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Management Characteristics, Managerial Ownership and Innovative Efficiency in High-technology Industry

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Abstract

This paper explores the impact of management characteristics and managerial ownership on a firm's innovation performance in transforming innovation resources into commercially successful outputs. These questions are investigated using a recent firm-level survey database for 440 innovative British small and medium enterprises (SMEs) over the period 1998-2001. Both Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) are employed to benchmark each firm's innovative efficiency against best practice. Quality and the variety of innovations are taken into account by combining Principal Component Analysis (PCA) with DEA. We find evidence suggesting that the innovative efficiency of SMEs is significantly affected by their management characteristics and ownership structure. Formality in management structure, incentive design and human resource management practices all show significant effects on the innovative efficiency of firms. Managerial ownership is found to have a non-monotonous, non-linear relationship with the firms' innovative efficiency, supporting both an alignment effect and an entrenchment effect of managerial ownership on the innovation performance of firms. Results of this study reveal a significant moderating influence of the industry's technological environment on the relationship between management characteristics, ownership structure and innovative efficiency of firms. Evidence from this study suggests that formal management structure and training intensity play a more important role in commercialising innovation inputs in high-technology sectors; while incentive schemes and managerial ownership are more important for innovative efficiency in the traditional sectors.

Keywords: Management characteristics, managerial ownership, innovative efficiency

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INTRODUCTION

The innovation performance of organisations is determined not only by its resources and innovation inputs, but more importantly, by its productivity in innovation and the factors that affect this productivity. Innovation is not a simple linear transformation with basic science and other inputs at one end of a chain and commercialisation at the other (Hughes, 2003). Successful innovation requires more than brilliant scientists. It takes leaders, entrepreneurial spirit, great ideas, quality design, good management, and the right organisational structures (Hjelt, 2005). It requires high-quality decision-making, long-range planning, motivation and management techniques, coordination, and efficient R&D, openness to external sources of knowledge for innovation, and production and marketing expertise. Therefore, the innovation performance of a firm is determined not only by 'hard' internal factors such as R&D manpower and R&D investment, but also by certain soft internal factors such as management practices and governance structures (Aghion and Tirole, 1994; Bessant et al., 1996; Black and Lynch (2001); Bertrand and Schoar (2003); and Cosh et al., 2004) and the firm's openness to external sources (Chesbrough, 2003). Top management characteristics, leadership, synergy between departments, research partnerships, marketing efficiency and human resource management are all found to be closely correlated with a firm's propensity to innovate (Hoffman and Hegarty, 1993; Bughin and Jacques, 1994; Nam and Tatum, 1997; Goes and Park, 1997; Tsai, 2001; and Laursen and Foss, 2003). The concentration of share ownership, institutional ownership, external ownership and CEO compensation schemes are also found to be related to the R&D intensity, or innovation propensity, of firms (Kochhar and David, 1996; Love et al., 1996; Bishop and Wiseman, 1999; Chowdhury and Geringer, 2001; Balkin et al., 2002; Czarnitzki and Kraft, 2004; and Hosono et al., 2004).

While substantial work has been done on a firm's propensity for innovation, research on the productivity of innovation is limited. Comparing the difference between Japan and the US in innovation cost and time, with special emphasis on the use of internal versus external technology, Mansfield (1988) finds the Japanese have great advantages in carrying out innovations based on external technology, but not internal technology. Firm size and spillovers, in particular from academic sources, are also found to be positively correlated with industrial research productivity (Henderson and Cockburn, 1996; Adams, 2000; and Siegel et al., 2003). Experiences and alliances are found to contribute to research productivity in the pharmaceutical industry (Danzon et al., 2003); and public versus private ownership is argued to be a contributing factor in the cross-sectional variance of R&D efficiencies (Zhang et al., 2003). Composing a patent quality index using a linear combination of observed indicators, a recent study by Lanjouw and Schankerman (2004) finds that research productivity at the firm level, measured by the number of patents divided by R&D, is inversely related to patent quality and the level of demand. A brief summary of the literature is presented in Table I.

INSERT TABLE I HERE

Prior research therefore shows the importance of certain internal firm characteristics as determinants of innovation productivity. To date, however, very little is known about the impact of management characteristics and collaboration on innovation productivity. Moreover, most research has explored this issue amongst large firms. Very few studies have addressed these issues in the context of small and medium-sized enterprises (SMEs), which may play a critical role in shaping industrial evolution a seedbed for novel innovation. This study seeks to fill this gap in the literature by examining the impact of management characteristics and collaboration on the efficiency of innovation in the context of SMEs. We draw our sample from a recent firm level postal survey data covering 2130 British SMEs for the year 2001 and their innovation experience in the previous two years.

The study makes several contributions to the literature. First, it attempts to link management science with innovation and industrial economics, and to examine the impact of management characteristics and collaboration on the productivity of innovation. As discussed earlier, management and governance systems are crucial factors affecting the innovative productivity of industrial organisations. However, empirical evidence on this issue is surprisingly rare.

Second, this study evaluates innovative efficiency in a multiple-output framework by attempting to capture different types of innovation and different qualities of innovation, whereas most past research on industrial research productivity uses a single indicator for the measurement of research productivity. We take into account not only the percentage of sales attributed to new or improved products, but also process and supply system innovations. Quality differences in innovations, measured here in terms of their novelty, have also been allowed for by incorporating Principal Component Analysis (PCA) into the multi-output model. It measures a firm's efficiency in innovation using both parametric and non-parametric frontier analysis to compare a firm's observed performance with best practice. Both the stochastic frontier analysis (SFA) and the data envelopment analysis (DEA) are employed in the estimation of innovation productivity to cross check the robustness of the results.

Third, firms in different industries have different technology opportunities and innovation strategies. The management and collaboration variables may impact innovation efforts differently in high-tech SMEs, for example compared to other firms. This study, therefore, explores the different patterns of the effects of management characteristics and managerial ownership across the manufacturing and services, high-technology and medium- and low-technology sectors and discusses its implications. It finds that in the high-technology sector, knowledge-related management factors, such as collaboration, training and formality in management play a crucial role in enhancing innovative efficiency; while in the low- and medium-technology sectors, it is managerial incentives and organisational flexibilities that play an important role in innovative efficiency.

The rest of the paper is organised as follows. Section 2 briefly discusses the theoretical framework and the hypotheses. Section 3 addresses the methodology. Section 4 discusses the data. Section 5 presents the econometric results. Section 6 concludes.

THEORY AND HYPOTHESES

Successful innovation requires the effective management of a wide range of complementary assets within the firm, and the development of an integrated system matched with its technological and economic environment. This includes the development of effective motivation and efficient allocation utilisation and reallocation of internal and external resources for innovation. A firm's potential innovative performance will necessarily be influenced by the economic and technological opportunities in the industry that it belongs, its interactions with other sources of knowledge such as suppliers, customers, universities and competitors and the ability of its innovative efforts to transform and transcend existing industrial patterns (Hughes and Scott Morton 2006; Cosh et al., 2006). Within the innovating firm, in practice, the creator, owner, user and financier of innovations are, in most cases, not the same party. Successfully commercialised innovation involves integrating inputs and efforts across top management and various functional departments such as production, finance and marketing as well as research. These elements of top management may have different interests and motivations which may give rise to agency problems, free-riding and extra transaction costs (Aghion and Tirole, 1994). Figure 1 attempts to map these elements of the complex innovation system at the firm level. Coordinating and managing such a complex system to achieve commercial success from an innovation, given the high degrees of uncertainty and a very low possibility of commercial success[1], requires determined and effective management. Therefore, managerial ownership and management characteristics of a firm such as management structure, decision-making practices and incentive arrangements may all affect the firm's innovation performance. The complexity revealed in Figure 1 indicates the range of factors which must be controlled for or included as independent variables I explaining innovation performance. We consider key elements of this system in turn.

- **Managerial ownership**

Innovation requires continuous investment in R&D so as to sustain a firm's capability to innovate at the cutting edge of technology (Jelinek & Schoonhoven, 1993). Innovation activities also involve considerable risk since less than 20% of all new product introductions succeed (Crawford, 1987); and even the few projects that do survive are typically unprofitable during their first few years (Block & MacMillan, 1993). Success in innovation, therefore, requires strong managerial support (Nam and Tatum, 1997; Kuratko et al., 1997; Scott and Bruce, 1994). Top management's commitment to beating the competition, their attitude towards innovation and willingness to take risks all affect firms' strategic decision-making (Papadakis and Barwise, 2002).

However, agency theory suggests that when ownership is separated from management, the objectives of managers and owners may diverge. Lack of an ownership interest in the companies they manage, may cause a lack of the willingness on the part of executives to support the risk-taking associated with innovation, or see it through to fruition (Wright et al., 1996). The executives may behave opportunistically by supporting projects that increase their own wealth and pursue short-term objectives instead of the long-run growth of the company and the interests of other shareholders. They will lack the incentives to support innovation which may put their positions at risk and which may require new skills (Fama and Jensen, 1983; Wright et al., 1996). This may therefore give the rise of X-inefficiency in innovation as top management plays an important role in decision-making, innovation planning and management in small firms.

The alignment effect of managerial share-ownership may reduce the agency problem to certain extent (Jensen and Meckling, 1976). Increased levels of executive ownership make executives' wealth more dependent on their companies' long-term performance. This gives the executive an incentive to support innovation which may raise the competitiveness of their companies in the long run (Jenkins & Seiler, 1990; Zahra et al., 2000). Managerial share-ownership can also empower managers to initiate innovation activities (Finkelstein and D'Aveni, 1994). The ownership interest for managers may motivate them to make more effort in R&D project decision making, resource allocation and innovation management (Jensen and Meckling, 1976).

However, when managerial ownership reaches a sufficiently high level, an entrenchment problem may arise as high share ownership may provide management with the power to insulate themselves from the pressures of external discipline and internal monitoring devices (Fama and Jensen, 1983) and in a small firm context pursue a 'quiet life' in a so called lifestyle business. Therefore, the relationship between managerial ownership and firm performance may be non-monotonic with firm performance first increasing with the increase in managerial ownership, then declining until managerial ownership reaches certain level (Morck, et al., 1988; McConnell and Servaes, 1990; Cosh, et al., 2006). Therefore,

H1: *Managerial share-ownership will be associated with innovative efficiency in a nonlinear way, where the slope is initially positive as the level of managerial ownership increases but becomes negative as the level of managerial ownership becomes larger.*

- **Management structure**

The debate over the benefits of organic and mechanistic (formal) management systems is well documented. Burns and Stalker (1961) argue that a mechanistic management system, characterized by specialised differentiation of functional tasks, precise definition of rights, obligations and hierarchy, is appropriate to stable conditions. Whereas organic structures, characterised by 'realistic' and continually re-defined individual tasks through interaction, spread commitment to the concern beyond any technical definition, and a lateral rather than a vertical direction of communication through the organization, are appropriate to dynamic environments. On the other hand, starting from the seminal 'ideal type' analysis of the 19th century sociologist

Max Weber a stream of literature has argued about the merits of the bureaucratic form of organisation, characterised by clear cut division of activities, assignment of roles and hierarchically arranged authority, and its technically superiority relative to other forms of organization. The claimed advantages of formal structures include greater precision, speed, task knowledge and continuity. They also include reduced friction and ambiguity. Seen from this perspective the relative lack of structure that allegedly characterizes new firms appears as a liability not a benefit (Stinchcombe, 1965). Firms with informal management structures will be less able to adopt cost leadership strategies that require sophisticated cost, budget and profit controls. It is unlikely that such simple structures could adequately support a broad extensive geographic or product diversification (Miller and Toulouse, 1986). A formal management structure may also have a positive reputational effect and help small firms establish a better access to external funding and establish collaboration links (Sine et al., 2004; Cosh et al., 2005). Therefore,

H2: *Firms with an informal management structure will be less efficient in innovation than those with a formal management structure.*

- **Strategic decision making**

The information-processing capabilities of top management are associated with the quality of the strategic decision-making of firms and thereby affect firm performance (Haleblian and Finkelstein, 1993). The limited foresight and bounded rationality of people mean that firms with key member groups taking strategic decisions will have increased capabilities and viewpoints relative to firms where Chief Executives personally control strategic and operating decisions. With a group involved in strategic decision making there will be greater volumes of information that can be absorbed and recalled; and there will be a greater number of critical judgements available in decision making; and the range of perspectives brought to bear on a problem will be wider (Harrison, 1975; Hoffman and Maier, 1961 and Haleblian and Finkelstein, 1993). Moreover, a balanced power distribution facilitates information sharing and idea exchange. Based on a study of 47 large US corporations, Haleblian and Finkelstein (1993) find that firms with large teams performed better and firms with dominant CEOs performed worse in a turbulent environment. The association between team size, CEO dominance and firm performance is significant in an environment that allows top managers high discretion in making strategic choices. Therefore, firms with key member group taking strategic decision are likely to make a more informed decision than those dominated by the CEO's personal preference (Miller and Toulouse, 1986; Papadakis and Barwise, 2002). This may enable better use of the available resources of the firm and better identification of market and technological opportunities. Hence,

H3: *Firms with key member group taking strategic decision are more likely to innovate effectively than firms whose Chief Executives personally controls strategic and operating decisions.*

- **Incentive schemes**

The presence of the agency problem may give rise to X-inefficiency (Leibenstein, 1978; Button and Weyman-Jones, 1992), and subsequently reduce a firm's efficiency in innovation. Given the presence of the agency problem, incentive schemes (e.g. stock options and performance-related pay) are designed to set up alignment mechanisms that alter the risk orientation of agents to align them with the interests of principals. The incorporation of accountability through performance-related payment schemes for managers and employees is found to have a significant correlation with various indicators of business performance (e.g., Fu and Balasubramanyam, 2003; Black and Lynch, 2004). We could expect that performance pay, which may motivate not only the managers but also the scientists and all other employees to devote more attention to firms' long-term growth and make their most efforts, and therefore enhance the X-efficiency in innovation. Therefore,

H4: *Firms that use performance-related pay will be more efficient in innovation than those who did not.*

- **Human resource management**

Innovation is an activity in which human capital plays a key role. Active human resource management is argued to be an essential contributor to firms' innovation capacity (Laursen and Foss 2003). There is a considerable literature on the relationship between training and the propensity for innovation. Baldwin and Yates (1999) and Cosh et al. (2000) argue that there is a two-way relationship between innovation and training. Better labour and managerial skills leads to more innovation; in the mean time, more innovation creates greater demand for training. As Acemoglue (1997) finds, workers are more willing to invest in their skills by accepting lower wages today if they expect their firms to innovate and pay them higher wages in the future. Similarly, firms are willing to innovate when they expect the quality of the future workforce to be higher when workers invest more in their skills.

What is the impact of training on a firm's productivity of innovation? Empirical studies on the effects of training on firm performance in general provide mixed evidence. While Bartel (1994) finds that formal training helps inefficient manufacturing firms catch up with their peers' average productivity, Black and Lynch (1995 and 1996) fail to find a significant effect of training on firm productivity. The increased workforce skills through training are likely to improve not only a firm's likelihood to innovate, but also its efficiency in innovation. Firms that have trained workers at the time of implementation of the new technology can really reap the quasi-rent generated by innovation (Ballot and Taymaz, 1997). Therefore,

H5: *Firms' investment in training is positively associated with their efficiency in innovation.*

- **Complementarities between different individual management characteristics**

The organisational studies and strategic management literature argues that it is not a single action that is the route to higher levels of organisational performance, but a number of complementary changes (Walker, 2004; Hughes and Scott Morton 2006). For instance, it is found that the magnitude of the performance effect of a set of human resource management practices is greater in the full system than in the sum of each practice taken individually (Ichniowski et al., 1997). As stated earlier, by aligning the interests of owners and managers and employees, and holding managers and employees accountable for their performance, performance pay is likely to reduce the agency costs and free riding problem, and thereby reduce X-inefficiency in innovation. Therefore, we should expect that in a firm with a formal management structure where responsibility is clearly defined and performance can be accurately measured, this mechanism may have a significant effect on innovative efficiency. Whereas under informal management structure with serious ambiguity in responsibility, performance pay will not have a significant effect on efficiency. Moreover, some management practices are complementary to each other. Although some firms have spent on training to enhance the skills level of their employees and managers, the benefits of training will take greater effect if performance related pay system is introduced in the firm that gives employees and managers the incentives to make the most of their effort. Hence,

H6a: *Performance-related pay will have a stronger positive association with innovative efficiency in a firm with formal rather than informal management structure.*

H6b: *Training will be more positively associated with innovative efficiency in a firm that has introduced performance-related pay scheme than in others that do not.*

- **Interactions between management characteristics and managerial ownership**

As discussed earlier, managerial ownership may affect managers' effort and behaviour through its alignment or entrenchment effects. Therefore, the impact of management characteristics on a firm's innovative efficiency is likely to be mediated by the level of managerial ownership in the firm. In firms with relatively low level of managerial ownership, interests of owners and the Chief Executives (CEs) may diverge. In such a case, incentive schemes, especially long-term performance related stock option scheme, will play a more significant role in motivating managers. Moreover, in firms with a low level of managerial ownership, leaving strategic and operating decisions to the CE's personal control may give the CE the power to make and implement those decisions that are favourable to his own interests. Group-based decision-making structure may overcome this problem and direct the strategic decisions of the firm are made in favour of the majority of the shareholder. Therefore,

H7. *Top management motivation and monitoring practices (e.g. group-based decision making and stock option schemes) will be more significantly associated with innovative efficiency in firms with low levels of managerial ownership.*

- **Moderating effects of industry technology environment**

Firms in different technological groups have different innovation opportunities and require different strategies for innovation. In industries of high technological dynamism, firms face greater uncertainty that springs from the economic and social feasibility of new technologies (Tushman & Rosenkopf), and uncertainty derived from the difference between the information needed to perform a task and the information available, which present crucial problems for decision makers (Galbraith, 1973). In addition to the technological uncertainty, there are also uncertainties over whether a technology will prove acceptable to the market. “Nonscientific” factors have caused many technologically effective inventions to fail to gain market acceptance (Tushman & Rosenkopf, 1992). Moreover, in the high-technology sector SMEs are often established to exploit the creative ideas and knowledge of their founders. The owners may be experts in science and engineering, but may be short in managerial skills (Bollinger et al., 1983; and Utterback et. al., 1988). Introduction of improved management practices may play a crucial role in assisting these high-tech SMEs to successfully commercialise their knowledge and skills. The adoption of a formal management structure based on function specialisation, may lead top and middle managers to have a clearer idea of their managerial job functions and greater specialised task knowledge (Stinchcombe, 1965). It also provides a clear structure for effective cost management (Miller and Toulouse, 1986). Formal structures are found to raise new venture turnover in dynamic emerging economic sectors (Sine et al., 2004), and enhance a firm’s propensity to innovate (Cosh et al., 2005). Moreover, in high-technology industries knowledge plays a crucial role. As a result, we should expect knowledge-enhancing management practices such as training will be more important in these industries than in traditional industries. Hence,

H8a: *Formal management structure will be more significantly associated with innovative efficiency in high-technology sectors than in traditional industries.*

H8b: *The impact of training on innovative efficiency is likely to be more significant in high-technology sectors than in traditional industries.*

METHOD

Data

Data for this study is drawn from the small and medium sized business postal survey for 2002 (CBR2002) conducted by the Centre for Business Research (CBR) at the University of Cambridge. This survey produced an achieved sample of 2130 SMEs in the British manufacturing and business services sectors covering the period 1998-2001. The sampling frame for the survey was all independent businesses in manufacturing and business services with less than 500 employees in Great Britain (including business partnerships and sole proprietors) and was based on the Dun & Bradstreet UK Marketing Database. The sample design was based on a stratified approach using size and sector proportions chosen to avoid swamping the sample with micro businesses. The survey covered two groups of firms both based on the same sampling frame and survey design. The first group had been surveyed in previous years as part of the development of the CBR unique longitudinal small firm database. (old panel). The second group were firms who were newly sampled to form the basis of a new longitudinal panel.(new panel). For the old panel, 521 usable responses were received, a unit response rate of 33% from eligible firms. For the new panel, 1609 usable responses were received and the unit response rate was 14%. A response bias analysis in terms of age employment turnover pre tax profit and legal status revealed that there were no major differences between the respondents and the non-respondents in these groups, although respondents had somewhat lower turnover but higher profit margins than non-respondents in the old panel and the respondents in the new panel tended to be somewhat older than the non-respondents in some manufacturing industries. A spatial analysis revealed that the combined achieved sample was representative of the regional distribution of the small business population in Great Britain.

The survey data includes responses covering the percentage of sales which the firms attribute to new or improved products introduced in the survey period, as well as indicators of the incidence of product process and logistic innovations. The incidence data distinguishes innovations new to the firm but not the industry (diffusion innovation) and innovation new to the firm *and* the industry (novel or original innovation). It also includes data on R&D employment and R&D expenditure

The survey questionnaire covers not only innovation, but also business performance management structure and ownership characteristics. The rich information embedded in this survey allows us to explore the impact of management and ownership on SME innovative capacity and compare the difference between micro, small and medium firms. Of the total 2130 SMEs, 978 firms reported themselves to have either product or process innovation. In order to focus on firms with measurable innovation inputs and because the data envelopment analysis (DEA) requires inputs and outputs to be positive, all the observations with zero sales due to new or improved products zero R&D expenditure or zero R&D staff are excluded from the sample. After pair-wise deletion of missing observations and outliers with zero values in these variables the number of cases entering the final sample is 440. The mean value of the number of employees in each firm is 66. Twenty percent of them are micro firms in the 1-9 size band; 36 percent are small firms in the 10-49 size band; and 44 percent of them are medium firms in the 50-499 size band. To test for possible sample biases arising from the reduction in sample size for these reasons we compared the mean levels and quartile levels of the number of employees and key management characteristics for our 440 firms with those for the whole sample of 900 innovating firms and found no significant difference.

Empirical studies of innovation in SMEs rely heavily on survey data because a firm's percentage of sales due to new or improved products and the number the number of R&D staff and amount of R&D expenditure is either never or rarely reported in small business company accounts.. Multi-method validation of survey responses, however, often cannot be achieved for such survey based studies. Using data solely from a single survey for statistical analysis may produce so called common methods bias if the design survey instrument predisposes answers following a similar profile across respondents. The potential for such bias can be addressed by careful survey design and post hoc statistical analysis. We assessed the presence of common method bias in our design in two ways. First, we randomly sapled respondents and compared the financial figures obtained from the survey for these firms with the financial data available in an independent data base (FAME). The vast majority of the financial data are consistent with each other, and less than 10 percent of the observations showed a significant variance. Second, we also assessed the evidence for common methods bias statistically using Harmon's single factor test, which uses factor analysis combining multiple variables from the survey to see if a single dominant factor or one general factor effectively summarises the responses (Podsakoff and Organ, 1986). We found no evidence of significant sole source bias using this test.

Measurement of Dependent Variable: Estimation of Innovative Efficiency

There are three main approaches to the measurement of efficiency: ratio analysis such as labour productivity and capital productivity, the normal econometric approach such as total factor productivity (TFP) index, and the frontier approach, such as data envelopment analysis (DEA). Total factor productivity (TFP) can in principle take into account the contribution of factors, other than labour and capital, such as managerial skills and technical know-how. The conventional total factor productivity approach defines TFP growth as the residual of output growth after the contribution of labour and capital inputs and other input variables have been subtracted from total output growth. This method, however, attributes all the deviations from the expected output to TFP without taking into account measurement error. It is also based on several well-known strong assumptions: (1) the form of production function is known; (2) there are constant returns to scale; (3) there is optimising behaviour on the part of firms; and (4) there is neutral technical change. If these assumptions do not hold, TFP measurements will be biased (Coelli et al., 1998; Arcelus and Arocena, 2000).

The frontier approach evaluates a firm's efficiency against a measure of the best practice. There are two main methods for the estimation. One is a non-parametric programming approach, the Data Envelopment Analysis (DEA); another is a parametric production function approach, the Stochastic Frontier Analysis (SFA). In the DEA approach, a best-practice function is built empirically from observed inputs and outputs. The efficiency measure of a firm's innovation activity is defined by its position relative to the frontier of best performance established mathematically by the ratio of the weighted sum of outputs to the weighted sum of inputs (Charnes et al., 1978). The strength of the programming approach lies not only in its lack of parameterisation, but also in that no assumptions are made about the form of the production function. In addition, the programming approach allows us to estimate efficiency from a multi-output and multi-input perspective. This technique has a main shortcoming in that there is no provision for statistical noise, or measurement error, in the model (Greene, 1997; Norman and Stoker, 1991). The econometric stochastic frontier approach, however, has the main advantage that measurement error can be minimised and hypotheses can be tested with statistical rigour; although it has the drawback that the production function is assumed to be known and to be homogeneous across firms.

Given the advantages and disadvantages of the different efficiency estimation approaches, we use the DEA approach in the estimation of the innovative efficiency because this method allows us to evaluates a firm's efficiency in innovation against best practice, We employ both programming and econometric methods to cross check the robustness of the results. Technical details of the two approached are given in Appendix 1.

In the analysis, since our major objective is to maximise innovation output, we concentrate on output-oriented efficiency, which reflects a firm's efficiency in producing maximum innovation output with given inputs, under variable returns to scale. Innovation output is measured by the percentage of sales that relates to new, or significantly improved, products. This indicator has the advantage over other output innovation indicators (e.g. the number of innovations and patents) because it reflects the extent of the commercial success of the innovations. Inputs in our models include the value of R&D expenditure as a percentage of sales and the total number of R&D staff as a share of the total labour force.

However, innovation includes not only product innovation, but also process and logistics innovation. In addition, there are also differences in degrees of novelty between innovations. Given that DEA analysis allows for multi-outputs in the model, we include these other measures of innovation as other outputs in our DEA model. Following Adler and Golany (2001), we combine the principal component analysis (PCA) of these other measures with DEA. PCA explains the variance structure of a matrix of data through linear combinations of variables which capture a large proportion of the variance in the data but, at the same time, reduce the data to a few principal components. If most of the population variance can be attributed to the first few components, then they can replace the original variables without much loss of information.

The results of a PCA can be negative but, following Charnes et al. (1985) and Ali and Seiford (1990), an affine transformation of data can be utilised with no change in the results. Therefore, following Adler and Golany (2001), all the factors produced from PCA used subsequently in the DEA have been increased by the most negative value in the vector plus one when necessary, thus ensuring strictly positive data for the DEA. The translation is as follows,

$$FAC' = FAC + a\,,$$

where FAC is the factors derived from PCA, and $a = Min\{FAC\} + 1$.

Our DEA analysis is carried out both for our principal output measure, the percentage of sales accounted for by new, or significantly improved, products; and for that measure combined with the two factors produced from the PCA.

For the Stochastic Frontier Approach, following Siegel et al., (2003), we assume a half-normal distribution for the efficiency component μ, which means the firms are either "on the frontier" or below it. The output of the knowledge production function, *y*, is measured by the percentage of sales that relates to new or significantly improved products (NEWSALE), as in the single-output DEA case. Inputs in the SFA model include the value of R&D expenditure as a percentage of sales (RDS) and the share of R&D staff[2] in the labour force (RDPS). The empirical model that yields our SFA measure of innovative efficiency is therefore as follows:

$$\ln NEWSALE = \eta + \phi \ln RDS + \xi \ln RDPS + \upsilon - \mu \qquad (1)$$

Having described our methods for evaluating innovative efficiency, we now turn to the variables that we have argued in our discussion of theory above should have important influences on the level of efficiency.

Explanatory Variables of Innovative Efficiency

There are five independent variables in this study: incentive schemes; management structure; decision-making structure; training; and managerial ownership. Below we explain how each of these variables was measured.

Incentive schemes

Compensation related incentive schemes include long-term and short-term pay. Stock options and other forms of equity-based compensation are tied to achieving objectives over periods ranging from three to five years. Performance-related pay normally relates compensation to short-term performance such as monthly sales revenue, or earnings. We therefore measure incentive schemes in two ways. One is the number of managers and employees participating in a stock option scheme as a percentage of the total labour force. Another is a dummy variable for performance related pay. Firms who answer they have used performance related pay during the previous three years have a value for 1, and those who have not are given a value of zero.

Management structure

In small businesses, many firms just have an informal structure without a clearly defined organisation structure. In the questionnaire, firms are asked to indicate which of the following structures most closely describes the structure of their management organisation: informal structure; structure based on functional specialisation; structure based on product markets; or structure based on geographic regions. Management structure is proxied by a dummy variable which equals to 0 if a firm has an informal structure and 1 if a firm's management structure is based on functions, product markets or geographic regions.

Decision-making structure

In small businesses, it is not unusual that managers, especially owner-managers, control both strategic and operating decisions of the firms. Our measure of decision-making structure is a dummy variable according to answers to a question asking firms to describe their CEO's involvement in decision making. Firms where the CEO is one of the key members of a group taking strategic decisions with indirect control of operating decisions are given a value of 1 and all other cases where the CEO has sole control of strategic and or operating decisions are given a value of zero.

Training

We measure training intensity by the ratio of a firm's formal training cost to its total labour costs.

Managerial ownership

Our measure of managerial ownership is the percentage of a firm's ordinary shares owned by the Chief Executive, or Managing Partner (with 100% attributed to Sole Proprietors).

Industry technological environment

We classify firms into high-technology industries and traditional industries according to the definition given by Butchart (1987). A dummy variable, which equals 1 for firms in high-technology sectors and zero for firms in traditional sectors, is used to indicate a firm's industry technology category.

Control Variables

In addition to the 6 independent variables, we included 4 control variables: organisational flexibility; collaboration; firm size; and the industry concentration ratio. Innovation requires organizational flexibility to facilitate the coordination between the departments within the innovating firm (Miller and Toulouse, 1986; Wissema et al., 1980). A flexible organization structure helps to reduce the transaction costs within organisations. It facilitates the learning from external sources, the adaptation of best practices and the exploitation of existing information. Therefore, such an organizational structure will provide a favourable environment for the generation and fostering of new ideas. Conversely, a high degree of organizational rigidity increases transaction costs and hampers necessary structural changes for innovation. It reduces not only a firm's propensity of innovation (Bughin and Jacques, 1994; Galende and de la Fuente, 2003), but also the productivity of innovation. We measure a firm's organisational rigidity on a scale from 1 to 5. Firms who regard organisational rigidities as a crucial barrier to innovation in their firms are given a value of 5 whilst those that regard it as insignificant barrier are given a value of 1.

External linkages, both public (including higher education institutions) and private, are found to benefit innovation in small businesses (Hoffman et al, 1998; Chesbrough 2003; Cosh et al., 2006). These linkages can be important sources of knowledge that directly strengthen the technological competences of the SMEs and hence their competitive advantage. Collaboration with customers, suppliers, higher education institutions, even competitors, allows firms to expand their range of expertise, develop specialist products, and achieve various other corporate objectives (Kitson et al., 2001). In recent years, important contributions to innovation from business collaborations, in particular the supply chains, have received increasing attention (Porter and Stern, 1999). Networking is found to be positively associated with innovation (Goes and Park, 1997), although there are sector and size variations (Rogers, 2004). Universities are found to contribute to basic research awareness and insight among the partners (Hall, 2000). University participation in research programmes is also found to have a positive impact on firm patenting (Darby et. al., 2003). Collaboration with competitors and customers provides a firm with greater access to domestic or international markets. This may lead to greater commercial success of the new products, and enhances the productivity of innovation through economics of scale. Collaboration with suppliers may lead to lower costs and better quality of the new products. All this may result in higher productivity of the innovation activities. We measure a firm's collaboration using a dummy variable which equals 1 for firms who have engaged in formal, or informal, collaborative or partnership arrangements with any other organisations, and zero otherwise.

According to the Schumpeterian hypothesis, firm size and market structure should be related to innovation activities. Large firms are often argued to be more innovative as they enjoy greater economies of scale and scope than the small firms (Cohen, 1996) and can capture the fruits of their innovation. They also have easier access to finance and greater capability to invest in R&D or acquire external innovation outcomes (Geroski et al, 2002). However, it is also argued that the relative innovative advantage between large and small firms is determined by market concentration, the extent of entry barriers and the overall importance of innovation activity. Small firms tend to have the relative advantage in industries which are highly innovative, and utilise a large component of skilled labour (Acs and Audretsch, 1987). Market structure affects innovation since a lack of competition in a market will give rise to inefficiency and result in sluggish innovative activity (Geroski, 1990). In a competitive market with low concentration, the competitive environment and competition pressure may induce small firms to be more innovative to survive (Segerstrom, 1991).

Firm size is measured by the number of employees; and industry concentration ratio is measured by the share of turnover of top three enterprise groups in total industry output obtained from the Annual Business Inquiry collected by the Office of National Statistics in the UK.

In the estimation of firm innovative efficiency, the efficiency scores have an upper bound of 1.0 and a lower bound of 0.0. In these circumstances ordinary least squares estimates would be inconsistent. Therefore, the regression model for technical efficiency is specified in form of the Tobit model as follows (Tobin, 1958).

$$IE = \begin{cases} \alpha + \beta X_i + \mu & \text{if } \alpha + \beta X_i + \mu < 1 \\ 1 & \text{otherwise} \end{cases} \quad (2)$$

where IE = innovative efficiency, and X_i is a vector of explanatory and control variables we have discussed above.

Because of possible endogeneity between innovative efficiency on one side, and CEO share-ownership, collaboration and training on the other, we first apply the Wu-Hausman specification to test for endogeneity. In this test we use as instrumental variables firms' limitations in financial resources; in access to domestic and international markets; in skilled labour; in management and marketing skills. We also use indicators of their difficulty: in implementing new technology; in recruiting skilled manual workers, technologists, scientists and managerial staff; the rate of labour turnover and all other exogenous variables in the model above as instrumental variables. If endogeneity is detected between innovative efficiency and collaboration and training, we utilise the 2-stage Tobit model for estimation, otherwise we use the standard Tobit model.

We also use the Moderated Regression Analysis approach (MRA) to ttest for the impact of moderating effects. An interaction term(s) is included as an explanatory variable, where the effect of one independent variable on the dependent variable depends on the level of a second independent variable (the moderator)[3]. When the moderator variable is a dummy variable, another way to test the moderating effect is to divide the sample into several sub-samples according to the moderating variable and compare the estimated coefficients of the equations for each sub-sample. The advantage of this method is that it avoids the multicolinearity problem between the main effect variables and the interaction term and clearly indicates the sign and magnitude of the main effects in different states with regard to the moderator. This method, however, does not demonstrate the significance of the differences across sectors. Given the advantage and disadvantages of the two approaches, we combine MRA with sub-group analysis wherever appropriate in our analysis.

RESULTS

Table II presents means, standard deviations and correlations among variables. Of all the innovating firms in the valid sample, the average share of new products in total sales is 41 percent. The average R&D expenditure to total sales ratio is 14 percent, and the proportion of R&D staff in the total labour force is 9 percent. On average, 52 percent of the ordinary shares is owned by the CE, 4 percent of the workforce has participated in stock option schemes and 44 percent of our sample has used performance-related pay. About 70 percent of the firms have reported a management structure based either on functional specialisation, or product markets or geographical regions, but in only 28 percent of the firms are strategic decisions is made by a group of key members rather than the CEO's personal control of strategic and/or operating decisions. The magnitude of the correlation coefficients between the independent variables is not large in most of the cases. This indicates that multicollinearity does not present a significant problem and that all the independent variables could be included in the regressions[4].

INSERT TABLE II HERE

Frontier estimates of innovative efficiency

The innovative efficiency of firms is estimated using both Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). The process and logistics innovation outputs were summarized using Principal Component Analysis (PCA). There are two factors which explain 52% of the variance across all the underlying variables. These two factors are retained and extracted, and the estimated 'factor loadings' which represent the weights attached to each underlying variable in the factor are reported in Table III. These two factors are: diffusion process and logistics innovation (new to the firm but not the industry (FAC1) and original process and logistics innovation (new to the firm and the industry) (FAC2). The latter factor has higher quality in terms of novelty.

INSERT TABLE III HERE

For the DEA analysis, the efficiency is estimated in three scenarios when innovation output is measured by: (1) percentage of innovative sales; (2) innovative sales as in (1) plus the two principal components without weights, and (3) innovative sales and the two principal components with weights restriction. The innovative sales variable indicates the extent of commercial success of the innovation. In this scenario we assume it has the same quality as original process and logistics innovations, and their importance is twice that of the diffusion innovations. Therefore, the weights restriction we use in the 3-outputs $DEA3_w$ model is as follows[5]:

$$q_{\text{newsale}} = q_{\text{new to industry innovation}} = 2\, q_{\text{new to firm innovation}}$$

As Table IV shows, the three DEA estimates and the SFA estimate are, in general, highly correlated with each other. The estimated correlation coefficients between the single-output DEA estimates (DEA1) on the one hand, and the weighted 3-output DEA estimates (DEA3w) and SFA estimates (SFA1) on the other, are higher than 0.90. The SFA estimates (SFA1) have the lowest variance as this approach has controlled for statistical noise. The impact-weighted, quality-adjusted multi-output DEA estimates (DEA3w) have the lowest standard deviations among the three DEA estimates. The differences in standard deviations between these estimates are, however, very small. These results seem to suggest that the percentage of sales on account of new or improved products has, to a certain extent, captured each firm's variation in innovation, both the type and the quality. The findings for only DEA1 and SFA1 are therefore presented in our subsequent analysis.

INSERT TABLE IV HERE

Breaking down the single-output DEA efficiency scores across the industries, Figure 2 shows that the Research and Development sector (SIC73) had the highest average innovative efficiency at 0.65 suggesting that, compared to other industry sectors in UK, they are the most efficient sector in transforming innovation inputs into innovative sales. This result is not unexpected as this sector should have the most experience in innovation management. The computer and related activities (SIC72) sector also enjoy a relative high average innovative efficiency at 0.55. The SMEs in the transportation, storage and communication sector (SIC60-64) are the least efficient in transforming innovation inputs into output. The manufacturing sectors do not show significant difference between each other in their innovative efficiency on average.

INSERT FIGURE 2 HERE

Analysis of determinants of innovative efficiency

What are the determinants of SME innovative efficiency? Table V presents the Tobit model estimation results. In view of the possible presence of heteroskedasticity, Quasi-maximum likelihood (QML) standard errors that are robust to general misspecification are adopted in estimation. As the Wu-Hausman test for endogeneity suggests that there is no significant endogeneity between innovative efficiency on one hand, and managerial share ownership, collaboration and training cost on the other, the standard Tobit model result is preferred to the 2-stage Tobit model result.

INSERT TABLE V HERE

The results show that the level of managerial ownership is non-linearly related to the innovative efficiency of firms. The percentage of share owned by the CEO is positively correlated with innovative efficiency and is statistically significant; while the estimated coefficient of the quadratic term is negative. The results are consistent across all specifications. The inflection point in the relationship is at 65 to 68 percent.[6] This result suggests that the marginal value of managerial ownership diminishes, and that beyond a threshold level the entrenchment effect of managerial ownership outweighs the alignment effect.

Incentive schemes exert a positive effect on innovative efficiency which is statistically significant in half of the specifications. The innovative efficiency for firms that have performance-related-pay scheme (PRP) is about 0.06 units higher than that for the firms without the PRP scheme. A one unit increase in the percentage of employees participated in stock option schemes is to raise innovative efficiency by 0.1 unit[7]. This result lends support to the significant effect of incentive schemes in reducing the agency and free-riding problem in the innovation process. Our findings suggest that with income related to their performance, individuals and groups will make greater effort and that this enhances the overall efficiency of the firm including its innovative efficiency.

Formal management structure shows a consistent significant positive impact on innovative efficiency. In other words, firms that have a formal management system are more efficient in innovation than those that have not. The estimated coefficient of the training variable shows the expected positive sign, and is statistically significant in half of the equations. However, the estimated coefficients of the decision structure variable are not statistically significant in any of the equations. This result seems to suggest that although decision-making structure has been found to have important effect on firm's likelihood to innovate, its impact on innovation efficiency is not significant.

Firms that feel they are hampered by organisational rigidities show a statistically significant worse performance in terms of innovative efficiency. The magnitude, the sign and the statistical significance level of the estimated coefficients are robust across the specifications. This result implies that organisational rigidities significantly increase operational costs within the firm, weaken a firm's adaptability to change, and reduce its efficiency in transforming resources into commercially successful outputs. As expected, collaboration shows a significant positive effect on innovative efficiency. This suggests that the complementary resources and skills shared through research partnership enable SMEs to innovate more efficiently and effectively.

Firm size shows a negative effect on innovative efficiency and is statistically significant in the regression with DEA-based efficiency model. There are several possible explanations for this. First, R&D effectiveness is higher in small firms than in large firms as best practice may be more often met in small firms (Rothwell, 1986) and small firms have a relative managerial advantage in innovation (Bughin and Jacques, 1994). The advantage of small firms in innovation management comes not only from R&D department efficiency, but also from synergy between the firm's departments. Second, larger firms are more likely to have broader product portfolios, with a wider range of novelty, than are the smaller SMEs. Young small businesses are more likely to concentrate on single newly introduced products. The proportion of sales accounted for by products that were new, or significantly improved, in the previous three years may, therefore, be lower in larger firms than in small firms. Finally, it should be remembered that the SFA estimates have excluded the statistical noise in measurement. This fact suggests that, controlling for statistical noise, there is no significant difference in innovative efficiency between large and small firms. Table V also demonstrates some significant industry effects to which we return below.

Complementarities between management characteristics

The regression results for the hypotheses on the interaction between incentive schemes and management structure, and incentive schemes and training intensity are reported for the DEA1 innovative efficiency measure only in Table VI. The estimated coefficients are positive and the interaction term between performance-related pay and formal management structure is statistically significant at 10% level. This lends some support to the hypothesis that simultaneous presence of a formal management structure and performance-based pay will reinforce the individual effects of these factors and improve innovative efficiency. Both of the estimated coefficients of the interaction terms between training intensity and incentive schemes show the expected signs; they are however not statistically significant.

INSERT TABLE VI HERE

The plot of the relationship in Figure 3 shows the interaction more clearly. This plot shows graphically that incentive schemes are positively related to innovative efficiency in firms with a formal management structure, but do not make a significant difference within an informal management structure. Both of the estimated coefficients of the interaction terms between training intensity and incentive schemes show the expected signs; they are however not statistically significant.

INSERT FIGURE 3 HERE

The moderating effects of managerial ownership

Tests of the hypotheses concerning the moderating effects of managerial ownership are reported in Table VII. Drawing upon our finding of a non-linear relationship between managerial ownership and innovative efficiency, we split the sample into two sub-sets by CEO share ownership at the estimated turning point 0.65. Firms whose percentage of ordinary shared owned by the CEOs are smaller than 65 percent are classified into the low managerial ownership sample, and firms whose percentage of ordinary shared owned by the CEOs are greater than 65 percent are classified into the high managerial ownership sample.

As expected, ownership exerts a significantly positive influence on innovation efficiency in the low managerial sample, but a negative yet insignificant in the high ownership group. Similarly, the estimated coefficient of the stock option scheme variable is positive and statistically significant at the 1% significance level in the low managerial ownership sample, but not statistically significant in the high ownership group. The magnitude of the estimated coefficient is 0.239 in the low managerial ownership sample, which is about 20 times of that in the high managerial ownership sample at 0.013. This evidence supports our hypothesis that top management motivation arrangements exert a larger and more significant effect in firms with a low level of managerial ownership. The estimated coefficient of the group-based decision variable in the low ownership group is positive, but the estimated coefficient for the high ownership group is negative; both are insignificant. These results suggest that, although group-based decision-making may take wider information into account and help to mitigate CEO's opportunity to take self-interested decision, its practical importance is questionable. The balance between the monitoring and autonomy of CEOs is a question for further research. Interestingly, in firms with a high level of managerial ownership, advanced management practices, such as formal management structure, training and collaboration play a significant role in enhancement of innovative efficiency.

INSERT TABLE VII HERE

The moderating effects of industry technology environment

Table VIII reports the regression results for the hypotheses on the moderating role of industry technology environment. We divide the whole sample into high-tech and traditional sub-samples. The research and development, computer and related activities and manufacturing of electrical and optical equipment sectors are classified into the high-technology sub-sample. The results shown in this Table clearly support the hypotheses that industry technology environment would moderate the relationship between management characteristics and innovative efficiency. Formal management structure and training intensity play a more important role in the high-technology sector; while incentive schemes and managerial ownership are more important for innovative efficiency in the traditional sectors.

INSERT TABLE VIII HERE

The magnitude of the estimated coefficients of formal management structure and training intensity are several times larger than those for the traditional sectors and they are statistically significant in the high-technology sector, but insignificant in the traditional sectors.

The significantly lower magnitude of the effect of managerial ownership in the high-technology sector seems to suggest a better alignment effect of managerial ownership on innovative efficiency in the traditional sector. The estimated coefficient of the performance-related pay variable is positive and significant in the traditional sectors sample, but negative and not significant in the high-technology sector. Results from this analysis suggest that the industry's technology environment affects the strength of relationships between management structure and innovative performance in a material way.

DISCUSSIONS AND CONCLUSIONS

Findings from this study suggest that, in general, management structure, management practices and ownership structure affect a firm's innovation efficiency. The form and strength of these effects vary across sectors. This is consistent with an evolutionary perspective in which managerial and organisational routines reflect the private (or tacit) aspect of learning, which enables firms to develop within their particular environment through their unique path-dependent dynamic capabilities (Teece et al., 1997).

Our finding that formal management structure enhances firms' efficiency in innovation is consistent with the arguments of Stinchcombe (Stinchcombe, 1965). The positive effect of formality in management structure is found to be most significant in the small high-technology sector. Managers in this sector face greater technological and economic uncertainties than in the traditional sector, but are often well trained in science and engineering rather than business and management. Therefore, adopting formal management structures, for instance by establishing a formal marketing division, will help these firms achieve greater success in commercialising their innovative ideas. Formal management structure is also found to moderate a firm's short-term payment scheme. Performance-related pay appears to work more effectively in a formal management structure. Policy implications of these findings are important in the context of the debate on the effect of 'organic' versus 'mechanistic' structures on firm performance. An 'organic structure is often regarded as more suitable for small businesses in dynamic environments and then in turn linked to be associated informal management structures (Burns and Stalker, 1961). We do find that organisational rigidity inhibits efficient innovation. However this does not means that informality promotes innovation. On the contrary our findings show that a formal management structure exerts significant benefits for small business, especially in the dynamic high-technology sector.

Managerial ownership is found to have a non-monotonous relationship with innovative efficiency. This finding is similar to those of Morck, et al. (1988) and McConnell and Servaes (1990) and others for the USA and in the context of takeovers for the UK (Cosh et al., 2006). In these cases the turning or tiling off point is at much lower proportions of share ownership. Our results suggest that the positive influence of managerial ownership in our small firm sample exists up to quite high levels of ownership but becomes negative after that optimal level is reached. Decision making structure does not show a significant direct, or indirect, effect on the innovative efficiency of firms. One interpretation of this could be that decision-making structure at top management level may have greater influence on a firm's decision over whether to innovate than on the productivity of innovation. Productivity in innovation may mainly rely on a firm's management and governance system in efficient utilisation of internal and external resources and effective motivation of managers and employees. These factors determine the allocative efficiency, productive efficiency and X-efficiency in the innovation process.

Tests of the interactions among management characteristics variables show support for only one hypothesis, the significant interaction effect between management structure and performance-related pay. The estimated coefficients of other interaction terms whilst having the expected signs are not statistically significant. However, when we take account of the interaction of managerial ownership with stock option schemes we do find significant interaction effects. The evidence presented here supports our hypothesis that top management motivation arrangements exert a larger and more significant effect in firms with a low level of managerial ownership. The implications of these findings are useful for practitioners and researchers in designing new management package and evaluating the effect of current practices.

Another primary finding from this study is that a firm's technological environment moderates the strength and, in some cases, the form of relationship between management characteristics, managerial ownership and innovative efficiency. The main indication for public policy and management is that the appropriate choice of management structure and methods for improving innovation efficiency depends on the technological environment in which the firm operates. For example, compared with traditional sectors, the innovative efficiency of high-tech SMEs is significantly associated with a formal management structure and training. The high-tech SMEs who have adopted a formal management structure and who have invested more in training are more efficient in innovation. On the other hand, in the traditional sectors, managerial ownership and incentive schemes play a significantly positive role in raising innovative efficiency.

The questions of how to measure innovation output and how to evaluate a firm's efficiency in innovation are important issues for empirical research in innovation economics and innovation management. This study has used two frontier analysis approaches to evaluate a firm's efficiency in innovation. The frontier approach differs from normal productivity measurement in that it benchmarks a firm's performance against best practice. It has also tried different measures of innovation outputs taking into account of different types and qualities of innovation. The estimated efficiency scores from the one-output and the weighted three-output DEA models and the SFA model are highly consistent. This finding suggests that despite the different advantages and disadvantages of various innovation measures, the percentage of sales due to new, or significantly improved, products picks up most of the quantity and quality aspects of the innovation performance of organisations.

Of course, the transformation of innovation inputs into successfully commercialised new products takes time. Given that the data used here are cross-sectional, this limitation of the current study needs to be noted. Future studies using longitudinal datasets and including time dynamics within the model could produce further insights in this field.

Conclusions

Productivity in innovation has been a key issue for managers and policy-makers. How a firm's general management characteristics and ownership structure impacts on its innovative efficiency is central to this issue. This paper has investigated the impact of management structure, management practices and ownership structure on innovative efficiency using a recent survey database for British SMEs. We find that firms' management characteristics and managerial ownership are significantly associated with their innovative efficiency. Formality in management structure affects firms' efficiency in innovation directly and indirectly by moderating the strength of other management factors. Incentive design and human resource management practices also have significant effect on innovative efficiency of firms. Managerial ownership is found to have a non-monotonous non-linear relationship with firms' innovative efficiency, supporting both an alignment effect and an entrenchment effect of managerial ownership on the innovation performance of firms. Results of this study reveal a significant moderating influence of a firm's technological environment on the relationship between management characteristics, ownership structure and its innovative efficiency. Evidence from this study suggests that SMEs in the high-technology sector have more to gain in terms of commercialising their innovative ideas and inputs by adopting a formal management structure and providing training to their managers and employees.

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Table I. A summary of selected literature on industrial research productivity

Study	Country	Sample	Method	Measure of research productivity	Results
Mansfield, E. (1988)	US and Japan	50 Japanese and 75 US major firms in 6 manufacturing industries, 1985	Questionnaire survey, Comparison.	The time and cost of innovation judged by the Chief Executives.	The impact of external and internal technology. The Japanese have great advantages in carrying out innovations based on external technology, but not in carrying out innovations based on internal technology. A large part of US's problem in this regard seems to be due to its apparent inability to match Japan as a quick and effective user of external technology.
Henderson, R. and Cockburn, I. (1996)	US and European	An unbalanced panel. 38 research programs from 10 firms over 30 years in pharmaceutical industry.	Poisson regression.	Number of patents.	Larger research efforts are more productive, not only because they enjoy economies of scale, but also because they realize the economies of scope by sustaining diverse portfolios of research projects that capture internal and external knowledge spillovers.
Mairesse, J. and Hall, B. (1996)	US and France	Two panels of about 1000 manufacturing firms in the US and France over the 1980s, including large and medium-sized firms.	Regression controlled for simultaneity bias with GMM (Generalised Method of Moments).	Output elasticity of R&D.	The contribution of R&D to sales productivity growth appears to have declined during the 1980s. The role of simultaneity bias is higher in the US than in France, possibly reflecting the greater importance of liquidity constraints for R&D investment in that country. Using sales instead of value added does not seriously bias the results.
Adams, J. (2000)	US	220 R&D laboratories in 4 manufacturing industries. 1996.	Postal survey. Negative binomial regressions	Number of patents.	The full effect of spillovers on research productivity of firms exceeds the structural effect. Learning expenditure transmits the effect of spillovers. And it increases in response to industrial and academic R&D spillovers. Academic spillovers appear to have a more pervasive effect on R&D than do industrial spillovers.

Table I. (Continued)

Danzon, P., Nicholson, S. and Pereira, N.S. (2003)	US	900 firms, 1988-2000 in pharmaceutical industry. Large and small firms.	Logistic regressions	Probability of success	Success probabilities are negatively correlated with mean sales by category (which is consistent with a model of dynamic, competitive entry). Success probabilities are larger for products developed in an alliance.
Zhang et al (2003)	China	8341 firms, 1995 large and small firms.	Cross-section regression.	Estimated using Stochastic Frontier Analysis.	Public and private ownership and R&D efficiency. Ownership to be a contributing factor in the cross-sectional variance of R&D efficiencies. The state sector has significantly lower R&D efficiency than the non-state sector.
Siegel, Donald S., Westhead, Paul and Wright, Mike (2003)	UK	Survey data for 89 science park firms and 88 non-science park firms in the late 1980s.	(1). Negative binomial regression. (2) Stochastic frontier analysis and Tobit model	Measures of innovation output: number of new products, number of patents, and number of copyrights, alternatively. (1) Estimates of science park dummy. (2) Estimates of the marginal product of R&D (3) Estimates of SFA	Companies located on university science parks in the United Kingdom have higher research productivity than observationally equivalent firms not located on a university science park. The preliminary results are robust to the use of alternative econometric procedures to assess relative productivity.
Lanjouw, J. O. and Schankerman, M. (2004)	US	Panel data for about 1500 US manufacturing firms over 1980-93.	Develop an index of patent 'quality'. OLS and IV	Ratio of patents to R&D.	Research productivity at the firm level is inversely related to patent quality and the level of demand.

Table II. Descriptive Statistics and Correlation Coefficients

		Mean	Std.Dev.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	NEWSALE	41.05	28.08	1.00													
2	RDS	0.14	0.19	0.21	1.00												
3	RDPS	0.09	0.13	0.14	0.92	1.00											
4	OS	52.08	32.49	0.11	0.10	0.13	1.00										
5	SOPT	0.04	0.18	0.16	0.14	0.10	-0.10	1.00									
6	PP	0.44	0.50	0.10	-0.02	-0.05	-0.03	0.13	1.00								
7	MS	0.70	0.46	0.06	-0.21	-0.31	-0.18	0.12	0.13	1.00							
8	DEC	0.28	0.45	-0.01	-0.13	-0.14	-0.19	0.06	0.06	0.26	1.00						
9	OG	1.58	0.89	-0.13	-0.07	-0.05	-0.06	-0.05	0.01	0.07	0.03	1.00					
10	COOP	0.53	0.50	0.09	0.05	-0.01	-0.13	0.17	0.13	0.20	0.17	0.05	1.00				
11	TR	1.44	1.56	0.09	-0.02	-0.08	-0.02	0.05	0.21	0.14	0.11	-0.02	0.06	1.00			
12	LFS	3.47	1.39	-0.09	-0.51	-0.58	-0.32	0.07	0.20	0.59	0.31	0.12	0.17	0.26	1.00		
13	CONC	2.56	0.75	-0.03	0.06	0.03	-0.09	-0.04	-0.03	0.06	0.01	-0.02	0.00	-0.07	0.04	1.00	
14	HITEC	0.28	0.45	0.11	0.28	0.20	-0.05	0.11	0.02	0.09	0.02	-0.02	0.09	0.06	-0.09	0.29	1.00

Notes:
NEWSALE: Percentage of sales accounted for by new or improved products.
RDS: R&D expenditure to total sales
RDPS: Share of R&D staff in total labour force
OS: Percentage of ordinary shares owned by the chief executive.
OS2: Quadratic term of OS
PP: Performance related payment dummy, 1=yes, 0=no
SOPT: Percent of managers and employees participated in stock option scheme.
MS: Management structure dummy, 0 for firms with informal structures and 1 for others
DEC: Decision making structure dummy, 1 for firms with group based strategic decision making and 0 for others.
TR: Training input, measured by formal training costs as a percentage of total labour costs.
OG: Organisational rigidities ranging from 1 to 5 which indicate this is an insignificant barrier and a crucial barrier, respectively.
COOP: Innovation co-operation agreements dummy, 1=yes, 0=no
LFS: Log of firm size measured by the number of employees
CONC: Industry concentration ratio measured by the share of turnover of top three enterprise groups in total industry output.
HITEC: High-technology industry dummy, 1 =yes, 0 =no.

Table III. Factor loadings of innovation outputs

	FAC1 Innovation New to firm	FAC2 Innovation New to industry
Diffusion innovation: manufacturing production methods	.726	2.319E-02
Diffusion innovation: manufacturing logistics	.777	8.824E-02
Diffusion innovation: service sector process innovations	.649	.117
Original innovation: manufacturing production methods	1.974E-02	.747
Original innovation: manufacturing logistics	.131	.700
Original innovation: service sector process innovations	7.683E-02	.681

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 3 iterations.

Table IV. Innovative efficiencies of firms

Part 1. Descriptive Statistics				
Variable	DEA1	DEA3	DEA3w	SFA1
Mean	0.432	0.576	0.497	0.511
Std.Dev.	0.279	0.266	0.263	0.255
Minimum	0.01	0.118	0.075	0.015
Maximum	1	1	1	0.896
Cases	440	440	440	440
Part 2. Correlation coefficients				
	DEA1	DEA3	DEA3w	SFA1
DEA1	1			
DEA3	0.739	1		
DEA3w	0.922	0.873	1	
SFA1	0.915	0.675	0.848	1
Part 3. Order statistics				
Percentile	DEA1	DEA3	DEA3w	SFA1
Min.	1.00E-02	0.118	7.48E-02	1.52E-02
10th	0.100	0.250	0.180	0.142
20th	0.200	0.353	0.250	0.237
25th	0.200	0.377	0.295	0.286
30th	0.200	0.380	0.309	0.320
40th	0.300	0.463	0.399	0.443
Med.	0.400	0.550	0.439	0.544
60th	0.500	0.614	0.516	0.623
70th	0.600	0.741	0.600	0.707
75th	0.600	0.765	0.700	0.747
80th	0.700	0.891	0.750	0.779
90th	0.900	1.000	0.919	0.837
Max.	1.000	1.000	1.000	0.896

Notes: DEA1: DEA 1-output model estimates;
DEA3: DEA 3-outputs model (no weights) estimates;
DEA3w: DEA 3-outputs model (with weights) estimates;
SFA1: SFA estimates.

Table V. Management characteristics, managerial ownership and innovation efficiency: Tobit model estimation

	Dependent variable							
	DEA1				SFA1			
	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value
Constant	0.551***	0.000	0.521***	0.000	0.492***	0.000	0.471***	0.000
OS	0.004**	0.012	0.004**	0.019	0.003**	0.017	0.003**	0.018
OS2	-0.000**	0.032	-0.000**	0.050	-0.000*	0.052	-0.000*	0.054
SOPT	0.170**	0.018			0.097	0.101		
PP			0.040	0.165			0.063**	0.015
MS	0.069*	0.081	0.088**	0.027	0.101***	0.004	0.095***	0.008
DEC	0.006	0.850	0.004	0.907	-0.011	0.718	-0.003	0.920
TR	0.017*	0.075	0.014	0.131	0.015*	0.062	0.011	0.185
COOP	0.054*	0.066	0.053*	0.070	0.061**	0.019	0.052**	0.046
OG	-0.027*	0.083	-0.034**	0.034	-0.032**	0.023	-0.032**	0.024
LFS	-0.037***	0.008	-0.038***	0.007	-0.017	0.177	-0.015	0.243
LCONC	-0.029	0.201	-0.026	0.261	-0.017	0.387	-0.019	0.352
SEC2 (Man. of raw materials)	-0.129***	0.001	-0.112***	0.005	-0.064*	0.070	-0.060*	0.091
SEC3 (Man. of electrical & optical equip.)	-0.056	0.228	-0.041	0.380	-0.057	0.162	-0.045	0.275
SEC4 (Real estate & business activities)	-0.114**	0.014	-0.091*	0.051	-0.040	0.345	-0.032	0.449
SEC5 (Computer & related activities)	-0.010	0.860	0.024	0.675	-0.051	0.316	-0.038	0.461
SEC6 (Research & development)	0.103	0.547	0.155	0.363	0.152	0.292	0.173	0.227
Log Likelihood	-125.192		-122.184		8.517		7.992	
DECOMP fitness	0.395		0.392		0.441		0.440	
N	440		440		440		440	

Note: 1. *** Significant at the 1% level. ** Significant at the 5% level. * Significant at the 10% level. 2. Base industry: SEC1 Light manufacturing industry. 3. Wu-Hausman test for exogeneity (H0: exogeneity) has been conducted for managerial share ownership, collaboration and training variables. None of these variables are reported to be endogenous at the 1% significance level. Therefore, the standard Tobit model is preferred to the simultaneous equations model.

Table VI. Management and the efficiency of innovation: interactions between management characteristics

Innovation efficiency measure:	DEA1							
	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value
Constant	0.563***	0.000	0.546***	0.000	0.552***	0.000	0.532***	0.000
OS	0.004**	0.014	0.004**	0.016	0.004**	0.012	0.004**	0.016
OS2	-0.000**	0.035	-0.000**	0.045	-0.000**	0.032	-0.000**	0.040
SOPT	-0.143	0.576			0.157	0.112		
PP			-0.046	0.433			0.003	0.935
MS	0.064	0.108	0.044	0.355	0.068*	0.082	0.088**	0.026
DEC	0.006	0.842	0.007	0.836	0.006	0.863	0.005	0.867
TR	0.017*	0.077	0.014	0.138	0.016*	0.092	0.000	0.992
COOP	0.055*	0.058	0.051*	0.082	0.054*	0.065	0.053*	0.073
OG	-0.027*	0.080	-0.034**	0.033	-0.027*	0.085	-0.034**	0.033
LFS	-0.038***	0.006	-0.036**	0.010	-0.037***	0.008	-0.037***	0.008
LCONC	-0.030	0.187	-0.026	0.259	-0.029	0.204	-0.025	0.263
SEC2 (Man. of raw materials)	-0.128***	0.001	-0.115***	0.004	-0.129***	0.001	-0.110***	0.006
SEC3 (Man. of electrical & optical equip.)	-0.050	0.286	-0.042	0.367	-0.056	0.226	-0.043	0.356
SEC4 (Real estate & business activities)	-0.117**	0.011	-0.096**	0.038	-0.114**	0.014	-0.087*	0.061
SEC5 (Computer & related activities)	-0.014	0.804	0.019	0.740	-0.011	0.853	0.021	0.712
SEC6 (Research & development)	0.098	0.565	0.173	0.308	0.102	0.550	0.150	0.377
SOPT*MS	0.325	0.202						
PP*MS			0.113*	0.091				
SOPT*TR					0.008	0.850		
PP*TR							0.026	0.164
Log Likelihood	-124.378		-120.758		-125.174		-121.217	
DECOMP fitness	0.396		0.393		0.395		0.392	
N	440		440		440		440	

Table VII. Moderating effects of managerial ownership

	Low managerial ownership		High managerial ownership	
	Coeff.	P-value	Coeff.	P-value
Constant	0.490***	0.000	0.726***	0.005
OS	0.003***	0.001	-0.001	0.732
SOPT	0.239***	0.006	0.013	0.923
MS	0.059	0.218	0.128*	0.072
DEC	0.018	0.634	-0.017	0.794
TR	0.011	0.346	0.035**	0.026
COOP	0.044	0.221	0.082	0.104
OG	-0.027	0.176	-0.019	0.438
LFS	-0.017	0.333	-0.062***	0.008
LCONC	-0.034	0.237	-0.030	0.423
SEC3 (Man. of raw materials)	-0.137***	0.006	-0.108	0.103
SEC4 (Man. of electrical & optical equip.)	-0.029	0.607	-0.108	0.184
SEC12 (Real estate & business activities)	-0.136**	0.017	-0.084	0.287
SEC13 (Computer & related activities)	0.062	0.396	-0.110	0.252
SEC14 (Research & development)	0.114	0.513		
Log likelihood	-85.89		-33.50	
DECOMP fitness	0.394		0.405	
N	292		148	

Note: Low managerial ownership sample: firms whose percentage of ordinary shared owned by the CEOs are smaller than 65 percent.
High managerial ownership sample: firms whose percentage of ordinary shared owned by the CEOs are greater than 65 percent.
Dependent variable: DEA1.

Table VIII. Moderating effects of industry technology environment

	Coeff.	P-value	Coeff.	P-value
Constant	0.568***	0.000	0.511***	0.000
OS	0.004***	0.006	0.004***	0.006
OS2	-0.000**	0.023	-0.000**	0.032
SOPT	0.195**	0.033		
PP			0.077**	0.021
MS	0.041	0.347	0.063	0.151
DEC	0.013	0.739	0.009	0.811
TR	0.007	0.551	0.004	0.721
COOP	0.054*	0.063	0.046	0.110
OG	-0.024	0.122	-0.030*	0.058
LFS	-0.037***	0.006	-0.038***	0.006
LCONC	-0.032	0.163	-0.028	0.220
SEC2 (Man. of raw materials)	-0.127***	0.001	-0.110***	0.006
SEC3 (Man. of electrical & optical equip.)	-0.114	0.207	-0.054	0.553
SEC4 (Real estate & business activities)	-0.116**	0.011	-0.090**	0.050
SEC5 (Computer & related activities)	-0.064	0.532	0.040	0.697
SEC6 (Research & development)	0.027	0.885	0.134	0.470
OS*HT	-0.002*	0.067	-0.002**	0.039
SOPT*HT	-0.056	0.622		
PP*HT			-0.139**	0.033
MS*HT	0.147*	0.055	0.143*	0.065
DEC*HT	-0.032	0.655	-0.009	0.900
TR*HT	0.032*	0.096	0.040**	0.046
Log Likelihood	-120.037		-114.935	
DECOMP fitness	0.397		0.394	
N	440		440	

Note: Dependent variable: DEA1.

Figure 1

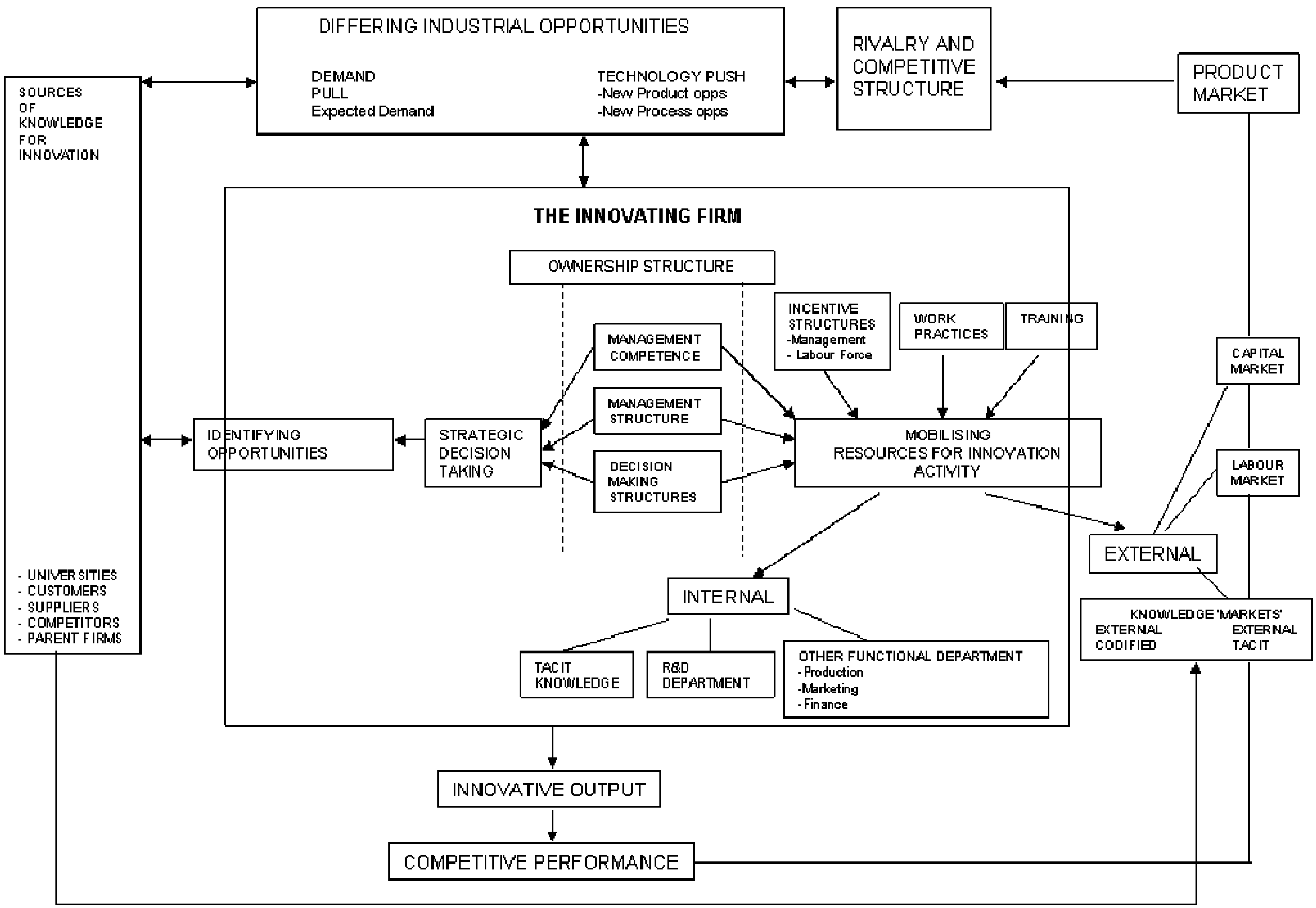

DIFFERING INDUSTRIAL OPPORTUNITIES
DEMAND
PULL
Expected Demand
TECHNOLOGY PUSH
-New Product opps
-New Process opps
RIVALRY AND COMPETITIVE STRUCTURE
PRODUCT MARKET
SOURCES OF KNOWLEDGE FOR INNOVATION
- UNIVERSITIES
- CUSTOMERS
- SUPPLIERS
- COMPETITORS
- PARENT FIRMS
THE INNOVATING FIRM
OWNERSHIP STRUCTURE
MANAGEMENT COMPETENCE
MANAGEMENT STRUCTURE
DECISION MAKING STRUCTURES
INCENTIVE STRUCTURES
-Management
- Labour Force
WORK PRACTICES
TRAINING
IDENTIFYING OPPORTUNITIES
STRATEGIC DECISION TAKING
MOBILISING RESOURCES FOR INNOVATION ACTIVITY
CAPITAL MARKET
LABOUR MARKET
EXTERNAL
INTERNAL
KNOWLEDGE 'MARKETS'
EXTERNAL CODIFIED
EXTERNAL TACIT
TACIT KNOWLEDGE
R&D DEPARTMENT
OTHER FUNCTIONAL DEPARTMENT
- Production
-Marketing
- Finance
INNOVATIVE OUTPUT
COMPETITIVE PERFORMANCE

Figure 2

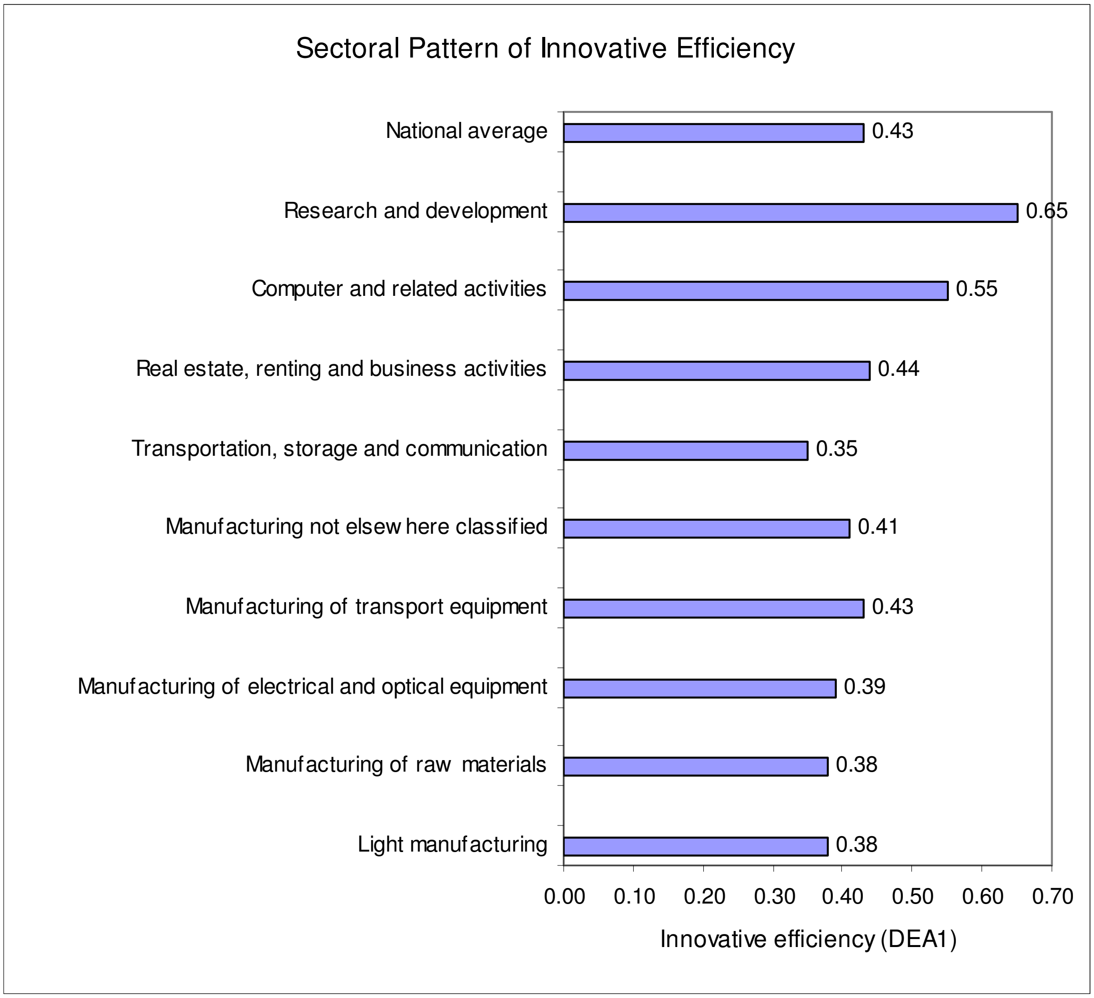
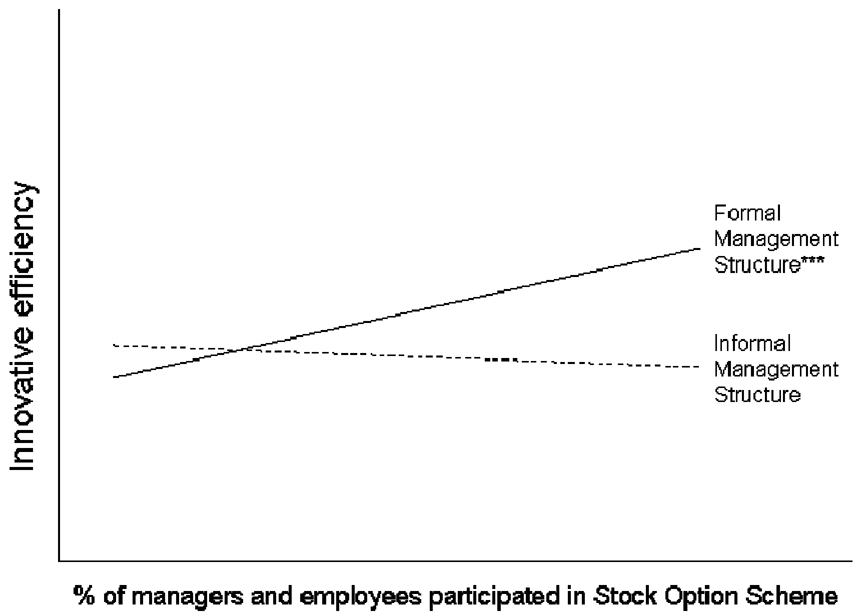
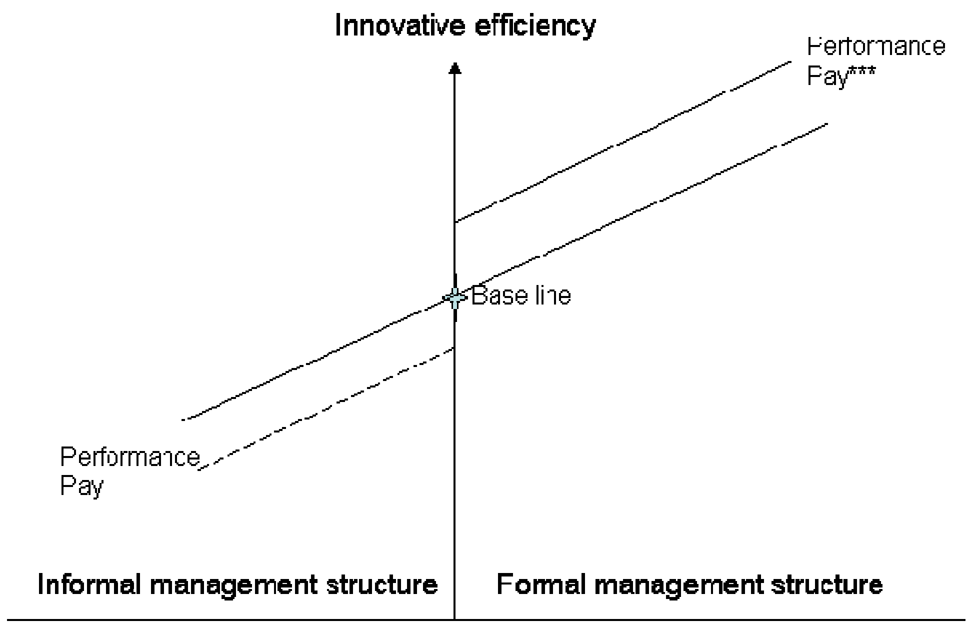

Sectoral Pattern of Innovative Efficiency
National average
0.43
Research and development
0.65
Computer and related activities
0.55
Real estate, renting and business activities
0.44
Transportation, storage and communication
0.35
Manufacturing not elsewhere classified
0.41
Manufacturing of transport equipment
0.43
Manufacturing of electrical and optical equipment
0.39
Manufacturing of raw materials
0.38
Light manufacturing
0.38
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
Innovative efficiency (DEA1)

Figure 3


Innovative efficiency
Formal Management Structure***
Informal Management Structure
% of managers and employees participated in Stock Option Scheme


Innovative efficiency
Performance Pay***
Base line
Performance Pay
Informal management structure
Formal management structure

Appendix 1. DEA and SFA approaches for the estimation of innovative efficiency

In the DEA approach, for a sample of n firms, if X and Y are the observations on innovation inputs and outputs, assuming variable returns to scale, the firm's innovative efficiency score, θ, is the solution to the linear program problem,

$$\begin{aligned} & Max_{\theta,\lambda}\ \theta \\ \text{st.} \quad & -\theta y_i + Y\lambda \geq 0 \\ & x_i - X\lambda \geq 0 \\ & \lambda_i \geq 0 \\ & \sum \lambda_i = 1 \qquad i = 1,\ldots,n. \end{aligned} \tag{1}$$

where θ is a scalar and λ is an nx1 vector of constants. The efficiency score ranges from 0 to 1. If $\theta_k = 1$ and all slacks are zero, the kth firm is deemed to be technically efficient (Cooper et al., 2000).

In the SFA approach, assuming a particular production functional form, technical inefficiency is modelled as a one-sided error term. Assuming a knowledge production function as follows:

$$y = f(x)\exp(v-u) \tag{2}$$

where y is innovation output, x is a vector of basic innovation inputs. The stochastic production frontier is $f(x)\exp(v)$, where v is a random disturbance that capture the effects of statistical noise and is distributed as $N(0,\sigma_v^2)$; u is a one side error term representing a variety of features that reflect efficiency. u is independent of v and $u \geq 0$, with certain distribution assumptions, e.g., half-normal and exponential distribution. The technical efficiency (TE) relative to the stochastic frontier is thus defined as

$$\text{TE} = \frac{y}{f(x)\exp(v)} = \exp(-u) \tag{3}$$

[1] About 3000 raw ideas are needed to produce 50 patent applications and, ultimately, one commercial success (Stevens & Burley, 1997).

[2] The weight is 1 for full-time staff and 0.5 for part-time staff.

[3] This method, however, is also subject to several limitations. For example, the model will be affected by measurement error and multicolinearity between the independent variables. Spurious interaction effects may be found if moderated regression analysis is used on data that in reality contain a non-linear relation between the dependent variable and one of the independent variables (Busemeyer and Jones, 1983; Shepperd, 1991; Celderman, 2000). As suggested by literature review that there is likely to be a non-linear relationship between managerial ownership and firm performance, following Celderman (2000) we introduced a quadratic term of managerial ownership into the model to reduce the problem.

[4] Although correlations among independent variables were generally small, the association between firm size and management structure is 0.59. To ensure multicollinearity is not a problem, we conducted the same analyses reported dropping each of these two variables in successive regression equations. Results did not change, indicating the correlation between firm size and management structure does not bias the results.

[5] We have also experimented with the DEA analysis using different weights. The estimated results do not appear to be significantly different.

[6] The inflection point is calculated as the derivative of innovative efficiency with respect of managerial ownership.

[7] The marginal effects of each Tobit model are not reported in the Tables.