power owed to its current product or/and services may employ other practices, legal (shipping costs savings by purchasing both the new and current products and/or services) and illegal (directly binding sales of the existing product and/or services to the new ones), to promote its new product or/and services.

- A dominant firm with monopoly profits may afford to employ the most innovative individuals (Kamien and Schwartz, 1982; Cohen and Levin, 1989).

However, some point to a potential reluctance of monopolists to heavily invest in R&D.

- Monopolists enjoying excessive profits currently may be less enthused to hunt for extra profits than a firm, making only normal profits; additional leisure may be traded off against extra profits. The current monopolist may be more anxious about shielding its existing monopoly than gaining a new one. The incumbent may also act slower replacing its current product or/and services with the new one (Reinganum, 1983). There is an argument made by Arrow (1962) for process innovations and Usher (1964) for product innovations that the new entrant's incentives to innovate are always higher than the otherwise identical incumbent enjoying monopoly profits on the current product or/and services. This is because the incumbent sees its gain from the new invention as the difference between its existing monopoly profits and the profits that might be generated from the new invention, while for the new entrant the profits from the new invention are the gain.

- Monopolists are in a better position to respond more swiftly to rivals' inventions and become 'a fast-second' due to resources availability, brand, and distribution channels. This allows them to take a wait-and-see approach until someone else successfully innovates (Baldwin and Childs, 1969).

Furthermore,

- There is a disagreement about the right amount of monopoly power necessary to encourage innovation. Some argue that the marginal losses in static efficiency as a result from the departure from perfect competition are trivial (e.g. Harberger, 1954), while others disagree; for neo-classicists they should equal the marginal social gains as a result of increased innovation. There is no comparative research evidence of these losses with the benefits from additional innovation (Kamien and Schwartz, 1982).

Empirical evidence is mixed. While some studies confirm the positive relationship between market concentration and R&D (Hamberg, 1964; Scherer, 1967a; Mansfield, 1968, Rosenberg, 1976), there is also some evidence that concentration affects negatively R&D (Williamson, 1965; Bozeman and Link, 1983; Mukhopadhyay, 1985). Others show that the impact of concentration on R&D intensity depends on other industry variables (Levin *et al.* 1985; Geroski, 1987; Cohen and Levin, 1989).

Scherer (1967b) suggests a non-linear, 'inverted-U' association between R&D effort intensity (measured by technical employment as a fraction of total employment) and concentration. Research effort intensity increases in line with concentration levels until reaching a four-firm concentration ratio between 50 and 55 percent, falling after that with further concentration increase. However, the significance of concentration decreases when dummy variables are introduced to categorise industry technology and its products. Scherer explains this with the positive relationship between concentration and technology class, thus, supporting Phillips's (1966, 1971) proposition that technological opportunity influences the level of innovation, which in turn affects market structure. Wilson's (1977) findings support Scherer's research. Shrieves (1978) and Lunn and Martin (1986) find a positive relationship between R&D intensity and concentration only in low technological opportunity markets. Scherer (1980) notes that the effect may be even negative in high technological opportunity markets.

Some researchers find that other industry-level variables such as the degree of product differentiation (Comanor, 1967; Shrieves, 1978) and the degree of technological uncertainty (Angelmar, 1985) also affect the relationship between concentration and R&D intensity although there is an issue in the measurement of the selected variables. Mueller and Tilton (1969) argue that the effect of industry structure on innovation depends on the stage of the industry's technology life-cycle. Other researchers (e.g., Scott, 1984; Geroski, 1987) suggest that as concentration may proxy for a variety of industry-specific effects, it is not a good explanatory variable of the variance in R&D intensity. Others take a similar position that even if any relationship is observed, it is not important (Kamien and Schwartz, 1982).

In summary, research on the effect of industry structure on innovation is faced with many methodological issues. Researchers employ loosely specified models, inherent simultaneity is unconsidered, important variables are omitted, and correlation between some of the variables is unaddressed. Furthermore, many studies use poor-quality data (Cohen and Levin, 1989). Wherever empirical research does not consider simultaneous endogeneity of innovation and competition, its results may be biased (Scherer, 1967a; Cohen and Levin, 1989; Aghion *et al*, 2005).

2.3 *Impact of Other Industry Characteristics: Customer Preferences, Technological Opportunities, and Appropriability Conditions*

Recent research suggests that industry structure and innovation are endogenous and they are both dependent on other industry characteristics such as customer preferences, technological opportunities, and appropriability conditions (Levin and Reiss, 1984, 1988; Cohen and Levin, 1989; Symeonidis, 1996) as well as research technology, capital market, and legal structure (Dasgupta and Stiglitz, 1980a). Studies covered in this section concern the following three propositions:

- High market opportunity leads to increased innovative activities (demand-pull hypothesis);
- High technological opportunity leads to increased innovative activities (technology-push hypothesis);
- High appropriability conditions lead to increased innovative activities.

As they influence the level of innovative activities, they need to be controlled for in empirical estimations of the relationship between innovation and industry structure.

As customer preferences, technological opportunities, and appropriability conditions change more slowly than firm size and industry structure, they are long-term determinants of inter-industry differences in innovative activity (Cohen and Levin, 1989). Accordingly they are normally taken as given in empirical studies of inter-industry differences in R&D and the evolution of industry structure.

2.3.1 Demand and innovation

Schmookler (1962, 1966) provoked a dispute among economists about the primacy of 'demand-pull' or 'technology-push' hypothesis in driving the technological change. He argued that generally, the quest for profit – the exploitation of market opportunities or 'demand-pull' – determines the rate and direction of technical change. Parker (1972) and Rosenberg (1974) find that in some cases (e.g., the mechanisation of agricultural manual operations, the exploitation of coal in the industries as fuel) the idea of technological change came from the state of technological knowledge base, not from customers demand. Scherer's (1982) empirical research provides statistical evidence that both 'demand-pull' and 'technology-push' are important for innovation.

According to the demand-pull hypothesis, innovation is the response of research staff to market opportunities identified by firm's marketing staff dealing directly with its customers (Kamien and Schwartz, 1982). Identified market opportunities trigger the search for a resolution which may rely on current scientific knowledge or go beyond it. It is argued that the probability of large diversified firms to identify market opportunities is higher than small firms, and that their R&D facilities employing a large number of scientists are able to respond faster to customers' demands and provide more innovative outcomes (see also section 2.2.1).

Differences in customer demands across industries influence incentives for R&D (Cohen and Levin, 1989). Larger industry and faster industry growth encourage innovative activities (Schmookler, 1962, 1966). Although R&D costs are independent of the level of output, their returns are higher for a larger market. Thus growing industries can accommodate more R&D than vanishing/stagnating ones. As they need extra capital equipment, they also offer an economic opportunity for equipment suppliers to innovate (Kamien and Schwartz, 1982). The structure of buyers' industry provides another account of the relationship between market structure and demand-pull for innovation, assuming that perfect competition in buyers' industry provides more incentives for R&D than monopoly (Arrow, 1962).

The price elasticity of demand may also affect marginal R&D returns. For process innovation, the more elastic the demand is, the higher the returns are (Kamien and Schwartz, 1970). Since the elasticity of demand for a product depends on the availability of substitutes; a product with many close substitutes (i.e., more elastic demand) encourages greater R&D to reduce the cost than a product with only a few substitutes. Kamien and Schwartz (1972a) find evidence supporting this, whereas Jackson (1972) shows that demand elasticity lowers the R&D incentives (although he does not control for scale effect). For product innovation, the more inelastic the demand is, the higher the returns (as inelastic demand increases the advantages from a rightward shift in the demand curve) (Spence, 1975). Studies that do not differentiate between product and process innovations may produce biased results (Cohen and Levin, 1989).

The emergence of new, more cost effective technology does not necessarily mean that the current monopolist, perfectly competitive firms, or government will immediately make redundant their old equipment. The pace of new technology implementation depends on whether monopoly power encourages or impedes the adoption of new technology, and particularly whether the invention is a result of the incumbent pre-emptive behaviour (Hall, 2003). Generally an incumbent with monopoly power is more interested in the implementation of new technology to protect its market than a firm without market power. Furthermore, growing industries incentivise firms to adopt the new technology faster while declining or stagnating markets discourage firms to adopt the new technology as the fixed costs are spread over smaller amount of units sold (Kamien and Schwartz, 1972b).

2.3.2 Technological opportunities and innovation

Firms conduct R&D according to technological opportunities, gaining excess returns on R&D investment. There is some evidence that inter-industry differences in technological opportunities have better explanatory power in accounting for differences in R&D intensities than inter-industry differences in concentration (Levin *et al.*, 1985). With the 'technology push' hypothesis, Philips (1966) and Rosenberg (1976) highlight the primacy of technological opportunity in determining innovative activities.

In neo-classical theory of production function, technological opportunities could be viewed as the set of firm production possibilities for transforming R&D resources into new production techniques that use conventional inputs such as labour and capital (Cohen and Levin, 1989). Some researchers (e.g., Griliches, 1979; Pakes and Schankerman, 1984) include technological opportunity in the production function alongside the conventional inputs as a parameter that links R&D resources to the stock of knowledge. Others define technological opportunity in different ways such as: elasticity of cost per unit in regards to R&D expenditure (Dasgupta and Stiglitz, 1980a; Spence, 1984); a shift parameter defining the position of an innovation possibility frontier which shows trade-offs in the direction of technical change (Levin, 1978); and a shift parameter defining the position of a frontier which represents trade-offs between time and R&D project cost (Scherer, 1984). For Jaffe (1986), technological opportunity refers to the exogenous disparity in the cost and complexity of R&D in different technological clusters. These differences arise from the inherent technological specifications or from the state of exogenous technological knowledge in different time. Due to poor quality of data, technological opportunities are not easily identifiable. Therefore, their findings may be biased.

According to some researchers, technologies develop along 'natural trajectories', and they are path-dependant (Nelson and Winter, 1977). R&D staff do not resolve issues by chaotically moving from one problem to another: they concentrate on a specific group of issues, making improvements in an evolutionary way. An example of path-dependent technology-push innovation is the progressive expansion of the variety of outputs over which scale economies are achievable (i.e. Hughes, 1971 on electric power; Levin, 1977 on chemical industries).

Some historical and case studies support the view that the trajectory of new technology development is independent of customer demands. For example, the technology-push invention of lasers created new technological problems and imbalances in other industries, which in turn necessitated further R&D to fully apprehend the benefits of the initial breakthrough.

For other researchers, the nature of innovative activities changes with the industry life-cycle (Utterback and Abernathy, 1975; Abernathy and Utterback, 1978). In infant industries many firms fight to establish a dominant position through radical product innovations. Over time, a 'dominant design' is established and product standardisation takes place where the focus is on process innovations. At a mature stage with one or only a few incumbents, the focus is on achieving economies of scale in production (e.g., mechanisation, automated production lines) and economies of scope (e.g., marketing, finance, sales). When all possibilities for process innovation are exhausted, the industry stagnates and eventually declines. In the meantime, new 'dominant designs' emerge and the cycle is repeated. Researchers suggest that a declining industry in developed economies could extend its life by entering markets in developing economies. Most of the radical innovations (e.g., mobiles, PCs) are first developed and marketed in the developed world (Vernon, 1966).

'Dominant designs' are often established with technical standards that realise external economies of scale (e.g., a railroad gauge, a colour television standard, a programming language). Technical standards are one of 'first-mover advantages' that allow first-movers to establish a dominant position and lock in customers in spite of the existence of a better alternative (e.g., David, 1985 on QWERTY keyboard; see also Arthur, 1985; Farrell and Saloner, 1985, 1986; Katz and Shapiro, 1985, 1986). Other structural characteristics of the industry, such as learning curve and network effects, also shield first-movers.

However, not many powerful heuristics exist to help firms in times of changing technological regimes, and their validity in the next round of technological change is also in doubt. The historical studies regarding the switch from steam to diesel locomotives, from propeller to jet aircraft engines, and from vacuum tubes to transistors show that the incumbent firms changed regimes too late or without dedication, allowing new entrants to take over their positions.

In conclusion, both the demand-pull and technology-push hypotheses are important for understanding of innovative activities. Opportunities for profits create incentives for innovation. Customer needs and demands for a specific product may be acknowledged earlier than the development of inventions that satisfy them (Mowery and Rosenberg, 1979). In other cases, technological opportunities affect the speed and direction of innovation, particularly in the long-term. Stoneman (1979) finds that technological opportunities complement market opportunities in the process of innovation. Market opportunities stimulate the utilisation of technological opportunities while in the long-term there is a feedback process running opposite, in which developments in basic knowledge facilitate the exploitation of market opportunities. Therefore, the technology-push and demand-pull hypotheses are better seen as complementary not as rivalry accounts of innovative activities, with technology-push being more of a long-term explanation while demand-pull, a short-term explanation (Kamien and Schwartz, 1982).

2.3.3 Appropriability conditions and innovation

If new knowledge created by a firm is easily transferable to its rivals so that they can produce competitive copy-cat products, there are no incentives for inventors to innovate. Although appropriability has an issue with the neo-classical economics' framework of perfect competition because of its implication that some monopoly power is necessary for innovation to occur, governments recognise this need in framing regulations, granting patents, and intellectual properties rights. These measures do not always secure innovators with perfect appropriability conditions but they assume that some appropriability is beneficial to the society on the whole.

Of a variety of measures designed to ensure appropriability, patents are one of the most well-known. Patent grants work only in some industries (Scherer *et al.*, 1959, Mansfield, 1986). Taylor and Silberstone (1973) show that patent grants are effective in pharmaceutical, moderately in chemical, and almost ineffective in mechanical engineering and electronics. Mansfield *et al.* (1981) and Mansfield (1986) present similar results confirming the importance of patents in pharmaceutical, partly in chemical, and their ineffectiveness in other industries. The ineffectiveness of patents in some specific industries is because rivals can lawfully 'invent around' patents or legally challenge patent authenticity (Levin *et al.*, 1987).

There are other ways of appropriation. Imitation (often through reverse engineering) is difficult when an invention is complex, containing integrated, tacit knowledge sourced from various departments. Under such conditions (e.g., aerospace and industrial machinery), technical barriers are erected by secrecy (Levin *et al.*, 1985). Other ways of appropriability include advertisement (Lee, 2005; Bagwell, 2007), lead-time, trade secrets (Gorodnichenko *et al.*, 2008), economies of scale (in marketing and sales), economies of scope in complimentary assets (e.g., customer service), and copyrights (Teece, 1986, Levin *et al.*, 1987). 'First-mover advantages' and learning-by-doing are also effective appropriability measures.

It is acknowledged that appropriability conditions influence R&D activities although the evidence remains inconclusive. Distinguishing between innovative R&D and imitative R&D, Cohen and Levin (1989) demonstrate that as imitation becomes easier, incentives for innovative R&D will decrease while incentives for imitative R&D will increase. However, they find that the effect on the total R&D is ambiguous. As for appropriability and industry structure, some studies are in line with the Schumpeterian hypothesis that concentrated industries enable firms to appropriate their R&D returns more easily than competitive markets. By contrast, Fellner (1951) and Arrow (1962) argue that under the neo-classical assumptions of perfect ex-post appropriability, firms' marginal returns from an invention are higher in ex-ante perfectly competitive industry than in ex-ante monopolistic ones.

Effects of spillovers are complex (Levin *et al.*, 1985). They decrease the innovators' incentives to innovate as they decrease the returns from R&D while they also improve R&D productivity as they advance the industry's knowledge base (Spence, 1984). Accordingly patents, inhibiting spillovers for a period of time, may stimulate R&D by minimising the spillovers disincentive effect. At the same time, patents may also lead to a decline in innovative output by decreasing the R&D productivity (Levin *et al.*, 1985). Cohen and Levinthal (1989a, 1989b) confirm the 'disincentive effect' of spillovers although they also find that R&D spillovers create incentives for firms to invest in absorptive capacity to benefit from them (Griffith *et al.*, 2004; Cameron *et al.*, 2005). Spillovers may lead to direct copy-cats or innovative products which are in competition (in the same or different markets) with the original inventor. Know-how spillovers could in the long-term make rivals' technological capabilities stronger. If knowledge produced by different firms is heterogeneous, knowledge produced by rivals may be complementary with each other, thus increasing the R&D productivity of an industry on the whole (Levin and Reiss, 1988; Luintel and Khan, 2004).

In summary, understanding the relationship among innovation, market structure, and appropriability is important. However, there is little conclusive evidence as to whether appropriability conditions increase or decrease R&D efforts and how these effects vary between industries and in different market structures. Most of the studies are also based on static models and poor quality of data. Accordingly, it is not clear how each appropriability mechanism impacts on innovative activity (Cohen and Levin, 1989).

2.4 Innovation Shapes Market Structure

Most studies reviewed in Section 2.2 neither differentiate cause and effect in the relationship between innovation and industry structure nor consider the feedback of innovation to industry structure (Kamien and Schwartz, 1982). However, innovation may increase concentration when firms pursue certain strategies that take advantage of learning-by-doing, high imitation costs, technological standards, network effects, and so on whereas it may decrease concentration by allowing small firms to enter a market (Geroski, 1991). Product innovations often lower concentration while process innovation can increase concentration (Mansfield, 1983). Successful innovators, launching new, technologically advanced products, may expand and flourish, causing others to shrink or disappear. Thus, industry structure evolves continuously as a result of innovative activities.

Innovation shapes industry structure in two primary, somewhat interrelated ways (Kamien and Schwartz, 1982; Cohen and Levin, 1989). First, innovation impacts industry structure through its effects on the optimal scale of production. Innovation works in both directions, increasing or decreasing the minimum efficient scale. During the industry life-cycle, innovation and market structure evolve interdependently with changes in the minimum efficient scale. Second, innovation affects market structure through the erection of innovation/technology-based entry barriers. The minimum scale of production may also constitute an entry barrier.

2.4.1 Innovation affects the optimal scale of production in an industry

Innovation can either increase or reduce the minimum efficient scale of production, affecting market structure. The minimum efficient scale is defined as the output level at which average cost is minimised. If technological change causes the minimum efficient scale of firms' operations to grow more rapidly than demand, the industry becomes more concentrated (Blair, 1972; Scherer, 1980). The decrease in the number of automobile producers in the early 20th century is partly due to the invention of automated assembly-line. The same direction of change is evidenced by Hughes (1971) on electric power generation, Scherer *et al.* (1975) on brewing and the manufacturing of steel, cement, refrigerators, batteries, and paints and Levin (1977) on chemical industries. If technological change causes the minimum efficient scale of firms' operations to decrease, industry concentration decreases. Levin (1978) demonstrates that changes in economies of scale and concentration are both endogenous.

Changes in the minimum efficient scale often take place in the form of plant size. Burns (1936) and Galbraith (1967) found that innovation tends to increase the size of plant that minimise average production costs. By contrast, Blair (1972) argues that the direction of changes in the minimum efficient scale of plant is specific to a period. From the middle of 18th to early 20th century (World War II), innovation increased the minimum efficient scale of most production plants, requiring higher capital expenditure for their buildings. Innovations giving rise to this during the period include the invention of steam powered engines, advances in materials, methods of fabrication, and development of railroads. Since World War II, the trend reversed as the nature of technological change shifted. New inventions in materials, production methods, electricity, trucks, plastics, fibreglass, high energy batteries, and the growing use of computers allowed production with smaller plants and less capital expenditure, thus reducing concentration in some industries.

Testing Blair's proposition that since World War II the number of inventions increasing the minimum efficient scale of plant have decreased, Mansfield (1983) finds mixed results. He evaluates the fraction of process innovations in a random sample of petroleum during 1919-1976, chemical during 1929-1976, and steel sectors during 1919-1960 that led to an increase in minimum efficient scale of a firm's operations. The total of inventions that led to scale expansion in the three industries was much higher than scale decreasing innovations, even when weighting the inventions by their significance. The results are evident particularly in chemical and petroleum industries; half of the innovations in steel industry sample are scale increasing while the other half affected the minimum efficient scale insignificantly. Then Mansfield compares the fractions of innovations introduced after 1950 that led to an increase in minimum efficient scale of plant with the fraction introduced prior to or during 1950 that did so. Contrary to Blair's proposition, the fraction was higher not lower, in the latter period. However, this may not apply to other industries.

Alexander's (1994) research of music recording industry finds that new scale-decreasing technologies can overturn existing industry structures by facilitating newcomers enter the market. The introduction of new methods for mass-producing pre-recorded audio the second half of the 1910s and the introduction of magnetic tape in the 1950s allowed newcomers with innovative products to displace the incumbents in the industry.

The minimum efficient scale creates barriers for newcomers through 'percentage' and 'absolute capital requirements' effects (Bain, 1956). The 'percentage' effect depends on the size of the minimum efficient scale plant relative to the industry. If a newcomer tries to penetrate the market at the efficient scale when the latter is a substantial portion of industry size, then its additional supply to industry output will decrease prices (subject to post-entry pricing conduct). If the newcomer penetrates the market at less than the efficient scale, cost penalty (depending on the slope of the cost curve) will appear. Either way entrants are disadvantaged. 'Absolute capital requirements' effect occur when a large fixed-sum is required for building a plant of the minimum efficient size or expanding a smaller plant to the minimum efficient size. In combination with market imperfections, this causes entrants to suffer an absolute cost disadvantage in comparison with incumbents running efficient-sized plants. As the percentage effect barrier depends on pricing conduct, the distance between the size of minimum efficient scale and the height of entry barriers erected by scale economies is different in each circumstance (Geroski, 1991). Scale advantages are modest except where demand comes from many homogenous consumers, where mass-production techniques in manufacturing a standardised product are advantageous. In most industries products are differentiated, hence, newcomers could overcome the disadvantages of scale economies and gain a competitive advantage by finding a niche and specialising in specific goods or/and services or by implementing flexible production methods (producing many different goods in short-runs), (Carlsson, 1989a, b).

Some argue that the optimal scale of production in an industry changes with different stages of the industry life-cycle due to their different focuses of innovation as discussed in Section 2.3.2. Small firms bring into the market a high fraction of the major innovations, especially radical innovations, particularly in highly innovative, skill-intensive young industries at the beginning of their life-cycle (Acs and Audretsch, 1987). As industry shifts to mature stages, the strategic focus shifts to process innovations aimed at producing goods at lower costs in mass quantities. This tends to increase the optimal scale of production, hence increasing industry concentration. Geroski and Pomroy (1990) support this, showing that there is a positive relationship between entry rates and innovation, both of which follow the industry life-cycle stages (see also Gort and Klepper, 1982).

In summary, the minimum efficient scale of production is an important determinant of industry structure (Kamien and Schwartz, 1982). Innovation affects industry structure through its effects on the optimal scale of production that acts as an entry barrier. Entry barriers are erected when high capital expenditures are required to expand or build plants. Scale and efficiency in production often become more important at later stages of the industry life-cycle, reducing opportunities for small firms. By contrast, when an industry is at high-growth stages, entry barriers are often less difficult to surmount. When the minimum efficient scale does not grow as fast as the industry's market, it has an effect of reducing the share of market required to achieve the most efficient scale of production.

2.4.2 Innovation affects industry structure through the erection of technology-based entry barriers

Modern definitions of an industry, and discussions of industry structure, employ the entry barrier faced by new entrants trying to penetrate a market (e.g., Porter, 1980). Entry barriers are relatively fixed, exogenous structural factors determining entry, exit, and intra-industry mobility. Exogenous variables affecting entry barriers include culture (determining consumer demand) and basic scientific knowledge (determining the pace and direction of technological progress) (Geroski, 1991).

Entry means new sources of supply, for example, newcomers building new plants, using new equipment, foreign-based firms entering an overseas market via imports, M&A, and so on (Geroski, 1991). Entrants have different comparative advantages, hence, different ability to overcome different industry barriers or utilise technologies. Entry varies across industries by type and other characteristics (Geroski, 1991). For Geroski, the effect of entry barriers also varies over time as those intervening factors which facilitate or impede entrants vary. For instance, industry expansion often allows entrants to eat into incumbents' market shares without decreasing their revenue as capacity restrictions may prevent incumbents from responding. Regulations can change 'the rules of the game', affecting industry structure directly. Regulatory calls for divestitures, forbidding or encouraging M&A or entry produce a direct impact upon entry barriers. Regulations also affect structure indirectly by restricting or necessitating certain behaviours related to entry barriers. For example, patent grants reduce the ease of imitation, thus helping to increase the height of entry barriers against copycats.

Long-term supernormal profits indicate the existence of barriers. The height of entry barriers is measured by profitability (i.e., price-cost margins) (Geroski, 1991). Geroski argues that high entry barriers indicate that only a few potentially successful entrants can compete with incumbents. As the rewards for them are high, any opportunity for entry is exploited. By contrast, low entry barriers indicate that there are many capable entrants. Prices cannot stay above marginal cost for a long-term, and hence the potential entrants' future is uncertain. However, these statements may not hold in the short-term. A successful entrant into an industry protected by high entry barriers could cause a price-war, whereas prices may be kept high in the long-run in an industry of low entry barriers as entry in the industry is slow with insignificant effects. Therefore, the long-run impact of entry depends on entry barriers while the short-run impact of entry depends on the penetration rate of newcomers and dominant firms reactions (which may depend on the height of entry barriers) (Geroski, 1991).

Bain (1956) identifies three sources of barriers: scale advantages, absolute cost advantages (exclusive resources access to raw material, finance, distribution channel, technical knowledge, and so on), and product differentiation advantages. Product differentiation is effective against imitative or non-innovative entrants. Innovators can change the foundation upon which consumers make choices or industries are defined (e.g., devising new production techniques to circumvent patents).

Firms often strategically adjust and maintain entry barriers. For example, a price-war, although sacrificing short-run profits, deters newcomers and helps to establish long-run market dominance. By contrast, incumbents may use an entry accommodating strategy by decreasing outputs and maintaining high prices if they believe that they can maintain barriers to newcomers.

Philips (1966) argues that monopoly power deriving from innovation-based entry barriers may not be transitory but persistent, leading to industry concentration as a consequence of the accumulation of past innovation. He argues that oligopolistic markets are determined by many factors, one of which is technical progress. Changing technological regimes, a new scientific paradigm provides opportunities for new products, services, and industries. The first firm successfully commercialising a new, perhaps radical innovation gains 'the first-mover advantage' over its competitors. The gains may be due to patent, license, hard-to-imitate product, learning-by-doing, brand name, loyal customers, and generation of extraordinary profits which sponsor further R&D. Extraordinary profits allow the innovator to make improvements which either are compatible with previous versions or accommodate past models as trade-ins. The 'first-mover advantages' represent entry-barriers. Surmounting them entails entrants to invest more than the innovator has invested in developing the product. Thus, technological progress instigates a 'success breeds success' spiral.

In a field of constantly changing technology, the initial innovator who gains the 'first-mover advantages' is more likely to succeed in the subsequent rounds of technological progress again than newcomers (Philips, 1966). Facilitated by the extraordinary profits and the motivation of their researchers from the initial success, the first-mover is also more inclined to innovate in the scientific areas related to its early success, creating opportunities for further technological change. If basic and applied research are constantly changing but path-dependent (i.e., each change depending partly on the past change), it incurs 'learning costs' to both new and old firms trying to penetrate the field as knowledge transfer and absorption consumes time and money. There is no one stagnant technology point around which firms effortlessly crowd. Progress in scientific research affects firms differently: with their 'first-mover advantages' and accumulated stock of knowledge, first-movers keep succeeding in increasing their size, profits, and innovative capabilities while others remain small or disappear in acquisitions and failures. This occurs not because an oligopolistic industry is inherently more innovative as assumed by Galbraith (1952), but because constant technical change creates an oligopolistic industry where a few large firms take advantage of their 'first-mover advantages' and accumulated stock of knowledge they have build through past R&D.

If innovation does not lead to the erection of high entry barriers, an atomistic industry may be technologically progressive for a long-term, stimulating the entry of newcomers. In such an environment, technical change is more likely to be initiated by outsiders than insiders, as the advantages of R&D conducted by one firm may be transferred to all firms in the industry. In a similar vein, when the process of technological change becomes sluggish, the abilities of incumbents to impede entry by technical advances diminish as knowledge becomes known across firms in the industry (Phillips, 1966).

Following Philips' studies (1966, 1971), similar views are presented by others. Levin (1978) emphasises the role of technical innovation in sustaining entry barriers over a long-term. Excess profits from the invention are invested in R&D, leading to further technical advances and repeatedly recreating the cost advantage over prospective newcomers. As a result, market structure may remain unchanged or follow its evolution towards entry or concentration. Levin (1978) and Dasgupta and Stiglitz (1980a) explain how incumbents may preserve their positions by continuous innovation. Under particular circumstances, the monopolist is incentivised to pre-emptively block prospective rivals, for example by rapid R&D which newcomers cannot afford, thus, continuing its monopoly (Dasgupta and Stiglitz, 1980b). Mueller and Tilton (1969) and Pavitt and Wald (1971) incorporate the erection of entry barriers through R&D into the industry life-cycle framework, which is discussed in Section 2.4.1.

Some researchers provide empirical evidence supporting Phillips' study. Comanor (1964) shows that R&D expenditures, risks undertaken, and high selling costs represent entry barriers in the pharmaceutical industry. Freeman (1965) echoes this, finding that R&D constitutes an entry barrier in the oligopolistic international electronic capital goods industry. Stonebraker (1976) demonstrates that the newcomers' risk of failure is positively associated with industry R&D and advertising intensity. Grabowski (1968) finds that firms' previous innovative success encourages further R&D, leading to more successful inventions and resulting in 'success breeds success'. However, some studies (e.g., Kelly, 1970; Williamson, 1972) suggest the opposite - 'success begets failure', as initial success can make firms complacent, or the initial innovator may not be as hungry for additional profits as the newcomer.

In summary, innovation is one of the sources with which entry barriers are erected. The long-run impact of entry upon industry structure depends on the success in erecting effective entry barriers. Accordingly, the erection of technology-based entry barriers is often discussed in relation to the 'first-mover' who introduces radical innovation. Some argue that in a sector of constantly changing technology, the erection of technology-based entry barriers by the 'first-mover' allows the innovator to grow successively at subsequent rounds of technical progress, drawing on its accumulated stock of knowledge.

2.5 The Dynamics of Innovation and Industry Structure

2.5.1 Theoretical studies

Earlier sections in this review show that while industry structure affects innovative activities, it is also shaped by technical advances. Innovations that are easy to imitate attract many firms, reducing concentration in the industry. By contrast, hard-to-imitate innovations decrease the number of firms particularly when scale economies exist (e.g., automated assembly-line in automobile industry). In a similar vein, the change in the strategic focus from product innovation to process innovation at mature stages of industry life-cycle tends to reduce the number of firms and thus increase concentration (e.g., hand calculator sector).

Recent theoretical studies have shown that productive and dynamic efficiency gains flow from innovation (e.g., Bailey and Gersbach, 1995; Nickell, 1996; Audretsch *et al.,* 2001). Incentivised by the disciplining effect of the market, competition stimulates innovation and in turn the process of mutation and selection (Geroski, 1991). Innovation makes inefficient firms exit or be substituted by more efficient firms. In dynamic competition, newcomers trying new innovations (usually path-dependent on their past innovative activities) are the driving force of technological progress (Ahn, 2002), forcing incumbents to innovate for survival (Uchida and Cook, 2007). Recent theoretical developments of the role of entry and innovation in the industry dynamics owe much to the work of Geroski (1991).

For Geroski, entry is one of the ways by which industries restructure themselves. Seeing competition as a selection process (an equilibrating force keeping industries at a steady position) helps us consider entry and market evolution as an interrelated process. That is, how industry structure and conduct, particularly innovation, interrelate over time, and whether they interact in a path-dependent manner. Entry as 'an agent of change' is the process by which firms discover the best way to penetrate a market, survive, and prosper in the constantly changing environment. The role of entry in industry restructuring is selective. Most industries encounter dynamism and instability at the bottom-end of the firm size distribution (where entry is easier than survival). Entry has an impact on prices because the newcomers or the threat of them incentivise incumbents to increase productivity and lower costs. Although entry has modest effects on profits, this disguises their more important effects on costs, which varies in strength during the product life-cycle. The effects are stronger at early stages of industry life-cycle than mature stages. A large cohort of entrants introducing new products displaces inefficient incumbents, leading to modifications in the nature of entry barriers and productivity growth. The industry dynamics caused by entry alter mainly the population characteristics of products or firms, less the size of the population of products or firms.

Using a comparison between 'imitative' and 'innovative' types of entry, Geroski suggests that entry plays an equilibrating and disequlibrating roles in markets. Excess profits attract imitative entrants ('copycats'). Imitation is equilibrating; it leads the industry towards a competitive equilibrium regarding the existing cost and demand conditions. Innovative entrants are disequilibrating; they shift industry demand or take advantage of new cost functions. Their profitability does not depend on incumbents' excess profits; therefore, the rate of innovative entry has different determinants from imitative entry. Innovative entry entails displacement of existing activities by new ones. Imitative entry is generally endogenous to incumbents' existing price and output decisions while innovative entry is not. When innovative entry is endogenous to existing industry outcomes, then it is affected by the existing and past technological and marketing decisions of incumbent firms. Therefore, entry can be an agent of and a response to industry changes (Geroski, 1991).

According to Geroski, the difficulties with creating models of entry and innovation to support the arguments above are that most of entry and innovation determinants – transitory variables (mediating industry conditions) and permanent variables (entry barriers and technological opportunities) – are hard to observe. The two sources of correlation between entry and innovation rates partly offset each other. The correlation emerging as a result of the permanent determinants of entry and innovation is positive since entry barriers and technological opportunities are negatively correlated across industries. Industries with higher technological opportunities generally have lower entry barriers; hence, high entry levels and innovation simultaneously occur. By contrast, transitory determinants of entry and innovation work the opposite way. The sign of correlation is negative for the lagged impact of entry on innovation through transitory industry factors. Accordingly, if the relationship between entry and innovation is positive, the relationship between entry barriers and technological opportunities is strong enough to overpower the causal effect of transitory industry factors running from entry to innovation.

Geroski argues that technological opportunities determine innovativeness whereas competitive rivalries have second-order effects. He also suggests that the way technological opportunities impact innovation is different between the top and the bottom of an industry. Rich technological opportunities encourage concentration at the top and entry at the bottom of the same industry. Accordingly, concentration indices and entry measures represent two different competitive environments at the top and at the bottom of an industry, which are divided by high mobility barriers. In a similar vein, competitive rivalries at the top may affect innovation differently from competitive rivalries at the bottom. Also effects of rivalry at the top and the bottom vary systematically over time as industries evolve. Rivalry matters in some periods of industry's history, less so in others (Geroski, 1991). For example, the analysis of the co-evolution of entry and innovation over the product life-cycle support this. Industries evolve through different stages that are identifiable by net entry rates (Gort and Klepper, 1982). The rate of entry is high at early stages of industry life-cycle, decreases over time, and eventually becomes negative as exit occurs and industry concentration is high.

2.5.2 Empirical evidence

Empirical evidence regarding the dynamics of innovation and industry structure is limited. This is in large part due to difficulties developing empirically-testable, dynamic, stochastic models, data availabilities, and the indeterminacy of the causal directions among variables (Cohen and Levin, 1989). Most studies, with the exception such as Mowery (1983), neglect simultaneity between innovation and industry structure. Although earlier research into the determinants of firm size and growth (Simon and Bonini, 1958; Scherer, 1965c) has facilitated studies of endogeneity involved (e.g. Evans, 1987a, b; Hall 1987; Pakes and Ericson, 1987), the evidence is sketchy.

The simulation of dynamic interactions between innovation and industry structure under the framework of repeated games requires difficult to estimate simultaneous equations. Futia (1980) and Iwai (1984a, b) are such studies. Futia's (1980) model where a firm's current market share depends on whether the firm has won the innovation game in the preceding phase shows that a firm's success in the current innovation game depends on the R&D expenditures of its own and competitors. Futia shows that moderately concentrated markets or markets with moderate entry barriers encourage more innovative efforts than markets with very high or low concentration. Nelson and Winter's (1982a) simulation models offer theoretical support of this dynamic relationship between structure and innovation. Their models are subsequently tested empirically by Pakes and Ericson (1987) with an 'active learning' model of innovation effort. Mazzucato (2000) uses evolutionary economics, non-linear mathematics, and computer simulations to explore various Schumpeterian hypotheses about the positive and negative feedback between firm size and innovation and the role of idiosyncratic random events in the evolution of industry structure. Researching into entry, exit, and survival of UK manufacturing firms, Disney *et al.* (2003) find interactions between survival, size, and age of firms that differ between single firms and firms consisting of a group. They argue that the evidence may be consistent with market selection based on learning.

Although some studies confirm endogeneity in the relationship between structure and innovation, employing instrumental variables for concentration (e.g., Howe and McFertridge, 1976; Levin *et al.* 1985) or multi-equation models with industry-level data (e.g., Wahlroos and Backstrom, 1982; Connoly and Hirschey, 1984; Levin and Reiss, 1984, 1988), the research remains inconclusive. Critics argue that endogeneity in these studies is declared for convenience: endogeneity is a result of misspecification or missing variables in econometric models and poor quality of data. Modeling different equations, studies have to control for changes in demand (which is difficult) and to estimate more accurate lags (as technical advances may be pulled by lagged demand). On the latter, Levin's (1981) study is an exception: it is based on a model where the distributed lag of historical R&D expenditure, not the present R&D intensity, is on the right-hand side of the concentration model.

2.6 Conclusion

The link between innovation and industry structure is complex. Unlike earlier studies, recent research recognises the two-way interaction in which innovation shapes industry structure while industry structure influences innovative activities. Innovation and industry structure are dependent upon some other industry characteristics and particularly technological opportunities and appropriability conditions. Furthermore, innovation and industry structure often vary with stages of the industry life-cycle. Recent research into the industry dynamics focuses on entry as an 'agent of change' and explores the way in which different types of entrants ('imitative' and 'innovative') influence the industry at its different segments ('bottom' and 'top') directly and indirectly.

Although the literature reviewed in this chapter concerns the dynamics at the industry level, it has a number of theoretical implications to the innovative conduct of individual firms (measured by R&D expenditures in this study) and its impact upon their performance (measured by market share). First, R&D activities are most likely to affect a firm's market share through the introduction of new products and processes. The literature recognises the role of entry, and particularly of 'innovative' entrants, as an 'agent of change' and its impact upon incumbents who respond for survival. As innovation is one of key means of entry and survival, it is likely to have some bearing upon a firm's market share. Second, a firm's ability to appropriate innovation impacts its growth, thus most likely influencing its market share. The literature suggests that when complemented by proper measures for appropriation, a firm pioneering new products and processes gains 'first-mover advantages'. Some argue that firms with 'first-mover advantages' are likely to succeed in subsequent rounds or in related fields ('success breeds success') due to past success and an accumulated stock of knowledge. In this sense, a firm's R&D activities leading to pioneering innovation are likely to have an impact upon its market share. However, R&D activities are not always geared towards pioneering innovation. In a similar vein, firms do not necessarily follow up their innovation with the adoption of proper measures for appropriation. This leaves some logical inconclusiveness in the contribution of R&D to a growth in market share through pioneering innovation. Third, the link between R&D activities and market share is likely to vary across industries due to cross-industry variations in appropriability conditions. Conditions of appropriability, which in part arise from the availability of measures for appropriation, vary significantly across industries. This may affect the way in which firms conduct R&D in anticipation of gaining/maintaining market share as it is expected that the industry structure tends to be atomic under weak appropriability conditions. Accordingly, significant cross-industry variations may be expected. Fourth, the variation in the strategic focus of innovation with stages of the industry life-cycle may influence the impact of R&D activities upon market share. This is another source of cross-industry variations since at a given point of time for analysis industries are situated at different stages of their life-cycles. Firms operating in an industry at early stages aim their R&D at product innovation while firms in an industry at mature stages target a greater proportion of their R&D resources at improving productivity through process innovation. The impact of this differentiated conduct of innovative activities upon market share is not clear and needs to be considered. Fifth, the way in which R&D activities affect market share may not be uniform within an industry due to different competitive environments at the bottom and the top of scale. It is suggested that if all firms in an industry face the same technological opportunities, rich technological opportunities encourage concentration at the top and entry at the bottom of the same industry. This may imply differentiated impacts of R&D expenditures upon market share between the top and the bottom (or the top, middle, and bottom) of an industry. Last, but not the least, the economics literature on the subject pays little attention to the concept of 'positioning' found in the strategy literature. The economics literature, for simplicity in modeling, often assumes homogeneity of products within an industry and do not differentiates firms by profitability. By contrast, the strategy literature emphasises strategic positioning of firms within an industry and acknowledges a possibility that the level of profitability varies among firms due to their positioning (e.g., high profitability in a small but lucrative niche). In such a case, firms may not necessarily undertake R&D to gain a larger market share but a higher level of profitability through positioning. All these points suggest a strong need of empirical evidence about the relationship between R&D and market share at the level of individual firms. Although this study does not aim to present a general model of the relationship, it helps to further the development of a general model by providing empirical evidence.

Chapter 3: Methodology

3.1 Introduction

This section focuses on the explanation and justification of the conceptual framework used for answering the research question: 'Does an increase in a firm's R&D expenditures (relative to the industry's total or firm's rivals) leads to an increase in the firm's market share?' Assessing the contribution of R&D expenditures to economic growth, economists employed case studies (e.g., Griliches, 1958; Mansfield *et al.*, 1977), surveys (e.g., Griliches, 1973) and econometric estimates of production functions containing R&D variables (Griliches, 1979). Case studies and surveys are data- and time-consuming, concentrating on prominent and successful innovations and fields. Also, their findings are not generalisable. Therefore, this research uses an empirical econometric approach which directly relates theory and data to formally test the validity of a theory.

The two way causality between innovation and market share affects the research methodology, which in this study follows a well developed standard adopted in previous empirical research. Section 3.2 discusses the theoretical model and specifications, while Section 3.3 explains the data sources, sample, potential estimation issues, and descriptive statistics.

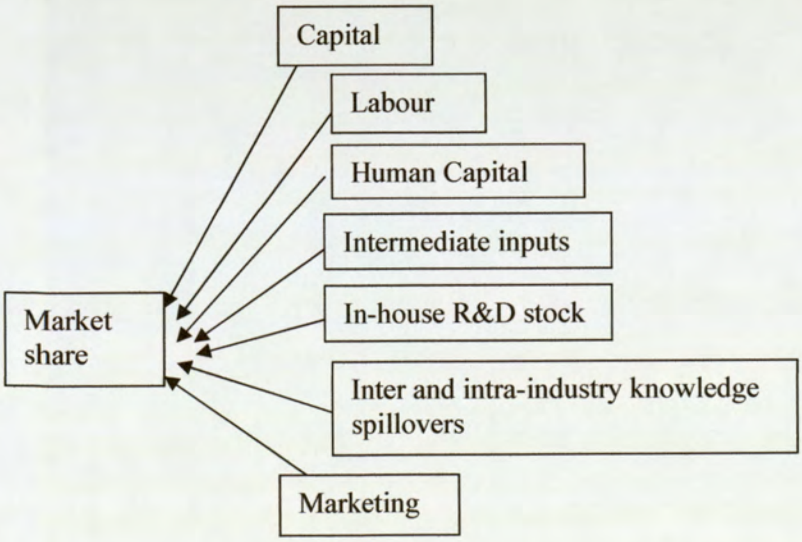
3.2 Theoretical Model and Specifications

3.2.1 Conceptual framework

Explaining how the conceptual framework (Figure 2) accounts for each of the key findings from the literature review, this study employs the Sources of Growth model which relates increases in output to increases in inputs of capital, skilled and unskilled labour, intermediate inputs and other variables such as R&D and marketing expenditures (Griliches, 1979; Katayama *et al.*, 2005; Cincera and Ravet, 2011). Marketing expenditures is included as a proxy for advertising and marketing activities.
Human capital affects a firm's capability to invent new techniques and products and its absorptive capacity (e.g., Griliches, 1964; Anon-Higon and Sena, 2006;). New growth

theory suggests that innovation is a major source of productivity growth. For this, in-house R&D and knowledge spillovers from external sources are accounted for. The model allows for comparison across industries covered in this study. Cross-industry variations in technological opportunities and appropriability are key factors that account for cross-industry variations in the relationship between R&D investment and market share, which is expected to be found in the empirical analysis. The model is also expected, in general, to shed light for cross-industry variations in stages of industry life-cycles, employing the method of industrial classification used by UK Department of Business, Enterprise and Regulatory Reform (BERR) – renamed as Department for Business, Innovation and Skills (BIS) in June 2005 – based upon ICB sector classification. ICB groups together companies that have similar primary revenue sources although there is a possibility that the classification conflates sub-industries at different life-cycle stages into one. The model will shed light on the relationship between R&D expenditures and market shares of the top and the middle end of industry players, as firms at a lower end are not included in the dataset used by the research. This model does not account for cases where firms undertake R&D for gaining higher level of profitability through market positioning. The baseline model is applied at two different levels: while a regression analysis is run for each industry (called 'each-industry' analysis or 'intra-industry' analysis below), it is also undertaken for all observations across industries with a view to obtaining more general insights (called 'all-industries' analysis or 'inter-industry' analysis below).

Figure 2: Conceptual framework



While the research focuses on effects of a firm's in-house R&D upon its market share, the baseline model also accounts for two types of spillovers: intra-industry spillovers (in 'each-industry' analysis) and inter-industry spillovers (in 'all-industries' analysis). Of them, intra-industry spillovers are interpreted as spillovers across rivals in the same industry. The coverage of high R&D spenders in this study accounts for a major source of potential spillovers in each industry. Inter-industry spillovers are spillovers from the top-end and middle firms of the highly innovative industries of the UK covered in this research.

3.2.2 Model and specifications

The study will employ the standard production function technique.[i] The model assumes that firm's output, Y_{it}, can be represented with a conventional Cobb-Douglas production technology. Equation (1) represents this technology, in which firm *i*'s real gross output $-Y_i$ (i.e. deflated sales) is a function of capital stock C_i (proxied for by the real value of the firm's fixed assets), labour L_i (i.e. number of workers), human capital E_i (proxied for by the firm's per-employee remuneration relative to the industry average), real cost of intermediate inputs M_i, advertising expenditures A_i, and R&D capital stock K_i. Nominal values are deflated using the 1995 GDP prices deflator.

$$Y_{it} = f(C_{it}, L_{it}, E_{it}, M_{it}, A_{it}, K_{it}) = \alpha C_{it}^{\beta_C} \cdot L_{it}^{\beta_L} \cdot E_{it}^{\beta_E} \cdot M_{it}^{\beta_M} \cdot A_{it}^{\beta_A} \cdot K_{it}^{\beta_K} \qquad (1)$$

where the subscripts *i* and *t* represent firm and time respectively, and the βs represent the input's *j* elasticity. By including marketing and R&D activities, the model accounts for both the demand-pull and technology-push of the innovation process and potential complementarities between them.

The objective of the study is to analyse the impact of R&D on a firm's performance in terms of gain or loss of market share. Therefore, the model is modified, measuring market share as a dependent variable. While the total firm growth is linked to all production factors, an effort is made to statistically estimate the fraction of firm growth due to in-house R&D.

Dividing both sides of equation (1) by industry's total gross output Y and assuming the inputs elasticity across firms are the same, the left hand-side represents firm *i*'s market share $MS_{i.}$

$$Y_{it} / Y_t = MS_{it} = \left(\frac{C_{it}}{C_t}\right)^{\beta_C} \left(\frac{L_{it}}{L_t}\right)^{\beta_L} \left(\frac{E_{it}}{E_t}\right)^{\beta_E} \left(\frac{M_{it}}{M_t}\right)^{\beta_M} \left(\frac{A_{it}}{A_t}\right)^{\beta_A} \left(\frac{K_{it}}{K_t}\right)^{\beta_K} \quad (2)$$

As the main interest of this study is the contribution of R&D stock of knowledge and associated advertisement, firm *i*'s R&D Stock of Knowledge K_{it} is separated from that of other firms K_t (i.e. ones in firm *i*'s own industry in the case of intra-industry analysis, and ones in all high-technology industries covered in this study in the case of inter-industry analysis). In a similar vein, the term for advertisement expenditures is divided into firm *i*'s advertisement expenditures A_{it} and those of other firms A_t. According to Lee (2005) and Bagwell (2007) advertisement is another key instrument of appropriability. Drucker (1954) states: 'There are only two things in a business that make money – innovation and marketing, everything else is cost'. Equation 3 shows the modified model.

$$Y_{it} / Y_t = MS_{it} = \left(\frac{C_{it}}{C_t}\right)^{\beta_C} \left(\frac{L_{it}}{L_t}\right)^{\beta_L} \left(\frac{E_{it}}{E_t}\right)^{\beta_E} \left(\frac{M_{it}}{M_t}\right)^{\beta_M} A_{it}^{\beta_{Ait}} \cdot A_t^{\beta_{At}} \cdot K_{it}^{\beta_{Kit}} \cdot K_t^{\beta_{Kt}} \quad (3)$$

The hypothesis to be tested is that an increase in a firm's R&D expenditure increases its market share. Division of the term expressing firm *i*'s share of R&D and marketing activities into the firm's activities and those of other firms enables us to still account for firm *i*'s share of activities by controlling for the activities of other firms in regression. Moreover, the separation allows us to interpret the R&D and marketing activities of other firms as sources of spillover effects through knowledge diffusion and a greater awareness of products respectively.

To sum up, equation (4) represents the baseline of our model.

$$MS_{it} = f(\boldsymbol{X}_{it}, A_{it}, A_t, K_{it}, K_t, u_{it}) \quad (4)$$

Equation (4) is the modified production function relating measure of MS, at the micro-level, to the 'inputs' X_i, A_i, A, K_i, K, and the disturbance term, u, where:

- vector **X** stands for an index of conventional inputs such as labour, capital, human capital and intermediate inputs where each variable represents a firm *i's* share of the variable in the industry;
- A_i is a measure of each firm's own marketing activities;
- A is a measure of marketing activities of rival firms in the same industry in the 'each-industry' analysis while it measures marketing activities of other firms in all high technology industries covered in this study in the 'all-industries' analysis;
- K_i is a measure of the in-house stock of technical knowledge (R&D capital), determined by current and past R&D expenditures of the firm;
- K is a measure of R&D capital of rival firms in the same industry in 'each-industry' analysis while it measures R&D capital of other firms in all high-technology industries covered in this study in the 'all-industry' analysis.;
- In the 'each-industry' analysis, when A or K enters the model with a negative sign, it means that a decline in firm *i*'s share of marketing activities or R&D capital in its industry leads to a decline in the firm's market share. Conversely, when A or K enters the model with a positive sign, it implies that there are positive spillovers of the activities undertaken by its rival firms, leading to a growth of firm *i*'s market share. In other words, R&D capital possessed, or advertising undertaken, by other firms end up contributing to a growth of market shares of some firms over other firms through diffusion of knowledge or a greater awareness of the industry's products. In the 'all-industries' analysis, the interpretation is similar. The case of A or K entering the model with a negative sign is interpreted as an effect of activities of rival firms in firm *i*'s industry (i.e. a decline in the share of firm *i*'s activities within its industry) or some sort of negative spillovers from firms in other high technology industries. Conversely, the case of A or K entering the model with a positive sign arises from spillovers of activities by other firms leading to a greater awareness of products or knowledge diffusion which increases market shares of some firms over others. More details of knowledge spillovers are provided in section 3.2.3 below.

– u stands for all other unmeasured determinants of output and productivity omitted for which there is no available data, such as managerial skills, luck, government policies, efficiency, historical chance and other variables.

This model assumes separability of the conventional inputs from the series of past and current R&D expenditure. Secondly, we assume that firm and industry prices do not differ. In that sense we measure market share in nominal terms.

The extended baseline model is represented by equation (5)

$$MS_{it} = F \cdot \exp(\lambda t + \varepsilon_{it}) \cdot c_{it}^{\beta_C} \cdot l_{it}^{\beta_L} \cdot e_{it}^{\beta_E} \cdot m_{it}^{\beta_M} \cdot A_{it}^{\beta_{Ait}} \cdot A_t^{\beta_{At}} \cdot K_{it}^{\beta_{Kit}} \cdot K_t^{\beta_{Kt}}$$
(5)

where c_{it}, l_{it}, m_{it}, e_{it} are firm i's share of each variable within its industry, A_{it} and K_{it} are the firm's own marketing activities and R&D stock of capital while the A_t and K_t are the firm's rivals or the rest of the companies' marketing and R&D capital of firm i's rivals in its industry or other firms in all high technology industries covered in this study respectively. The βs are their respective output elasticities (some of the parameters we are interested in estimating), F is a constant, $\exp(\lambda t)$ represents exogenous technical progress (in the science-base, namely, non-firm R&D) and $\exp(\varepsilon_{it})$ is an *i.i.d.* disturbance.

For ease of exposition, the assumption of a common intercept term and time trend, λ, is maintained throughout the derivation. The estimation procedure relaxes this assumption by incorporating industry/ICB codes- and year-specific intercept terms. The assumption of constancy in the other parameters should not be too offensive since the scope of the analysis will be limited to sectors in the R&D Scoreboard industry classification. Assumed are constant returns in the firm's own inputs which simplify the model greatly. The issue of multicollinearity (i.e., time series of R&D expenditures are correlated from year to year) is dealt with by assuming a functional form for the lag-distribution on the grounds of past knowledge and broad considerations (Griliches, 1967). There is a simultaneity issue due to loop causality in the relationship between R&D and market share: future market share may depend on prior R&D while R&D may depend on both past and expected market share. The issues of interdependencies (the current firm market share may depend on the firm's past market share) and endogeneity are accounted for by the dynamic model estimated which also accounts for any dynamic effects (6).

$$MS_{it} = F \cdot \exp(\lambda t + \varepsilon_{it}) \cdot MS_{it-1}^{\beta_{MS}} \cdot c_{it}^{\beta_C} \cdot l_{it}^{\beta_L} \cdot e_{it}^{\beta_E} \cdot m_{it}^{\beta_M} \cdot A_{it}^{\beta_{Ait}} \cdot A_t^{\beta_{At}} \cdot K_{it}^{\beta_{Kit}} \cdot K_t^{\beta_{Kt}}$$
(6)

The research employs and compares a number of different methods using the same or similar logarithmic-specification of the model strategy: Ordinary Least Squares (OLS), Fixed Effects (FE): one-step (robust) static System Generalised Method of Moments (GMM), and one-step (robust) dynamic System GMM. All models are estimated using the statistical software STATA 11 and, in particular, to estimate the GMM models the "xtabond2" command is used (see Roodman, 2006 and 2008). Accounting for industry effects, separate regression was performed for each industry ('each-industry' analysis). However, when the GMM estimators are used in the 'each-industry' analysis, it was not possible to find sensible results due to a small number of firms and the issue of weak instruments. Numerous experiments were made with the first-differences GMM and different combinations of instruments and 'GMM' style variables, and other complex GMM models (Roodman, 2008) (Appendix 1) which provided invalid estimators due to the weak instruments problem.[ii]

The most often used OLS does not address the omitted variable problem (so called heterogeneity bias, resulting from possible correlation between firm-specific fixed effects and the regressors) and the endogeneity (resulting from potential correlation between the regressors and the error term) issue. This study assumes that capital, market share, labour, human capital, materials and advertisement are potentially endogenous as they are likely to be correlated with the firm-specific effects, productivity shocks and measurement errors which are included collectively in the error term of the model. R&D is also potentially endogenous as there may be a double causality between market share and R&D. The strictly exogenous variables are the industry/ICB code and year dummies. In the presence of endogeneity, OLS can produce biased and inconsistent parameter estimates. There is likelihood that industry/ICB codes and time-specific factors may influence a firm's market share. The models try to control for individual firm heterogeneity by including sets of industry/ICB codes dummies and time-dummies which take into account industry/ICB codes- and time-specific factors that are exogenous and common to all firms. The FE method does take into account the unobserved differences across firms but not the endogeneity issues which would affect the consistency of FE. In simple dynamic panel models, the FE estimator is inconsistent when the time span is small as in this case – 7 years (Nickell, 1981), as is OLS estimator. The GMM addresses both unobserved differences across firms and potential endogeneity (Arellano and Bond, 1991; Blundell and Bond, 1998). It also addresses potential measurement errors in the independent variables when instruments are uncorrelated with the errors in measurement but it may be subject to a weak instruments problem (Roodman, 2009). GMM, introduced by Hansen (1982) makes use of the orthogonality conditions to allow for efficient estimation in the presence of heteroskedasticity of unknown form. Estimators are derived from so-called moment conditions. The system GMM estimator utilises lagged values of the endogenous variables for the first differences equation while it utilises lagged differences of the endogenous variables for the equation in levels (Arellano and Bond, 1991; Blundell and Bond, 1998).

GMM estimators fit well with the situation in regards to the data set and models used in this study. According to Roodman (2008), GMM estimators are designed for limited time periods and many firms. Also, they are designed for cases as in this research where: (1) the dependent variable (market share) is not firmly exogenous but dynamic; (2) the independent variables are also not firmly exogenous; (3) fixed firm effects exist; and (4) where suspected heteroskedasticity and autocorrelation within firms but not across them exist. Many estimators (e.g. OLS) can be seen as special cases of GMM, based on minimal assumptions and partial specification of the model. Comparing all the methods, the one-step dynamic System GMM is more efficient with greater explanatory power accounting for interdependencies and endogeneity. However, the other simpler methods also provide sensible boundaries of the estimators. The dynamic System GMM estimators are found to be unbiased, consistent (failing to reject the null hypothesis that there is no second order correlation of the first differenced equation residuals) and valid (failing to reject the null hypothesis in the Hansen test of over-identifying restrictions that the instrument set as a group is exogenous, hence, uncorrelated with the error term). In all model specifications reported, the Hansen and the Arellano-Bond tests confirm that the GMM estimators perform well: by failing to reject the joint hypothesis that the over-identifying restrictions are valid (that is, our instruments are exogenous) and by rejecting the presence of autocorrelation (Roodman, 2006/2008, 2009; Mileva, 2007).

3.2.3 Variables of interest and measurement

In-house R&D capital (K_{it}) is estimated using the perpetual inventory method, with data on both accumulated 'knowledge capital' and R&D spending in the current period[iii], taking into consideration the rate of stock depreciation, (Griliches, 1984; Coe and Helpman, 1994; Blundell *et al.*, 1999; Cameron *et al.*, 2005).

Using the perpetual inventory method (Griliches, 1979), R&D capital stocks, K_{it}, are calculated from deflated R&D expenditures (R):

$$K_{it} = (1-\delta)\, K_{i(t-1)} + R_{i(t-1)}$$

where δ is the depreciation or obsolescence rate (which is assumed to be constant and usually of 15 percent). The assumed 15 percent depreciation rate corresponds to an average R&D stock vintage of six years[iv].

The estimation of a starting R&D capital for each firm is based on the first observation on the annual flow. Assuming that actual expenditures have been increasing since minus infinity at a certain rate (e.g., at rate g), the first observed year's flow is divided by $(\delta + g)$. As a depreciation rate of 15% is taken, then it is $(g + 0.15)$. Therefore, the benchmark for the initial capital stock, K_0, is estimated following Griliches (1980) procedure as:

$$K_0 = R_0/(g + \delta)$$

where g is the average compound annual growth rate of R&D expenditures over the period for which published R&D data is available (in this case 0.05 in line with generally adapted practice in such cases, articulated in Hall (1993)), R_0 is the value of R&D expenditures of the first year for which the data is available.

External R&D capital (K_t): The effects of the different types of spillovers are hard to estimate (Griliches, 1992; Guellec and Van Pottelsberghe, 2004). Some researchers suggest that the effects depend on adequate measures of technological 'distance' between firms and industries and of R&D capital. In this study, the estimation of R&D spillovers is based on the total of R&D capital possessed by rival firms in the industry or other firms in all high technology industries without the use of any weighting. Due to data limitations, more sophisticated methods (e.g. input-output tables, and bilateral import transactions as per Anon-Higon (2007)) were not employed.

a) Intra-industry spillovers in the 'each-industry' analysis: Following Griliches (1979) and Lumenga-Neso *et al.* (2001), it is assumed that:

(1) R&D conducted by other firms within the industry under analysis means that there is a 'pool' of R&D spillovers that firm *i* can take advantage of in time period *t*. Suppose:

$$K_t^{total} = \sum_j K_{jz}$$

where the aggregate level of research capital in the industry *z* – is simply the sum of R&D capital possessed by all *j* firms in the industry *z*.

(2) If it is assumed that own resources are allocated optimally and all firms in the industry face the same relative factor prices, then the size of K_t will vary with firm – the spillover for firm *i* (K_t) is K_t^{total} less R&D capital of firm *i* and less the R&D that is not useful to firm *i* in time period *t*. Mathematically we can express this as:

$$K_t = (1 - \rho_i)K_t^{total}$$

where ρ_i is the proportion of firm *i*'s own R&D capital and old or irrelevant knowledge available to firm *i*. Assuming all firms in the industry have similar outputs, therefore, the majority industry R&D is relevant, ρ_i is roughly the proportion of R&D capital possessed by firm *i*. According to this model, K_t for a firm possessing a big part of the industry's whole R&D capital (i.e., ρ approaching 1) will be much lower than for a firm possessing a very small part (i.e., ρ approaching 0). Unless all firms conduct an equal portion of R&D, any model based only on K_t^{total} will be biased – the term (1- ρ_i) will not be observed.

3) When a great majority of R&D is assumed to be relevant to all firms in the industry, then more or less ρ_i is equal to the proportion of R&D capital possessed by firm *i*. Accordingly:

$$K_t = K_t^{total} - K_{it}$$

The term intra-industry spillovers in this research refers to spillovers from the sum of R&D capital possessed by rivals at the top and the middle end of the size distribution of each industry's R&D investors (which account for a great majority of the industry's total R&D spends).

b) Inter-industry spillovers in the 'all-industries' analysis: Firms do not operate only within one closed industry but also assimilate a sum of knowledge from different sources outside their own industry according to their economic and technological distance. However, the distance is difficult to estimate empirically.

Denote the total of R&D capital in industry *m* in period *t* by K_{mt}^{total}. Then the amount of R&D capital which firm *i* in industry *j* accesses outside of its own industry in period *t* is expressed by:

$$K_t^* = \sum_{m \neq j} w_m K_{mt}^{total}$$

where w_m is a weight given to R&D capital in industry *m*. An often-employed assumption is that w_m is getting smaller as the distance between *m m* and *j* increases. Therefore we need to add an estimate of distributed lag over space to create a measure of the stock of borrowed knowledge[v]. However, weighting is not used due to a lack of data with which to construct such weights.

Accordingly, the total of R&D capital accessed by firm *i* both within its own industry and outside the industry is expressed by:

$$K_t = \left(K_t^{total} - K_{it}\right) + K_t^*$$

The term inter-industry spillovers in this research refers to spillovers from the sum of R&D capital possessed by firms at the top and the middle end of the size distribution of the high-technology industries in the UK (which account for a great majority of the total R&D spends in those industries).

Measuring foreign R&D capital stock, although initially planned in the qualifying report, was not conducted because of lack of appropriate data and multicollinearity issues[vi]. Some studies find that foreign spillovers are not beneficial to advanced economies such as the US (Branstetter, 2001; Luintel and Khan, 2004) and UK (McVicar, 2002; Anon-Higon, 2007), while other studies (e.g. Huggins *et al.* 2010) found that a significant proportion of technology-based firms source knowledge from abroad.

Capital is measured as the book value of the firm's fixed assets at 1995 prices. New knowledge is usually embedded in capital investments (Hulten, 2001). However, there is no agreement in the literature on the short-run correlation between firms' R&D investment, inventions, and physical capital investments, although long-run correlation is observed (De Jong 2007).

Labour is measured by the total number of employees, used in many studies as a size control variable (Shan *et al.*, 1994; Rothaermel and Deeds, 2004; Quintana-Garcia and Benavides-Velasco, 2004).

Human capital was proxied for by the firm's remuneration per employee divided by the remuneration per employee of the industry.
The data available does not provide a breakdown by skill type but the average wage serves as a proxy for the average level of human capital per worker. It is assumed that *all things being equal*, firms with high employment costs per person employed are more knowledge and skill intensive than firms in which the average cost is lower (Kodama 1995; Kim 1997; George *et. al.,* 2001).

Material costs (intermediate inputs) are measured as the difference between nominal gross output and nominal value added.

Marketing will account for advertising, branding, and product differentiations according to the SCP framework. Several scholars have included measures of advertising intensity in models of concentration (e.g., Mueller and Rogers, 1980). Davies and Geroski (1997) argue that advertising plays a major role in the dynamics of market shares affecting both concentration and turbulence. Due to data constraints, marketing activities will be measured more generally by 'intangibles'.

Structure-Conduct-Performance variables unaccounted for in this model include government policies, management skills, pure luck, efficiency and other unobservable variables, as well as other measures of the parameters of the stochastic process (e.g., the level of technological risk, entry barriers, historical chance)[vii].

3.3 Data Sources, Sample, and Estimation Issues

3.3.1 Data set

The research merges data from the database FAME and the UK R&D Scoreboard published by the Department for Innovation, Universities & Skills (DIUS) in collaboration with the Department for BERR (BIS since June, 2005). FAME is a firm-level dataset from UK offering comprehensive financial and other operational data, compiled by Bureau van Dijk – an electronic publishing and consultancy firm. The R&D Scoreboard includes data of R&D expenditure, financial and other performance of the most innovative UK companies (including foreign-owned companies whose R&D is conducted and reported in the UK850, in the last years, UK1000). It indicates the overall level of R&D funded by UK companies, not all of which is carried out in the UK. The R&D investment included in the Scoreboard is the cash investment funded by the companies themselves. It excludes the R&D undertaken under contract for customers (such as governments or other companies) and R&D investment made by any associated company or joint venture (although joint venture companies that publish accounts and disclose R&D are included)[viii] . The matching of firms in the R&D Scoreboards and their R&D investment was conducted manually due to reporting inconsistencies (different firms conducting the data collection and manipulation). Only firms whose data matched consistently during the period researched (i.e. 2003/2004 to 2009/2010) were included. The matching between each firm in FAME and the R&D scoreboard was complicated requiring a manual matching procedure based on specific criteria to avoid mistakes (different company names, company location, company status, different model variables, mainly sales and employees). Those firms which were not found in FAME were searched in other relevant databases (Amadeus, ORBIS). Wherever matches were found, the firms were included although some were still excluded due to unconsolidated accounts or other inconsistencies.

The research uses the method of industrial classification used by BERR, based upon ICB sector classification. ICB groups together companies that have similar primary revenue sources. There are 10 industries, which are further disaggregated into 18 super-sectors, 39 sectors, and 104 sub-sectors in an increasing order of disaggregation. Each stock is uniquely classified, based on the company's primary revenue source, in one of the 104 subsectors. Consequently, it is automatically and uniquely classified into one of the 39 sectors, one of the 18 super-sectors and one of the ten industries[ix]

The dataset consists of the top 420 R&D investors in the UK highly innovative industries during 2003/2004 – 2009/2010, although the R&D Scoreboard data sets include initially 850 firms while in the last years – 1000 firms. Observations were deleted if the raw sales, employment, capital investment, or R&D expenditure entries are missing or combined with other variables. Further data trimming excludes observations where sales, employment, constructed capital stock, intermediate inputs, or constructed R&D stock are non-positive and where intermediate inputs are greater than output. Outliers in terms of the firm-specific output and input variables are excluded.

There are some limitations and considerations. The main limitation is the reliance on disclosure of R&D investment in published annual reports and accounts. The data mainly reflects the more benign economic environment of the 7 year period researched, however, the last two periods capture to some extent the impact of the global downturn. Some recent studies on firms' behavior during financial downturns in terms of investment decisions found that in recessions most firms cut investments in innovation and marketing activities to conserve resources (e.g. Srinivasan *et al.* 2010). In addition, the implementation of the International Financial Reporting Standards (IFRS) creates issues in comparing present year accounts with those of past years, not reported under IFRS. The Scoreboard remedies this problem by using IFRS comparatives for previous years specified in the latest accounts instead of the previous published accounts. However, longer term changes need to be interpreted with caution. Finally, although the initial aim was to control for firm age (measured in years, defined in 3 groups: 1 to 10 years, 11 to 20 years and above 20), due to complications of the manual data matching process (each firm's incorporation date had to be checked manually and matched with the Amadeus data set as changes in legal status change the incorporation date) between FAME, R&D Scoreboard and Amadeus, this was not undertaken.

The analysis will rely not only on statistical significance, but also, on the magnitude of estimated parameters and the ability of specific regressors to explain variance in the dependent variable. Associations repeatedly significant but with low magnitude and unworthy in the explanation of variance will be treated with caution.

Full sets of industry/ICB codes and time dummies are included to control for industry/ICB codes and time specific variations. Coefficients on dummy variables are not strictly elasticities (Halvorsen and Palmquist, 1980). In order to compare coefficients a test was performed to show that coefficients are indeed significantly different from each other. Goodness of fit is tested in both between- and within-firm regressors.

3.3.2 Sample frame and descriptive statistics

This research focuses on UK high technology sectors due to their technology-based nature and often-assumed significance of R&D to firm competitiveness. In general, firms in the sectors spend a greater amount of R&D than firms in other sectors. There also needs to be a sufficient number of firms represented in the sector data for results to be statistically meaningful taking into account the impact of M&A and R&D overlap. It also takes into account the availability of data in FAME and R&D Scoreboard, therefore the period researched is 2003/2004-2009/2010.

The selection of the 420 panel of firms during 2003/04 – 2009/10 was based on satisfying at least one of the following criteria: number of employees equal to or over 20, total operating revenues and total assets equalling to or over 1.5 million and 3 million, respectively. The selection criteria are based on high innovativeness, high R&D expenditure, high R&D expenditure as a proportion of sales, business performance, data availability and reliability, and other relevant criteria. However, due to data unavailability, the panel is unbalanced with data missing for some firms, especially in regards to marketing activities and costs of intermediate materials.

Some sectors are not included in the sample of this study in spite of heavy R&D investment. For example, in fixed-line communications, companies have increased their R&D investment as a proportion of sales. However, the sector is not part of the research, as the number of companies is not sufficient. The latest R&D scoreboard shows that banks have also increased their R&D investment. Historically, although they invest heavily when they modernise their IT systems, their R&D investment is intermittent. Therefore the sector is not included in the sample.

Accordingly, the sample frame of this research includes the following sectors (the number of sample firms in parentheses): Pharmaceuticals & Biotechnology (129 companies), Aerospace & Defence (43 companies), Software & Computer services (146 companies), Technology & Hardware equipment (71 companies), and Automobiles & Parts (31 companies) sectors, which together account for most of the R&D in the UK (R&D Scoreboard, 2009), (Table 1).

Table 1: Summary Statistics

N of Ind.	Industry	N of firms	N of Icb. Codes	Icb.Code	N of firms
1.	Aerospace & Defence	43	1.	2713 Aerospace	27
			2.	2717 Defence	16
2.	Automobiles & Parts	31	3.	3353 Automobiles	8
			4.	3355 Auto Parts	20
			5.	3357 Tyres	3
3.	Pharmaceuticals & Biotechnology	129	6.	4573 Biotechnology	55
			7.	4577 Pharmaceuticals	74
4.	Software & Computer Services	146	8.	9533 Computer Services	33
			9.	9535 Internet	4
			10.	9537 Software	109
5.	Technology & Hardware	71	11.	9572 Computer Hardware	6
			12.	9574 Electronic Office Equipment	3
			13.	9576 Semiconductors	25
			14.	9578 Telecommunications Equipment	37

Table 2 summarizes the descriptive statistics of the variables in the 'all-industries' models while Tables 3-7 summarizing the variables of the 'each-industry' industry models. All the variables are in thousands except the R&D capital variables measured in millions. As we can see from Table 1, the means of the conventional input variables and the market share in 'all-industries' models are similar as well as the standard deviations except for the Education (due to the calculations discussed above in this chapter).

Table 2: Descriptive Statistics: 'All-Industries'

All Industries			
Variable	**Obs.**	**Mean**	**Std.Dev**
Market Share	2585	.0133	.0450
Capital	2712	.0128	.0473
Labour	2632	.0131	.0454
Human Capital	2605	1.2125	1.5266
Materials	2046	.0166	.0536
Advertising by other firms	1598	8945664	7148653
R&D capital of other firms	2485	15124.15	14905.53
Firm Adv.	1598	161864.7	856852.9
Firm R&D Capital	2485	167.6424	1056.976

Comparing all industries (Tables 3, 4, 5, 6 and 7), Automobiles & Parts has the highest mean (.0340) in regards to the market share variable, meaning that is the most concentrated, followed by Aerospace & Defence (.0245), Technology & Hardware (.0153) and Pharmaceuticals & Biotechnology (.0097) while the Software & Computer Services has the lowest mean (0.0070). However, the standard deviation is lowest in the Software & Computer Services (.0242) followed by Technology & Hardware (.0357), Pharmaceuticals & Biotechnology (.0519), Automobiles &Parts (.0587) and highest in Aerospace & Defence (.0676).

Table 3: Descriptive Statistics: Aerospace & Defence

Aerospace & Defence			
Variable	**Obs.**	**Mean**	**Std.Dev**
Market Share	286	.0245	.0676
Capital	284	.0246	.0830
Labour	286	.0245	.0740
Human Capital	284	1.1916	1.1643
Materials	222	.0315	.0923
Advertising by other firms	211	1.37e+07	4220642
R&D capital of other firms	239	5728.475	1271.626
Firm Adv.	211	455451.2	1472956
Firm R&D capital	239	164.4753	438.4627

Table 4: Descriptive Statistics: Automobiles & Parts

Automobiles & Parts			
Variable	**Obs.**	**Mean**	**Std.Dev**
Market Share	206	.0340	.0587
Capital	208	.0337	.0600
Labour	204	.0343	.0456
Human Capital	204	1.0642	.4029
Materials	182	.0385	.0667
Advertising by other firms	102	1271771	818461.4
R&D capital of other firms	193	7503.631	716.9686
Firm Adv.	102	86804.93	170362.9
Firm R&D capital	193	280.689	577.8823

Table 5: Descriptive Statistics: Pharmaceuticals & Biotechnology

Pharmaceuticals & Biotechnology			
Variable	**Obs.**	**Mean**	**Std.Dev**
Market Share	722	.0097	.0519
Capital	804	.0087	.0494
Labour	789	.0089	.0517
Human Capital	777	1.1430	.6514
Materials	506	.0138	.0533
Advertising by other firms .	456	1.55e+07	7695336
R&D capital of other firms	759	37250.49	4263.457
Firm Adv.	456	223803.1	1191771
Firm R&D capital	759	339.3215	1854.437

Table 6: Descriptive Statistics: Software & Computer Services

Software & Computer Technology			
Variable	**Obs.**	**Mean**	**Std.Dev**
Market Share	912	.0070	.0242
Capital	945	.0072	.0261
Labour	896	.0073	.0278
Human Capital	885	1.4331	2.4223
Materials	715	.0084	.0348
Advertising by other firms	592	6610856	2078597
R&D capital of other firms	842	5577.86	904.4861
Firm Adv.	592	74044.33	250597.4
Firm R&D capital	842	44.8838	111.557

Table 7: Descriptive Statistics: Technology & Hardware

Technology & Hardware			
Variable	**Obs.**	**Mean**	**Std.Dev**
Market Share	459	.0153	.0357
Capital	471	.0149	.0351
Labour	457	.0153	.0321
Human Capital	455	.9812	.3643
Materials	421	.0166	.0408
Advertising by other firms	237	1143139	295653.2
R&D capital of other firms	452	3974.627	508.9397
Firm Adv.	237	32983.58	82171.41
Firm R&D capital	452	61.4413	109.8172

Conventional inputs in Tables 3, 4, 5, 6 and 7, such as Capital and Labour have the highest mean in Automobiles & Parts (.0337 and .0334) followed by Aerospace & Defence (.0246 and .0245), Technology & Hardware (.0149 and .0153), Pharmaceuticals & Biotechnology (.0087 and .0089) and lowest mean in Software & Computer Services (.0072 and .0073). However, the standard deviation is lowest in Software & Computer Services (.0261 and .0278), followed by Technology & Hardware (.0351 and .0321), and highest in Aerospace & Defence (.0830 and .0740) with Automobiles & Parts and Pharmaceuticals & Biotechnology in the middle range.

The mean of the Cost of Intermediate Materials in Tables 3, 4, 5, 6 and 7, is highest in the Automobiles & Parts (.0385), followed by Aerospace & Defence (.0315), Technology & Hardware (.0166), Pharmaceuticals &Biotechnology (.0138) and lowest in Software & Computer Services (.0084). The standard deviation is lowest in Software & Computer Services (.0348), followed by Technology & Hardware (.0408), Pharmaceuticals &Biotechnology (.0533), Automobiles & Parts (.0667) and highest in Aerospace & Defence (.0923).

According to the descriptive statistics, the more concentrated industries (Automobiles &Parts and Aerospace & Defence) are more capital, labour and intermediate inputs intense.

The mean of the per-employee remuneration relative to the industry average as a proxy for human capital in Tables 3, 4, 5, 6 and 7, is highest in Software & Computer Services (1.4331) meaning that is the most knowledge and skills intense but with highest standard deviation (2.4223), followed by Aerospace & Defence (1.1916), standards deviation of 1.1643, Pharmaceutical & Biotechnology (1.1430), standard deviation of .6514, Automobiles &Parts (1.0642), standard deviation of .4029) and lowest in Technology & Hardware (.9812), standard deviation of .3643.

The mean of advertising expenditures made by other firms in Tables 3, 4, 5, 6 and 7, is highest in Software & Computer Services (6610856), meaning that is the most rivals spillovers intense in regards to advertisement, standard deviation of (2078597), followed by Automobiles & Parts (1271771), standard deviation of 818461.4, Technology & Hardware (1143139), standard deviation of 295653.2 and lowest in Aerospace & Defence (1.37e+07), standard deviation of 4220642 and Pharmaceutical & Biotechnology (1.55e+07), standard deviation of 7695336.

The mean of the firm's own advertising expenditures in the same tables is highest in Aerospace & Defence (455451.2), meaning that is the most advertisement expenditure intense, standard deviation of 1472956, followed by Pharmaceuticals & Biotechnology (223803.1), standard deviation of 1191771, Automobiles & Parts (86804.93), standard deviation of 170362.9, Software & Computer Services (74044.33), standard deviation of 250597.4 and the lowest in Technology & Hardware (32983.58), standard deviation of 82171.41.

The mean of R&D capital stock possessed by other firms in Tables 3, 4, 5, 6 and 7, is highest in Pharmaceutical & Biotechnology (37250.49), meaning that is the most rivals spillovers intense in regards to R&D capital, standard deviation of 4263.457, followed by Automobile & Parts (7503.631), standard deviation of 716.9686, Aerospace & Defence (5728.475), standard deviation of 1271.626, Software & Computer Services (5577.86), standard deviation of 904.4861, and the lowest in Technology & Hardware (3974.627), standard deviation of 508.9397.

The mean of the firm's own R&D capital stock in the same tables is highest in Pharmaceutical & Biotechnology (339.3215), meaning that is the most R&D capital intense, standard deviation of 1854.437, followed by Automobiles & Parts (280.689), standard deviation of 577.8823, Aerospace & Defence (164.4753), standard deviation of 438.4627 , Technology & Hardware (61.4413), standard deviation of 109.8172 and lowest mean in Software & Computer Services (44.8838), standard deviation of 111.557.

Looking at the descriptive statistics in average it seems that the industries with a higher mean value for R&D are also those with the highest market share, on average (Automobile & Parts and Aerospace& Defence), which is in line with the research hypothesis. Therefore in the next chapter we will see if after controlling for other factors this relationship is confirmed.

Chapter 4: Empirical Findings and Discussion

4.1 Introduction

This chapter provides econometric evidence on the relationship between a firm's R&D capital stock and its market share in five high technology industries in the UK. To operationalise the analysis, we transform the baseline models presented in Chapter 3 (equations 5 and 6) into a linear form by taking log of their both sides. The log transformation of equations 5 and 6 produces:

$$\begin{aligned}\ln MS_{it} = {} & \beta_C \ln c_{it} + \beta_L \ln l_{it} + \beta_E \ln e_{it} + \beta_M \ln m_{it} + \beta_{Ai} \ln A_{it} + \beta_A \ln A_t \\ & + \beta_{Ki} \ln K_{it} + \beta_K \ln K_t + \lambda_t + \varepsilon_{it}\end{aligned} \tag{7}$$

$$\begin{aligned}\ln MS_{it} = {} & \beta_{MS} \ln MS_{i,t-1} + \beta_C \ln c_{it} + \beta_L \ln l_{it} + \beta_E \ln e_{it} + \beta_M \ln m_{it} + \beta_{Ai} \ln A_{it} \\ & + \beta_A \ln A_t + \beta_{Ki} \ln K_{it} + \beta_K \ln K_t + \lambda_t + \varepsilon_{it}\end{aligned} \tag{8}$$

respectively. While the first model is used in both 'each-industry' analysis and 'all-industries' analysis, the second dynamic model is estimated only in the 'all-industries' analysis where the system GMM estimator is applied as one of the estimation techniques in addition to the pooled OLS and Fixed Effects estimators.

The rest of the chapter is structured in the following way. Section 4.2 presents findings of the 'each-industry' analysis. Here each of the five high technology sectors covered by this study is analysed separately. Two different estimation techniques are employed in the 'each-industry' analysis: pooled OLS and Fixed Effects. The pooled OLS provides a first idea of how the data are correlated without controlling for firm effects within the error term ε_{it}. By contrast, the Fixed Effects estimator controls for a firm-specific time-invariant component (α_i) of a composite error term ($\varepsilon_{it} = \alpha_i + v_{it}$). An analysis of each industry, together with the use of dummies for ICB sectors, helps to control for industry effects such as appropriability conditions discussed in Chapter 2. However, neither the pooled OLS nor the Fixed Effects models deals properly with simultaneity implied by the two-way interaction between industry structure and innovation, which is highlighted in the literature review. The Fixed Effects estimator, as well as the pooled OLS estimator, biases the coefficients in presence of correlation between any of the regressors and a time-varying component (v_{it}) of a composite error term ($\varepsilon_{it} = \alpha_i + v_{it}$). Unfortunately, GMM estimators did not produce satisfactory results in the 'each-industry' analysis due to a relatively small number of firms in each industry and issues of weak instruments (which will not be reported below). Therefore, results of the pooled OLS and Fixed Effects estimators reported in the 'each-industry' analysis (Section 4.2) should be interpreted with caution. Section 4.3 presents findings of the 'all-industries' analysis. Pooled OLS, Fixed Effects, and system GMM are employed as estimation techniques. System GMM is applied to both equations 7 and 8, whereas the pooled OLS and Fixed Effects estimators are applied to equation 7 only. Equation 8, which is a dynamic panel data model, shows a serious difficulty with the Fixed Effects estimator (as well as the pooled OLS estimator), particularly in the 'small *T*, large *N*' context of the 'all-industries' analysis. Correlation between the lagged dependent variable and the error term creates a large-sample bias in the estimate of the coefficient of the lagged dependent variable. A solution to this problem involves taking first differences of the original model. The first difference transformation, while removing both the constant term and the individual firm effect, still leaves correlation between the differenced lagged dependent variable and the differenced error term. GMM estimators use additional lags of the dependent variable as instruments. Particularly the system GMM estimator employs both lagged differences and lagged levels as instruments, as lagged levels are often rather poor instruments for first-differenced variables (especially if the variables are close to a random walk). All estimations reported are performed in Stata 11. For the OLS and Fixed Effects estimators, built-in commands 'reg' and 'xtreg' are used respectively. The GMM estimator is obtained with the 'xtabond2' command whose details are found in Roodman (2006). The chapter concludes with Section 4.4 by summarising findings.

4.2 Determinants of Market Share: Analysis by Industry

4.2.1 Aerospace & Defence (Table 8)

The Aerospace & Defence industry is highly concentrated with a few major players at the top end of the size distribution and a strong cohort of small firms supplying high-tech products and components (Ecorys, 2009).

Table 8: Aerospace & Defence

Dependent variable: ln (market share)		
Model:	1	2
Estimation method:	Pooled OLS	Fixed effects
Constant	2.0712	4.8311
	(.1884)	(.2115)
ln (Capital)	.0560	.0668***
	(.0367)	(.0222)
ln (Labour)	.2256	.1213***
	(.1138)	(.0428)
ln (Human capital)	.2359	.1387***
	(.0940)	(.0451)
ln (Costs of materials)	.6092**	.7720***
	(.0157)	(.0571)
ln (Advertising)	.0554	.0147
	(.0131)	(.0131)
ln (Advertising of other firms)	.4899	.0951
	(.7045)	(.8259)
ln (R&D capital)	-.0367	.0225
	(.0496)	(.0389)
ln (R&D capital of other firms)	-1.3651*	-.8797
	(.2237)	(.7904)
Defence (ICB group dummy)	.0626	
	(.0210)	
Observations (groups)	130	130 (29)
R^2	0.978	0.973
s.e.e.	.243	
F		F(14,87) = 39.37***

Notes: Standard errors are reported in parenthesis. In pooled OLS, robust standard errors clustered by ICB sectors are shown. Time dummies are included in the regressions.
*, **, *** indicates significance at 10%, 5%, and 1% level, respectively.

Firms in the industry focus their innovative activities in specialised areas to push the technological frontier. The technological life-cycle of products in this industry is highly complex and long – on average 200 engineering hours per component, compared with the average of 21–28 hours for the Automobile & Parts industry (Alix Partners LLP, 2010). R&D investment in the industry is extremely lumpy: the estimates for the A380 reached USD 15 billion in 2004 (Alix Partners LLP, 2010). Under such conditions, the industry structure leans towards a monopoly/oligopoly, as the chance of 'second-movers' to enter the market is slim, supporting Philips' view (1966, 1971) of 'the first-mover advantage'.

Table 8 reports results of estimations. Estimates are obtained for two models: the pooled OLS model (model 1) and the Fixed Effects model (model 2). In the pooled OLS model, all conventional inputs enter the model with expected positive signs. However, costs of materials alone is significant at the 5% level. Neither a firm's advertising expenditures nor advertising expenditures of other firms enters the model significantly. A firm's R&D capital stock takes a negative sign but is insignificant. R&D capital stock of other firms enters the model at the 10% level. A negative sign of the variable's coefficient indicates that an increase in R&D stock capital of other firms in the industry leads to a decline in the market share of a firm under question.

In the Fixed Effects model reported in the second column of Table 8, all conventional inputs enter the model significantly with an expected positive sign. By contrast, neither a firm's advertising expenditures nor advertising expenditures of other firms enters the model significantly. As for a firm's R&D capital stock, it takes a positive sign but remains insignificant. R&D capital stock of other firms in the industry fails to enter the Fixed Effects model significantly while its coefficient remains negative. In the defence sector, the government subsidises R&D activities of selected firms (Ecorys, 2009). The failure of R&D capital stock to enter both models may reflect the subsidy which distorts the market.

4.2.2 Automobiles & Parts (Table 9)

Since 2000 the production of vehicles in the UK has been decreasing due to the demise of MG Rover, and the closure of manufacturing facilities by GM and Ford. This has led to a change in the business model from volume car manufacturing to niche and luxury products, and engine manufacture in the UK. In the mature Automobiles & Parts industry, threat of new entrants is generally low except for parts and tyres sectors, as barriers to entry are high (e.g., upfront capital requirements, brand name, legislation and government policy). Fierce competition, accelerated in part by worldwide production over-capacity and customer expectations, has led to 'infinite' product diversification and shortened product life-cycles of 2–3 years (Holweg and Greenwood, 2000). Globally, the industry is expected to move to completely new, ecologically clean models. However, the paradigm shift is a slow process. Vehicles are in operation for an average of 12 years, meaning that it would take about ten years for

75% of cars on the road to be replaced with models based on green technology (Holweg and Greenwood, 2000). Requirements of a new fuel distribution infrastructure further delay the transition. Therefore, investments in research into green technology have yet to show significant impacts upon market shares during the period covered by this study.

Table 9: Automobiles & Parts

Dependent variable: ln (market share)		
Model:	1	2
Estimation method:	Pooled OLS	Fixed effects
Constant	17.4303***	-80.7969**
	(.3271)	(37.6154)
ln (Capital)	.2373*	-.0764
	(.0914)	(.1364)
ln (Labour)	-.0542	1.1498** *
	(.0484)	(.3140)
ln (Human capital)	-.0163	-.0512
	(.0258)	(.0414)
ln (Costs of materials)	.7163***	.6250***
	(.0435)	(.2126)
ln (Advertising)	.0128	.0995*
	(.0089)	(.0595)
ln (Advertising of other firms)	-.1220**	-.0930
	(.0257)	(.2013)
ln (R&D capital)	-.0830***	.1325
	(.0040)	(.4971)
ln (R&D capital of other firms)	-1.8310 ***	9.4447**
	(.1265)	(.2130)
Auto parts (ICB group dummy)	.1964**	
	(.0312)	
Tyres (ICB group dummy)	-.0012	
	(.0238)	
Observations (groups)	82	82 (19)
R^2	0.986	0.854
s.e.e.	.332	
F		F(14,49) = 4.59***

Notes: Standard errors are reported in parenthesis. In pooled OLS, robust standard errors clustered by ICB sectors are shown. Time dummies are included in the regressions.
*, **, *** indicates significance at 10%, 5%, and 1% level, respectively.

Table 9 reports results of the analysis of the Automobiles & Parts industry. In the pooled OLS model, capital and costs of materials enter the model with expected signs at the 10% and 1% levels respectively. By contrast, labour and human capital enter the model with negative signs although not significantly. A firm's advertising expenditures enters the model with an expected positive sign but it is not significant, whereas advertising expenditures of other firms in the industry takes a negative sign at the 5% level, indicating that an increase in advertising expenditures of other firms in the industry leads to a decline in the market share of the firm under question. As for a firm's R&D capital stock and R&D capital stock of other firms in the industry, both enter the model significantly with negative signs. The negative sign of R&D capital of other firms is in line with the interpretation that its growth causes a relative decline in R&D capital of a firm under question, leading to a loss of the firm's market share. The negative sign of a firm's own R&D capital is problematic, and inconsistent with the result of the Fixed Effects model.

In the Fixed Effects model (Model 2), labour and costs of materials enter the model significantly with expected positive signs. Capital and human capital take a negative sign but are insignificant. A firm's advertising expenditures enters the model marginally (10% level) with a positive sign, whereas advertising expenditures of other firms in the industry takes a negative sign and is insignificant. A firm's R&D capital stock fails to enter the model significantly while R&D capital stock of other firms in the industry enters the model significantly. Both the variables take positive signs.

Comparison of the two models shows some inconsistencies between them, as well as a few unexpected signs of coefficients (e.g., negative signs of capital and human capital in Fixed Effects model and of R&D capital in Pooled OLS). This is likely to indicate the significance of firm effects, as well as potential specification issues of the baseline model when applied to the industry.

4.2.3 Pharmaceuticals & Biotechnology (Table 10)

The Pharmaceutical & Biotechnology industry has experienced a mega merger boom in the last few years. The development of a new drug to its authorization is a time-consuming and expensive process taking on average 7–14 years and $50 million USD in very lean biotech companies, and almost five times in big pharmaceutical companies (IMAP, 2010). Productivity of R&D is very low in the last several years (9 out of 10 new drugs show lack of efficacy or safety, or harmful side effects during the clinical phase) with the rate of introduction of one new drug per year per firm on average (IMAP, 2011). As pipelines dry out, companies are staving off the R&D crisis via joint ventures, M&A, geographic expansion and diversification into new segments (e.g., consumer health). They are also experimenting with new R&D models. For example, Pfizer and GSK exchanged intellectual property rights in an attempt to invent new drugs (e.g., HIV).

Table 10: Pharmaceuticals & Biotechnology

Dependent variable: ln (market share)		
Model:	1	2
Estimation method:	Pooled OLS	Fixed effects
Constant	3.5774	40.3379
	(.7202)	(37.1651)
ln (Capital)	-.0185	-.0069
	(.0100)	(.0525)
ln (Labour)	.1703	.3094***
	(.0573)	(.0840)
ln (Human capital)	.0373	.0028
	(.0115)	(.0339)
ln (Costs of materials)	.7062*	.6098***
	(.0731)	(.0379)
ln (Advertising)	.0573	.0099
	(.0159)	(.0289)
ln (Advertising of other firms)	-.8379*	-.20329
	(.1807)	(.4540)
ln (R&D capital)	.1346*	-.0174
	(.0277)	(.0637)
ln (R&D capital of other firms)	.6496	-3.7307
	(.9434)	(3.7546)
Pharmaceuticals (ICB group dummy)	.4292	
	(.1328)	
Observations (groups)	316	316 (69)
R^2	0.950	0.922
s.e.e.	.5645	
F		F(14,233) = 38.83***

Notes: Standard errors are reported in parenthesis. In pooled OLS, robust standard errors clustered by ICB sectors are shown. Time dummies are included in the regressions.
*, **, *** indicates significance at 10%, 5%, and 1% level, respectively.

Table 10 reports results of the analysis of the Pharmaceutical & Biotechnology industry. In the pooled OLS model, costs of materials enters the model marginally (10% level), whereas other conventional inputs including capital, labour, and human capital fail to enter it significantly. The conventional inputs take expected positive signs with the exception of capital taking a negative sign. A firm's advertising expenditures takes an expected positive sign but fails to enter the model significantly. By contrast, advertising expenditures of other firms in the industry marginally enter the model with a negative sign, indicating that an increase in the variable causes a relative decline of the particular firm's share of advertising expenditures in the industry and a resultant drop of its market share. As for a firm's R&D capital stock, it marginally enters the model with an expected positive sign. R&D capital of other firms in the industry takes a positive sign, implying knowledge spillovers, but is insignificant.

Results of the Fixed Effects model show a few changes from those of the pooled OLS model. Labour and costs of materials enter the model significantly while advertising expenditures of other firms cease to do so. Furthermore, a firm's own R&D capital stock takes an unexpected negative sign although its coefficient is insignificant.

4.2.4 Software & Computer Services (Table 11)

The Software & Computer services industry is in its mature phase with consolidations taking place (Rönkkö *at al.*, 2010). Key players are shifting away from product-based business model to service-based business model with new products (e.g., cloud computing) appealing to both customers and enterprises. Mobile computing platform has not yet established its domain design and the competition for this is fierce. Software industry has not suffered by the recession as much as the other industries. Industry dynamics are accelerating while new firms' appetite for growth is even higher than in the past. Due to consolidations in recent years, the industry's firm size distribution is strongly polarised. Top end players have consolidated their positions while second-tier players are focusing on their own specific utilities to avoid head-to-head competition with the top end players (IMAP, 2010).

Table 11 reports results of the analysis of the Software & Computer services industry. In the pooled OLS model, all conventional inputs take expected positive signs with labour and costs of materials entering the model marginally (10% level). A firm's advertising expenditures takes a negative sign but fails to enter the model significantly. By contrast, advertising expenditures of other firms in the industry enters the model marginally with a negative sign, implying that an increase in the variable leads to a relative decline in the particular firm's share of the expenditures and a resultant loss of its market share. A firm's R&D capital stock enters the model significantly with an expected positive sign. R&D capital stock of other firms in the industry also enters the model significantly with a positive sign, implying knowledge spillovers. However, this is not the case in the Fixed Effects model.

In the Fixed Effects model, both advertising expenditures and R&D capital stock of other firms in the industry cease to enter the model significantly with signs of their coefficients opposite to their equivalents in the pooled OLS model.

Table 11: Software & Computer Services

Dependent variable: ln (market share)		
Model:	1	2
Estimation method:	Pooled OLS	Fixed effects
Constant	-9.7676*	7.1705
	(2.7878)	(15.1858)
ln (Capital)	.1513	.1221***
	(.0665)	(.0381)
ln (Labour)	.5771*	.5083***
	(.1408)	(.0560)
ln (Human capital)	.0971	.0507***
	(.1225)	(.0195)
ln (Costs of materials)	.2236*	.1776***
	(.0607)	(.0260)
ln (Advertising)	-.0494	-.0335
	(.0374)	(.0237)
ln (Advertising of other firms)	-.5252*	.3900
	(.2112)	(.5789)
ln (R&D capital)	.1563**	.1363**
	(.0293)	(.0589)
ln (R&D capital of other firms)	2.0951**	-1.7391
	(.3297)	(1.7867)
Internet (ICB group dummy)	.82374***	
	(.0925)	
Software (ICB group dummy)	.0008	
	(.0341)	
Observations (groups)	411	411 (95)
R^2	0.925	0.917
s.e.e.	.476	
F		F(14,302) = 40.48***

Notes: Standard errors are reported in parenthesis. In pooled OLS, robust standard errors clustered by ICB sectors are shown. Time dummies are included in the regressions.
*, **, *** indicates significance at 10%, 5%, and 1% level, respectively.

By contrast, all the conventional inputs including capital, labour, human capital, and costs of materials enter the model at the 1% level with expected positive signs. Moreover, a firm's R&D capital stock enters the Fixed Effects model significantly (5% level) with a positive sign of its coefficient. Comparison of these two models shows smaller coefficient values for those variables entering them significantly (i.e. capital, labour, human capital, costs of materials, R&D capital stock) in the Fixed Effects model than in the pooled OLS model. This is likely to indicate a presence of time-invariant firm effects which produce upward biases in the pooled OLS model.

4.2.5 Technology & Hardware Equipment (Table 12)

While M&A activities in the industry significantly decreased during the financial crisis, the industry on the whole is growing with the emergence of new sub-sectors (e.g., data centres) and non-PC markets (e.g., tablets and smart phones) (Deloitte LLP, 2011). There is great diversity in the operating systems of tablets and the smart phones. This is likely to prevent any single player from establishing a dominant design in the near future, which is in contrast to what has happened in other computing markets in the past. Proliferation of different systems has led to a great level of segmentation and complexity in the hardware market, creating problems for application developers, enterprises, and individual customers who are experiencing high costs in supporting different hardware types. Another trend observed in the industry recently is the rise of new, radical technologies, such as self-organising molecular devices, carbon nanotubes, quantum computing, and graphene transistors, which may circumvent the physical boundaries of the current semiconductor technologies.

Table 12 reports results of the analysis of the Technology & Hardware Equipment industry. In the pooled OLS model, costs of materials enters the model significantly whereas other conventional inputs including capital, labour, and human capital fail to do so. In addition, the coefficients for capital and human capital take unexpected negative signs. A firm's advertising expenditures and advertising expenditures of other firms in the industry enter the model significantly. The signs of their coefficients are opposite: positive for a firm's own expenditures and negative for expenditures of other firms, which conforms to the interpretation of a firm's share of the expenditures within the industry and its expected relationship with the firm's market share. By contrast, both a firm's R&D capital and R&D capital of other firms in the industry take a positive sign although neither of them fails to enter the model significantly.

In the Fixed Effects model, there are a number of changes in the signs of coefficients. Capital and human capital take positive signs whereas labour takes a negative sign. In a similar vein, a firm's advertising expenditures takes a negative sign while advertising expenditures of other firms in the industry takes a positive sign. Furthermore, capital and labour, in addition to costs of materials and advertising expenditures of other firms, come to enter the model significantly. In spite of these changes, a firm's R&D capital as well as R&D capital of other firms in the industry remain insignificant in the Fixed Effects model.

Table 12: Technology & Hardware Equipment

Dependent variable: ln (market share)		
Model:	1	2
Estimation method:	Pooled OLS	Fixed effects
Constant	12.8477	47.9762
	(9.8797)	(51.3785)
ln (Capital)	-.0785	.2128***
	(.1771)	(.0749)
ln (Labour)	.0081	-.3988***
	(.2393)	(.1027)
ln (Human capital)	-.0021	.1181
	(.1310)	(.1448)
ln (Costs of materials)	.7013***	.8279***
	(.0520)	(.0516)
ln (Advertising)	.1044***	-.0857*
	(.0094)	(.0461)
ln (Advertising of other firms)	-1.3534***	1.1160***
	(.0993)	(.3889)
ln (R&D capital)	.2545	.0017
	(.1336)	(.1513)
ln (R&D capital of other firms)	.0947	-7.8842
	(1.3711)	(6.3894)
Electronic office equipment (ICB group dummy)	.3572	
	(.2801)	
Semiconductors (ICB group dummy)	-.2251	
	(.0901)	
Telecommunication equipment (ICB group dummy)	-.0437	
	(.0250)	
Observations (groups)	213	213 (49)
R^2	0.915	0.830
s.e.e.	.609	
F		F(14,150) = 25.49***

Notes: Standard errors are reported in parenthesis. In pooled OLS, robust standard errors clustered by ICB sectors are shown. Time dummies are included in the regressions.
*, **, *** indicates significance at 10%, 5%, and 1% level, respectively.

The inconsistencies between the two models suggest issues of endogeneity. Given the unexpected negative sign for labour, the Fixed Effects model is likely to suffer from correlation between regressors and a time-variant component of the error term.

4.2.6 Discussion

The analysis of the five industries reported above may indicate a sign of potential variations across industries in the relationship between a firm's R&D capital stock and its market share. A firm's R&D capital stock enters a model significantly (5%) with a positive sign in the Software & Computer services industry, and this is consistent in both the pooled OLS model and the Fixed Effects model. For the Pharmaceutical & Biotechnology industry, a firm's R&D capital stock enters the pooled OLS model with a positive sign marginally (10%) but fails to enter the Fixed Effects model significantly. For the Aerospace & Defence industry and the Technology & Hardware equipment industry, the variable enters neither the pooled OLS model nor the Fixed Effects model significantly. For the Automobile & Parts industry, a firm's R&D capital stock takes a negative sign at the 1% significance level in the pooled OLS model, whereas the variable fails to enter the Fixed Effects model significantly but takes an expected positive sign.

A potential interpretation of the cross-industry variations in the results is a generally shorter product development cycle in the Software & Computer services industry than in the other industries. Although some specific types of software such as operating systems take years to develop, a significant proportion of application software are developed within a short cycle, which is often in the order of months and even weeks in some cases (e.g., applications for mobile devices). By contrast, new product development cycles are considerably longer in Aerospace & Defence, Pharmaceutical & Biotechnology, and Automobile & Parts in general. The variation across industries in the cycle of new product development is translated into a variation in the lag between investment into R&D (and particularly basic research as opposed to near-market development) and its impact upon a firm's revenue. Given a shorter product development cycle in the Software & Computer services industry, a change in a firm's R&D capital stock is more likely to appear in the firm's market share in a short period of time in the industry than in the other industries covered by this study. This might account for the significant association between a firm's R&D capital stock and market share in the Software & Computer services industry and the lack of such relationship in the other industries.

However, the results of the above analysis by industry should be viewed with caution. There are considerable differences in the results between the pooled OLS model and the Fixed Effect model. Differences are large particularly in the results of the Automobiles & Parts industry and the Technology & Hardware equipment industry where some coefficients take opposite signs between the pooled OLS and the Fixed Effects models. Those differences between the two models indicate a presence of biases in the estimators due to the endogeneity of regressors.

As stated at the beginning of this chapter earlier, the pooled OLS and Fixed Effects estimators are biased in presence of correlation between any of the regressors and a time-varying component (v_{it}) of a composite error term ($\varepsilon_{it} = \alpha_i + v_{it}$). Although the above results of the Fixed Effects model, which excels the pooled OLS model by controlling for a firm-specific time-invariant component of an error term, tend to better conform to our expectations, there are still a few instances where its results are problematic (e.g., a negative coefficient for labour in the Technology & Hardware industry). Given the two-way interaction between industry structure and innovation highlighted in the literature, the issue of simultaneity is likely to exist in estimation. To deal with the issue, we attempted to employ GMM estimators but did not obtain satisfactory results due to a small number of firms in each industry and weak instruments. This calls for an analysis of a single panel data including all industries covered by this study, to which we now turn.

4.3 Determinants of Market Share: "All-industries" analysis (Table 13)

Table 13 reports results of the analysis of a single panel data including firms in the five high-technology industries covered by this study. Of six models reported in the table, the first two models – the pooled OLS and the Fixed Effects – are the same as those reported in Tables 8 to 12, except for the coverage of firms in all the five industries in Table 13 as opposed to the coverage of firms in each of the five industries in Tables 8 to 12.

The rest of the models reported in Table 13 employ the system GMM estimator. Models 5 and 7 are static (equation 7 presented at the beginning of this chapter), whereas Models 6 and 8 are dynamic, including the lagged dependent variable (equation 8). Models 5 to 8 are also divided into another two groups by dummies used. Given the panel data's coverage of the five different industries, we need to control for industry effects such as different appropriability conditions across industries (which is discussed in Chapter 2). Models 5 and 6 include industry dummies for this purpose. Models 7 and 8 use dummies for ICB sectors to control for industry effects at a finer level.

Table 13: 'All-industries' analysis

Dependent variable: ln (Market share)						
Model	3	4	5	6	7	8
Estimation method	Pooled OLS	Fixed Effects	System GMM	System GMM	System GMM	System GMM
Constant	-.0989	1.5697	4.9781	5.1622*	1.1260	-.3965
	(2.9899)	(.051337)	(6.1729)	(3.3359)	(6.1095)	(4.0120)
ln (Market share $_{t-1}$)				.4504***		.4575***
				(.0790)		(.0793)
ln (Capital)	.0784*	.0909***	.0561	.1231**	.0192	.1289***
	(.0476)	(.0254)	(.1317)	(.0594)	(.1245)	(.0560)
ln (Labour)	.2207*	.1228***	.3332***	.1461**	.3065**	.1048*
	(.1123)	(.0287)	(.1315)	(.0673)	(.1287)	(.0641)
ln (Human capital)	.0574	.0501***	.1943*	.1042*	.1166	.0781
	(.0554)	(.0176)	(.1316)	(.0624)	(.1192)	(.0541)
ln (Costs of materials)	.5702***	.4999***	.7001***	.2858***	.7053***	.2947***
	(.1117)	(.0205)	(.0911)	(.0821)	(.0981)	(.0830)
ln (Advertising)	.0188	-.0122	-.0790	-.0618*	-.0728	-.0757**
	(.0271)	(.0154)	(.0745)	(.0359)	(.0677)	(.0343)
ln (Advertising of other firms)	-.0173	.0321	.1695	.0769	.1803*	.1243
	(.0622)	(.0440)	(.1172)	(.0873)	(.1120)	(.0866)
ln (R&D capital)	.1284***	.0409	.0197	.0141	.0696	.0486
	(.0296)	(.0393)	(.0684)	(.0359)	(.0701)	(.0357)
ln (R&D capital of other firms)	-.1768	-.4459**	-.7442	-.6866**	-.3706	-.1154
	(.3038)	(.2050)	(.6312)	(.3477)	(.6221)	(.4050)
Industry dummies			Yes	Yes		
ICB dummies	Yes				Yes	Yes
AR(1) Test			0.059*	0.032**	0.038**	0.028**
AR(2) Test			0.211	0.772	0.182	0.722
Hansen's J test			0.670	0.223	0.603	0.129
Difference-in-Hansen test: GMM instruments in levels			0.497	0.471	0.486	0.154
Observations (groups)	1152	1152 (261)	1152 (261)	1025 (257)	1152 (261)	1025 (257)
Number of instruments			91	163	100	171
R^2	0.933	0.904				
s.e.e.	.572					
F		F(14,877) = 76.75***	F(18, 260) = 100.65***	F(18, 256) = 461.86 ***	F(27, 260) = 401.31***	F(27, 256) = 1224.22***

Notes: Standard errors are reported in parenthesis. In pooled OLS, robust standard errors clustered by ICB sectors are shown. Time dummies are included in the regressions. AR(1) and AR(2) are Arellano-Bond tests for serial correlations. Coefficients and standard errors of industry/ICB dummies are given in Appendix 2.

*, **, *** indicates significance at 10%, 5%, and 1% level respectively.

Another difference of the analysis reported in Table 13 from those in Tables 8 to 12 is the definition of R&D capital stock of other firms and advertising expenditures of other firms. In each analysis reported in Tables 8 to 12, those two variables include R&D capital stock and advertising expenditures of all firms in each industry, except for a firm under question. This allows those variables to be interpreted as (a) (approximately) the denominator used in the calculation of the firm's share within the industry concerned (see equation 2 in Chapter 3), as well as (b) the source of intra-industry spillovers (see Section 3.2.3 in Chapter 3). By contrast, R&D capital stock of other firms and advertising expenditures of other firms in Table 13 include those of all firms in the five high-technology industries except for a firm under question. The construct of the variables (which combines the sources of intra-industry and inter-industry spillovers, see Section 3.2.3 in Chapter 3) makes their interpretation as (a) above less immediate to see. However, the variables still correlate with (a). This is evident when we take firms within the same industry, since the sum of R&D capital outside of their industry is constant, while the sum of R&D capital owned by other firms within the industry varies. Results of each model are described below.

Model 3 (pooled OLS model) is distinct from the rest of the models reported in Table13 in the following two points: (1) this is the only model which a firm's R&D capital stock enters significantly; and (2) the signs of the coefficients for a firm's advertising expenditures and advertising expenditures of other firms are positive and negative respectively in Model 3, whereas they are opposite signs in the rest of the models in Table 13. Except for the points, the results of the model are largely consistent with the rest in Table 13. All conventional inputs take a positive sign for their coefficients. Of them, costs of materials enters the model significantly (1%) while capital and labour enter marginally (10%). As noted, a firm's R&D capital stock enters the model significantly (1%) with a positive sign whereas R&D capital stock of other firms is insignificant and takes a negative sign. Taking opposite signs, a firm's R&D capital and R&D capital of other firms are in the relationship conducive to the interpretation of a firm's share of R&D capital within the industry.

Model 4 uses the Fixed Effects estimator. All conventional inputs – capital, labour, human capital, and costs of materials – enter the model significantly (1%). While a firm's R&D capital stock fails to enter the model significantly, R&D capital stock of other firms enters it significantly (5%).

Models 5 to 8 employ the system GMM estimator. All independent variables except industry and ICB sector dummies are instrumented. Arellano-Bond tests, labelled as AR(1) and AR(2) in Table 13, check serial correlation in ν_{it} in the error term $\varepsilon_{it} = \alpha_i + \nu_{it}$. Since $\Delta\nu_{it}$ is mathematically related to $\Delta\nu_{i,t-1}$ via the shared $\nu_{i,t-1}$ term, negative first-order serial correlation is expected in evidences. AR(1) is significant in Models 5 to 8 (10% in Model 5 and 5% in the rest) as expected. AR(2) is a statistic for second-order correlation in differences. It is used to check first-order serial correlation in levels, as it detects correlation between the $\nu_{i,t-1}$ in $\Delta\nu_{it}$ and the $\nu_{i,t-2}$ in $\Delta\nu_{i,t-2}$ (Roodman, 2006). AR(2) statistics for Models 5 to 8 are all satisfactory. Hansen's J statistic is a test of the validity of the overidentifying restrictions. A rejection of the null hypothesis implies that the instruments do not satisfy the required orthogonality conditions. The statistics for Models 5 to 8 do not show any serious problem. We also tested the validity of the overidentifying restrictions for a set of GMM instruments in levels, as lagged levels are often rather poor instruments for first-differenced variables. The statistic, labelled as Difference-in-Hansen test in Table 13, is satisfactory for Models 5 to 8.

Models 5 and 6 use industry dummies to control for industry effects such as different appropriability conditions and technological opportunities across industries. All conventional inputs enter Model 5 positively but only labour and costs of materials are significant (1%). Neither a firm's R&D capital stock nor R&D capital stock of other firms enters the model significantly. Model 6 includes the lagged dependant variable. The variable enters the model significantly (1%), showing that a firm's market share in the current year depends on its market share in the previous year. All conventional inputs enter the model either significantly (costs of materials at 1% and capital and labour at 5%) or marginally (human capital at 10%). A firm's advertising expenditures enters the model marginally (10%) with a negative sign. This implies that when other variables are held constant, an increase in the priority given by a firm to its advertising activities tends to reduce the firm's market share. Of the two types of R&D capital stock, R&D capital of other firms enters the model significantly (5%) with a negative sign, whereas a firm's own R&D capital fails. It appears that a relative decline in a firm's share of R&D capital stock, caused by an increase in the stock owned by other firms, leads to a loss of the firm's market share.

Models 7 and 8 employ ICB sector dummies to control for industry effects at a finer level. Results of Model 7 are similar to those of Model 5, except for human capital no longer entering the model significantly and advertising expenditures of other firms entering the model marginally. In a similar vein, results of Model 8 remain largely unchanged from those of Model 6 with the exception of human capital and R&D capital stock of other firms not entering the model any longer significantly.

Comparison of dynamic models with static models (Model 5 with Model 6, and Model 7 with Model 8) shows that when the lagged dependent variable is included, the coefficient values for labour, human capital, and costs of materials drop significantly. In a similar vein, the coefficient value for advertising expenditures of other firms declines to a great extent. By contrast, the coefficient value for capital gains a lot when the lagged dependent variable is included. As for a firm's R&D capital stock, a change in its coefficient value is relatively small after the inclusion of the lagged dependent variable. In other words, when accounting for a firm's market share, the firm's R&D capital stock in the current year carries a relatively small amount of information correlated with its market share in the previous year.

Although there are variations in the significance for a few variables (e.g., human capital), the results of the system GMM models largely conform to our expectations. When the lagged dependent variable is included (Models 6 and 8), all conventional inputs take positive signs and, except for human capital in Model 8, enter the models at the 10% or greater significance. Of the conventional inputs (i.e., capital, labour, human capital, and costs of materials), costs of materials takes the highest coefficient value in all four GMM models, suggesting its immediacy to turnover in the current year. The results of a firm's advertising expenditures and advertising expenditures of other firms are contrary to our expectations. Although their being in opposing directions conforms to our expectations, a firm's advertising expenditures works to reduce its market share. A possible interpretation is the inadequacy of the expenditure on intangibles as a proxy for advertising. When expenditures on other items are held constant, an increase in the expenditure on intangibles might mean a lower level of efficiency in a firm's production system, resulting in a drop of its market share.

As for a firm's R&D capital stock, the sign of its coefficient is positive and in an opposing direction to R&D capital stock of other firms, implying that a firm's R&D

capital stock and R&D capital stock of other firms are in the relationship of a numerator and a denominator of a firm's share. However, a firm's R&D capital stock fails to enter any of the system GMM models significantly, indicating that its relationship with the firm's market share is statistically not strong.

In view of the two-way causation between innovation and industry structure and the dynamic process of industry structure formation highlighted in the literature, we are inclined to take the results obtained from the application of the system GMM estimator to the dynamic panel data analysis (Models 6 and 8). Of the models reported in Table 13, the results of the dynamic GMM models are also in line with those of the Fixed Effects model (Model 4). Taken together, as far as firms on the top and middle end of the size distribution within the five high-technology industries in the UK are concerned, we do not find strong evidence to support positive association between a firm's R&D capital stock and its market share in general.

4.4 Summary

As opposed to static efficiency (i.e., an equilibrating force keeping industries at a steady position), dynamic efficiency, or competition through innovation, is a major source of long-run change in the capitalist economy. The literature recognises the role of entry, in particular of 'innovative' entrants, as an 'agent of change' and its effects upon incumbents who respond for survival. While innovative entry gives rise to responses of incumbents for survival, the entry is also affected by the existing and past technological and marketing decisions of incumbent firms (Geroski, 1991). In this interrelated process, innovation is assumed to act as a key factor linking industry structures of the past and the present.

Against this backdrop, this study examined the relationship between innovation, measured by a firm's R&D capital stock, and its market share, using a dataset of firms in the five high-technology industries in the UK. The findings of the empirical examination can be summarised as follows: (a) there is a sign of variations across the five industries in the relationship between a firm's R&D capital stock and its market share although the evidence is only indicative; and (b) there is no strong evidence to support positive association between a firm's R&D capital stock and its market share in general.

On (a), the results of the analysis by industry (Section 4.2) show some difference across the five industries in the relationship between a firm's R&D capital stock and its market share. While there is some evidence for positive association between them in the Software & Computer services industry, no significant relationship is found in the other industries when the Fixed Effects estimator is employed. The literature suggests that the link between R&D activities and market share is likely to vary across industries due to cross-industry variations in technological opportunities, appropriability conditions, and strategic focus of innovation. However, given the lack of general evidence which differentiates the five industries in each of those factors, it is safe to refrain from attributing the observed cross-industry difference in the R&D capital-market share relationship to any one of them. Moreover, in view of simultaneity between innovation and industry structure highlighted in the literature, the results of the pooled OLS and Fixed Effects estimators are most likely to be biased. Therefore, the cross-industry difference observed in the analysis by industry should be seen as indicative rather than suggestive, let alone conclusive.

On (b), the analysis of a single panel data combining all the five industries shows that there is not strong evidence supporting positive association between a firm's R&D capital stock and market share in general. The results of the system GMM estimator, applied to a dynamic model as well as a static model, and the Fixed Effects estimator are consistent on this. The economics literature on the subject pays little attention to the concept of 'positioning' found in the strategy literature. The economics literature, for simplicity in modelling, often assumes homogeneity of products within an industry and does not differentiate firms in their profitability. By contrast, the strategy literature emphasises strategic positioning of firms within an industry, acknowledging that the level of profitability varies across sectors. In this view, firms do not necessarily undertake R&D to gain a larger market share but use it as part of their positioning aimed at a higher level of profitability. The study's finding of the lack of a general relationship between a firm's R&D capital stock and market share supports the view of the strategy literature.

Finally there are a couple of qualifications about the interpretation of the findings. First, R&D capital stock derived from an R&D input (i.e., expenditure on R&D in this study) is not identical to innovation. In-house R&D is associated with a number of market failures such as uncertainty, inappropriability, and indivisibility (Spence, 1984). These simultaneous market failures manifest themselves in different industries at different levels, impacting the relationship between R&D inputs and outputs. Furthermore, firms often acquire innovative solutions and products through M&A instead of in-house R&D activities, although the resource-based theory suggests the difficulty of transferring technical know-how across organisations and the importance of resource accumulation through in-house R&D (Zander and Kogut, 1995; Szulanski, 1996; Galunic and Rodan, 1998; Rodan, 2005). Given this, there are some reservations about taking R&D capital stock as a proxy for innovation. Although this study is motivated in part by the literature on innovation and industry structure, the unit of its analysis is, strictly speaking, different, thus calling for care in the interpretation of its findings.

Second, this study focuses on firms generally at the top and middle end of the size distribution in the five high-technology industries in the UK, examining the relationship between R&D capital and market share within the cohort. Accordingly, the rest of the firms in the five industries, and particularly firms at the bottom end, are excluded from the analysis. The literature suggests that the way in which R&D activities affect market share may not be uniform within an industry due to different competitive environments at the bottom and the top of scale. If all firms in an industry face the same technological opportunities, rich technological opportunities encourage concentration at the top and entry at the bottom of the same industry (Geroski, 1991). Because of the sampling framework adopted by this study, the findings do not capture any relationship which such entry creates between R&D investment and market share at the lower end of the industries covered by this study.

Explaining how the conceptual framework (Figure 2) accounts for each of the key findings from the literature review, this study employs the Sources of Growth model which relates increases in output to increases in inputs of capital, skilled and unskilled labour, intermediate inputs and other variables such as R&D and marketing expenditures (Griliches, 1979; Katayama *et al.*, 2005; Cincera and Ravet, 2011). As noted in Chapter 3, although the objective of this study is to analyse the impact of R&D on a firm's performance in terms of gain or loss of market share, statistically estimating the fraction of firm growth due to in-house R&D, the total firm growth is linked to all production factors (as per equations 7 and 8). As the R&D are also incorporated into the conventional variables, e.g. capital, labour, human capital and intermediate inputs, their coefficient estimates account for normal returns to R&D inputs (Schankerman, 1981). New knowledge is usually embedded in capital investments (Hulten, 2001). It is also assumed that *all things being equal*, firms with high employment costs per person employed (as a proxy for human capital) are more knowledge and skill intensive than firms in which the average cost is lower (Kodama 1995; Kim 1997; George *et. al.,* 2001).

As discussed in Chapter 1, Market share as a performance indicator generally relates to a firm's long-run profitability and it is also a growth performance indicator (Scherer, 1980). The research findings suggest that increasing conventional inputs in short and medium terms leads to an increase in a firm growth and long-run profitability (measured by market share) in regard to the top and middle end firms in the UK high technology sectors. Firms invest in conventional inputs to increase current supply capacity hoping that increased sales will lead to increases in revenues and profits or lead to lower costs (economies of scale), and improvements in productivity and efficiency. However, these research findings cannot make any suggestions whether firms with increased market share as a result of increased conventional inputs (as well as R&D capital and marketing activities) are more productive and efficient which is a subject of a different methodology.

Chapter 5: Conclusions

As discussed in the previous chapters, in spite of the widespread focus on innovation, on the one hand, and the popularity of market share-oriented strategy, on the other, in strategic management, there is a lack of evidence about the relationship between in-house R&D and market share. The available literature is concentrated on the social aspects of welfare: market share is reviewed in the context of monopoly/oligopoly and its impact upon firms' behaviour within an industry (e.g. pricing). For managers at individual firms, the existing evidence in regards to R&D expenditure at the level of an individual firm is insufficient and inconclusive as to its contribution to the firm's growth in terms of market share. This research hopes to provide a richer, more subtle interpretation on how in-house R&D influences a firm's market share. It addresses both theoretical and practical issues, merging academic and experiential knowledge. The research question is: 'Does an increase in a firm's R&D expenditures (relative to the industry's total or the firm's rivals) leads to an increase in the firm's market share?' It explores whether a firm could grab a larger market share at the cost of its competitors through a growth in the share of R&D expenditures in the industry. The research is relevant to both academics and practitioners. The sample of industries examined includes Aerospace & Defence, Automobiles & Parts, Pharmaceuticals & Biotechnology, Software & Computer services, and Technology & Hardware equipment, which together account for more than a half of the UK's top 1000 R&D spending firms. The methodology is based on econometric estimates of production functions containing R&D variables for a panel of firms over the period from the financial year of 2003/2004 to 2009/2010.

The research findings are in line with the Sources of Growth theory: in short and medium terms, increasing conventional inputs such as capital, labour, human capital, and intermediate inputs lead to increased growth (in this case measured by market share). The research findings are also consistent with the 'first-mover advantage' theory. The lagged market share is significant and positive, showing that 'success breeds success', in line with Philips' (1966) arguments.

There is a general consensus that technical progress promotes economic growth at the macro level and that significant part of technical progress derives from R&D activity of profit-seeking firms. While classical and early neo-classical economists treat technical progress as exogenous, Schumpeter (1942) argues that the corporate hunt for profits drives the implementation of efficiency improvements coming from innovation; therefore, it is an important determinant of dynamic efficiency. This Schumpeterian view is incorporated into neo-classical frameworks of endogenous growth theory (Romer, 1986, 1990) which links macro-economic growth to firms' R&D. However, this research finds that although innovation leads to economic growth at a macro-level according to the economic growth theory, this may not be so obvious at the level of individual firm (measured by market share) in short and medium terms. In spite of the prevailing view that a growth of market share is the primary strategic objective firms seek to achieve at any cost, the findings of this research suggest that firms do not necessarily aim their in-house R&D at increasing a market share.

A qualification to this is a possible lag between R&D expenditure and its impact. R&D capital stock adopted in this study as unit of analysis is by construct cumulative over years, capturing a firm's past behaviours of R&D investment. Also, the lagged dependent variable in our dynamic panel data analysis contains a lagged R&D capital stock. However, the analysis by industry shows a sign that the cycle of new product development might be a factor influencing the relationship between a firm's R&D capital stock and market share. There is some evidence, although not conclusive, that in Software & Computer services where the cycle is very short, an increase in R&D capital stock leads to an increase in market share. Given this, taking a deeper lag of R&D capital stock than adopted in our study might reveal different results.

The research findings will be of interest to investors, managers, consultants, professional bodies, and government. Although the subject of this research is not novel, it offers practical insights to companies examining their R&D investment needs, and assistance to analysts and investors (Rindova, 2008). As discussed earlier and in the rest of this thesis, there are a few qualifications to its findings. For instance, given the focus upon firms at the top and middle end of the size distribution in the five high-technology industries in the UK, this study's findings might be different if firms at the bottom end were included. In a similar vein, there may be a possible lagged impact of a firm's R&D expenditure upon its market share which is not captured under the framework of this study. The limitations of this research provide opportunities for future research. A follow up study, for instance covering all UK industries over a longer period (e.g., 10 years), might reveal different results and implications to the strategic decision taken by managers for their firms' R&D activities. Follow up research is also expected to further contribute to the academic knowledge and theories in regards to the endogenous relationship between market structure and innovation and its dynamics.

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End Notes

[i] Researchers (e.g. Griliches, 1992; Hall and Mairesse, 1995) recommend it as the most appropriate when the aim is to quantify the R&D importance in the production process. Also, it does not yield biased estimates of R&D elasticity when controls for permanent firm effects are incorporated. The R&D coefficients may be understated due to failure to control for double counting of R&D expenditures. As these charges are also incorporated in the conventional variables, their coefficient estimates account for normal returns to R&D inputs (Schankerman, 1981). Therefore, the R&D coefficients will reflect only the returns associated with R&D expenditures not the total return.

[ii] The instruments are 'weak' (poor predictors) if they do not explain the endogenous variables in the first stage equation. Although the System GMM is in general more robust to weak instruments than the difference GMM, it may still experience weak instrument biases. The dynamic panel GMM can produce too many instruments, which could overfit endogenous variables and lead to a weak-instruments bias (Roodman 2009). Some of the solutions are: restricting the number of lagged levels used in the instrument matrix; collapsing the instrument matrix; or combining the two (used in this research). A standard test of weak instruments in dynamic panel GMM regressions does not exist (Bazzi and Clemens, 2009).

[iii] Nominal R&D expenditures are deflated using the 1995 GDP prices deflator (1995=100, converted to 1995 PPP UK sterling).

[iv] The depreciation rate is not critical for the regression results as the R&D expenditure within firm does not vary considerably (Hall and Mairesse 1995). The lag structure of R&D has an inverted V shape, the peak weight from R&D flows at five to eight year lags; contribution from R&D expenditure at lags more than 10-16 years is modest (Evenson, 1968). The lags are shorter for industrial R&D, reflecting the applied character of private R&D expenditures (Wagner, 1968).

[v] Different studies have based the weighting function on different techniques. For example, on 'vertical borrowing' notion. Brown and Conrad (1967) used input-output matrix for calculating the proximity of industries relative to their purchases from each other, while Terleckyj (1974) used the capital and intermediaries matrix weights. Raines (1968) used the 'horizontal' product classification of The National Science Foundation to incorporate inputs to an industry's R&D and also the other industries R&D expenditures, allocated to its product field. All of these cases assume simple weighting functions (e.g., the impact declining exponentially with increasing the distance) or cluster the data into categories: strongly related (within a firm's own industry group), related fields, and the rest.

[vi] Direct benefits from foreign R&D take place through learning from overseas sources of knowledge about new technologies and materials, production processes, or organisational methods. Indirect benefits are derived from imports of products and services developed by trade partners. Different researchers used different techniques to construct foreign R&D. Coe and Helpman (1995) modelled foreign R&D as a weighted average of the domestic R&D of trading partners employing bilateral import shares as weights. Coe, Helpman and Hoffmaister (1997) employ import shares of intermediaries as weights. Bayoumi, Coe and Helpman (1999) build the stock of foreign R&D capital employing a vector of bilateral manufactures imports over total manufactures imports from all industrialized countries. Lumenga-Neso *et al*, (2001) results are similar when foreign R&D is defined as the simple sum of rest-of-the-world R&D, instead of a trade-weighted sum. They evidenced that the results on long-run growth are not sensitive to whether foreign R&D is trade-related or not.

In regards to this research, for each firm, two measures of the foreign R&D capital stock can be constructed. The first is simply the sum of the domestic R&D capital stocks of the rest of the world or of the each UK firm's international trading partners, depending on the data available (Keller, 1998; Lumenga-Neso *et al.*, 2001). The justification for using this approach is that UK is a developed country which has free access to all inputs available in the world economy. UK firms can purchase an input and use it in its production process wherever the input is created. Also, many inputs are not tradable but UK firms also could benefit from them. The second estimate of the foreign R&D capital stock is a bilateral import-share weighted sum of the domestic cumulative R&D expenditure of each firm's international trading partners (Coe and Helpman, 1995). The weights are portions that add up to 1, hence not reflecting accurately the level of imports. The bilateral import shares may be calculated for each year based on data from OECD bilateral trade data. Data on R&D at industry level (internationally) is available from STAN OECD dataset. This data is either country-level or industry-level, not a firm-level, but to build up the spillovers it may suffice for the purposes of this research. The choice of method depends on data availability and quality. Due to multicollinearity and data issues, this research will focus on internal R&D effects and leave the international spillover effects for a follow-up.

[vii] The above unobservable variables are likely to enter positively in the error terms of the production function model, influencing the investment decisions of profit maximizing firms. This depends on how those variables are defined. To some people, government policy is something that influences investment decisions negatively (e.g. crowding out). In the basic model, more productive firms would select higher levels of investment, which means that the error terms and some of the regressors will be positively correlated, hence the coefficients will be upwardly biased.

The standard resolution to this problem in a panel data is to assume that the unobservables for each firm are unchanging over time. This restricts their contamination to the cross-sectional aspect of the data, meaning that unbiased estimates of structural parameters for each firm can be obtained from the covariance 'within' firms over time. This will result in calculating the 'fixed effects' estimates. In this research, Hausman test shows Fixed Effects model is more appropriate compared to Random Effects model. There are some issues with this technique one of which arises from the fact that most of the variance in firm data is generally in the cross-sectional aspect. The fixed effects approach discards much of the information in the data, and frequently generates uninformative estimates as a consequence. The other issue is that R&D is likely to be measured with error; this will result in bias that is usually exacerbated by within estimation. Lastly, the assumption that the unobservables are constant over time is only for convenience; if this does not hold, it follows that the 'fixed effects' estimates are also biased.

Another solution is to regard the issue as a standard one of endogenous regressors, modelling equations for the endogenous explanatory variables as a function of other variables. This way the cross-sectional data can be used, the bias due to measurement error could be minimised, and the assumption that the unobservables are time-invariant could be lifted. However, the problem with this alternative approach is that an assumption about the validity of the instrumental variables should be made. If in this research firm's R&D, capital stock, and marketing are seen as endogenous, the assumption is that in general, they depend on industry characteristics such as the industry's size, growth rate, and R&D intensity. Therefore, it would be assumed that unobserved firm variables do not influence significantly these industry characteristics, and that the industry characteristics are correctly not included in the structural models.

[viii] For more information regarding the R&D Scoreboard data please see http://www.innovation.gov.uk/rd_scoreboard/

[ix] For full information please refer to http://www.icbenchmark.com/index.html

Appendices

Appendix 1: GMM models experiments

Static GMM:

```
xtabond2 Logms Logcap Loglabor Logwages Logcos Logind_adv Logfirm_adv
Logind_rd Logfirm_rd yr2003-yr2009 icb1-icb14, gmm( Logcap Loglabor
Logwages Logcos Logfirm_adv Logfirm_rd, lag(1 2) collapse) iv(Logind_adv
Logind_rd l yr2003-yr2009 icb1-icb14,eq(level)) robust twostep small h(2)
```

Dynamic GMM:

```
xtabond2 Logms l.Logms Logcap Loglabor Logwages Logcos Logind_adv
Logfirm_adv Logind_rd Logfirm_rd yr2003-yr2009 icb1-icb14, gmm( l.Logms
Logcap Loglabor Logwages Logcos Logfirm_adv Logfirm_rd, lag(1 2)
collapse) iv(Logind_adv Logind_rd l yr2003-yr2009 icb1-icb14,eq(level))
robust twostep small h(2)
```

Table of results:

Variable	GMM (Static)	GMM (Dynamic)
LogMS (L1)		**.2692****** (.0838)
LogC	omitted	.0673 (.1227)
LogL	omitted	**.1659**** (.0848)
LogE	omitted	**.0654*** (.0415)
LogCoS (Materials)	omitted	**.3990***** (.0886)
Logind_adv	**-.2708***** (2.54e-11)	-.2166 (.1985)
Logind_rd	omitted	-.4923 (.4987)
Logfirm_adv	omitted	-.0012 (.0790)
Logfirm_rd	omitted	.0594 (.0666)
Icb code/time dummies included	-.3663 .2558	.5137 (.5543)
Constant	omitted	6.4344 (4.8835)
R^2		
Number of obs.(groups)	1152 (261)	1025 (257)
Number of instruments	41	43
F	F(27, 260) = 39.01***	F(27, 256) = 441.02***
AR(1)	**0.078***	**0.096***
AR(2)	0.501	0.922
Hansen test of overid. restrictions	**0.000*****	0.066*
Difference-in-Hansen tests, GMM: Hansen test excluding group:	**0.000*****	0.320
Difference-in-Hansen tests, GMM: Difference	**0.000*****	**0.040****
1. St. errors and number of groups are reported in parenthesis. 2. *, **, *** indicates significance at 10%, 5%, and 1% level respectively		

Appendix 2: The rest of Table 13 'All-industries' analysis

Dependent variable: ln (Market share)						
Model	3	4	5	6	7	8
Estimation method	Pooled OLS	Fixed Effects	System GMM	System GMM	System GMM	System GMM
Aerospace & Defence (Industry dummy)			-.5573	.0314		
			(.5130)	(.3204)		
Automotive & Parts (Industry dummy)			.3257	.4294*		
			(.4137)	.2386		
Pharmaceutical & Biotechnology (Industry dummy)			1.0128	1.3081*		
			(1.5741)	(.8355)		
Software & Computer Service (Industry dummy)			.4319	.3488*		
			(.3708)	(.1924)		
Aerospace (ICB group dummy)					-.7437*	-.3129
					(.4880)	(.3415)
Defence (ICB group dummy)	.0954***				-.7221*	-.2932
	(.0315)				(.4917)	(.3524)
Automobiles (ICB group dummy)	.2993**				.0026	.0487
	(.1255)				(.3936)	(.2401)
Auto parts (ICB group dummy)	.3662*				.1404	.0368
	(.2276)				(.4400)	(.2737)
Tyres (ICB group dummy)	.6966***				.2302	.0983
	(.1693)				(.4418)	(.2888)
Biotechnology (ICB group dummy)	-.1884				-.2084	-.3572
	(.6250)				(1.5532)	(.9980)
Pharmaceuticals (ICB group dummy)	.3599				.1333	.-0564
	(.5618)				(1.5364)	(.9976)
Computer services (ICB group dummy)	.4712 ***				-.14091	-.1421
	(.1000)				(.3614)	(.2494)
Internet (ICB group dummy)	1.0753***				.7309*	.4216*
	(.1088)				(.4265)	(.2816)
Software (ICB group dummy)	.7033***				.3264	.0785
	(.1831)				(.3517)	(.2406)
Computer hardware (ICB group dummy)	.2917				.1203	-.0045
	(.2112)				(.0872)	(.0615)
Electronic office equipment (ICB group dummy)	.5097***				.0824	.2180*
	(.1447)				(.1699)	(.1436)
Semiconductors (ICB group dummy)	.0982				-.0730	-.1081
	(.2509)				(.2360)	(.1109)
Telecommunication equipment (ICB group dummy)	.2716					
	(.2008)					