Technological trajectories as moderators of firm-level determinants of innovation.

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Technological trajectories as moderators of firm-level determinants of innovation.

Abstract

Pavitt (1984) identified different patterns of technological change (technological trajectories) in four sectoral classes of industrial firms. This paper tests the applicability of Pavitt's taxonomy (which derived from an economic perspective) to moderate the inconsistent results of the management literature on the determinants of technological innovation.

An empirical test in a sample of 105 Greek companies showed that firms in different trajectories of Pavitt's taxonomy had differences in the rate of technological innovation. 'Specialised suppliers' and 'science-based' firms were found to have higher rates of innovation than 'supplier dominated' and 'scale intensive' ones. Most importantly, different variables proved to be significantly associated with innovation for each category of firms: Innovation for 'supplier dominated' firms was related to the competitive environment, acquisition of information, technology strategy, risk attitude and internal co-ordination. For 'scale intensive' firms the important determinants were related to the ability to raise funding and the education and experience of personnel. For 'specialised suppliers' innovation was associated with high growth rate and exporting, as well as training and incentives offered to the employees to contribute towards innovation. 'Science-based' firms depended upon technology-related variables, education and experience of personnel, growth in profitability and panel discussions with lead customers. The application of Pavitt's

model can resolve the apparent problem of inconsistent results in the management research on the determinants of technological innovation.

1. Introduction

This paper proposes and tests the contribution of Pavitt's (1984) taxonomy of sectoral patterns of technological change (derived from the economic perspective) to the management literature searching for the determinants of technological innovation. The management literature has been generally inconclusive regarding the factors which characterise innovative firms. Researchers have recognised that the determinants of innovation are specific to a number of moderating 'conditions' such as the size of the firm, the industrial sector and the country environment (Wolfe, 1994; Souitaris, 1999). Pavitt's taxonomy could prove a practical classification tool, simplifying the complex set of potential contingencies to four easily-identifiable firm-classes with distinct determinants of innovation: Supplier dominated firms, scale intensive firms, specialised suppliers and science-based firms.

To test the above idea, the author collected empirical evidence from 105 manufacturing firms in Greece, attempting to answer the following research question: "Do firms in different technological trajectories (according to Pavitt's classification) have significant differences in the factors determining innovation?"

The paper is structured as follows: Section 2.1 includes a brief review of the economic literature on patterns of technological change, followed by a presentation of Pavitt's taxonomy and a review of more recent literature testing and expanding the original idea. Section 2.2 describes the origins of the management literature on the determinants of innovation leading to the problem of inconsistent results. Section 2.3 introduces the idea of using Pavitt's taxonomy as an integrative tool linking the two literature streams and proceeds to the research hypotheses. Section 3 presents the study's portfolio model of potential determining variables. This was the starting point for the survey, testing the variation of the important determinants of innovation in the four trajectories of the Greek manufacturing industry. The research methodology is presented in section 4 and the results are discussed in section 5. Finally, section 6 concludes and identifies the research implications.

2. Background

2.1) The economic perspective leading to Pavitt's taxonomy

Pavitt's (1984) taxonomy of patterns of technical change was influenced by economic schools of thought analysing the emergence of major new technologies over the previous 150 years. Already in the 18th century, Adam Smith was aware of the diversity in the sources of technical change (Smith, 1895). In the late 1950s, Woodward (1958) and Penrose (1959) made major contributions leading to the argument of sectoral differentiation of technological change. In the late '70s and early '80s, evolutionary economists introduced the notion of technological trajectories, namely directions of technical development that are cumulative and self-generating without repeated reference to the economic environment external to the firm (Nelson & Winter, 1977, Dosi, 1982, Freeman et at, 1982). They argued that changing technological opportunities along trajectories, governed by paradigms, is a central regulating variable in the economy and the society (Andersen, 1998).

In the 1980s, another influential writer - von Hippel (1982 & 1988) - demonstrated empirically that the 'source' of innovation varies significantly across industries. For example, 90% of all innovations in pultrusion process and 77% in scientific instruments were generated by users, whereas 92% and 90% of innovations in plastics additives and engineering plastics respectively were generated by the manufacturer. Finally, 56% of all innovations in wire termination equipment were generated by the suppliers (von Hippel, 1988).

Based on the above studies, Pavitt (1984) suggested that industrial sectors differ greatly in the sources of technology they adopt, the users of the technology they develop, and the methods used by successful innovators to appropriate the benefits of their activities. The research was based on the Science Policy Research Unit database (at Sussex University), which included data on about 2000 significant innovations in Britain since 1945. Observing and comparing trends in the data, Pavitt produced a simple and practical classification with four categories of firms (see table 1):

a) '*Supplier dominated firms'*. These can be found mainly in traditional sectors of manufacturing, and they are generally small with weak R&D and engineering capabilities. Most of their innovations come from suppliers of equipment and materials although in some cases large customers and government research institutions also make a contribution.

b) '*Production intensive firms*' which are subdivided in two groups:

b1) '*Large scale producers*' such as automobile or steel manufacturers are usually big and produce a high proportion of their process technologies to which they devote relatively high proportion of their resources. They have a relatively high level of vertical technological diversification into equipment related to their own process technology and they make a relatively big contribution to all the innovations produced in their principal sectors of activity.

b2) On the other hand, '*specialised suppliers*' such as small mechanical and instrumental engineering firms also produce a high proportion of their own process technologies but the main focus of their innovative activities is the production of product innovations for use in other sectors. They diversify technologically relatively little and they do not make a big contribution to all the innovations produced in their principal sector of activity. Users and other firms outside the sector make significant contributions.

c) '*Science based firms*'. These belong usually to the chemical, pharmaceutical and electrical and electronic engineering sectors. Their main source of technology is internal R&D. These firms produce a relatively high proportion of their own process technology, as well as a high proportion of product innovations that are used in other sectors. They are also relatively big, most of their technological diversification is conglomerate and they produce a relatively high proportion of all the innovations made in their principal sector of activity.

Table 1 about here

Other researchers have elaborated on the initial results and presented variations of Pavitt's taxonomy (e.g. Archibugi et al., 1991; Cesaratto & Mangano, 1992; Tidd et al, 1997). For example, Archibugi et al., (1991), categorised Italian firms according to the type of innovation, size of the firm and the activities innovations are based on, and proposed a version of Pavitt's taxonomy with one extra class the 'suppliers of traditional intermediate goods'. These firms were in-between traditional firms and specialised suppliers, selling their products to other companies and receiving information through this channel. De Marchi et al. (1996) tested empirically Pavitt's model concerning both the realism of the predicted associations between industrial sectors and patterns of technical change, and the predictive power of the model. The results of the test did not seem inconsistent with the model's predictions and re-confirmed the variability of innovative behaviour at firm level.

Tidd, Besant & Pavitt (1997) presented a new version of the taxonomy with a fifth class, the 'information intensive firms', which includes mainly newly emerged service industries such as finance, retailing and software. The focus of our study was manufacturing in the traditional sense (the software industry was excluded) and therefore the paper was based on Pavitt's original work (1984). Despite the subsequent variations on the taxonomy theme, this author felt that the original typology was robust and simple enough for the purposes of this work. The usefulness of Pavitt's taxonomy was indicated also by the fact that the original paper was ranked the 5th most popular paper in Research Policy with 135 citations (Callon et al., 1999).

The major contribution of Pavitt's work was the reduction of the apparent wide sectoral diversity of the nature, sources, directions and strategic implications of innovation to four generalised classes. The creation of taxonomies of firms is encouraged in theory development, as it allows large amounts of complex information to be collapsed into more convenient categories, which are easier to comprehend (Carper & Snizek, 1980). However, Niosi (2000) noted that firms within Pavitt's sectoral classes, have technology-related similarities, but are by no means homogenous groups. Pavitt had set the 'firm' as his unit of analysis, but in reality the value of his work lay with the identification of common technological patterns at the level of the sectoral class. The taxonomy did not attempt to differentiate between individual firms within each class in terms of their innovativeness. Moreover, Pavitt did not consider organisational and managerial factors, apparently distinct from the sectoral technological trajectory but nonetheless potentially related to the rate and success in technological innovation.

2.2) The management perspective: Determinants of innovation

The identification of the distinguishing characteristics of highly innovative companies at the micro/ firm-level has been the aim of organisational theorists since the late 1960s. The intention of this literature stream was not to map the patterns of technological change and its macro-effect on industries and countries (as in the economic perspective) but to spot innovative firms based on managerial and organisational indicators. The literature encompassed a large number of factors that affect a firm's rate of innovation. They derive from a wide range of company functions and are often referred to as the 'determinants of innovation' (Duchesneau et al., 1979).

However, despite more than three decades of empirical research designed to determine 'the characteristics of innovative firms' and 'the factors associated with success or failure in innovation' there still exists no precise prescription for successful innovation (Rothwell, 1992). Different researchers have tested similar variables but discovered differing degrees of association with innovation rate (Wolfe, 1994; Souitaris, 1999).

This variation of the determinants of innovation from case to case has been frustrating integrated theory building efforts since the 1970's. Three important sources of instability have been identified in the literature - the type of innovation, the industrial sector, and the size of the firm: Downs and Mohr, (1976) stressed the importance of the type of innovation as a moderating factor. For instance, the determinants of high-cost innovation seemed to be markedly different from those of low-cost innovation. Rothwell, (1974, 1977) acknowledged that the factors associated with innovation were significantly different (certainly in order of priority) in different industrial sectors. Project SAPPHO showed that in the chemical industry technical factors were most important while in the scientific instruments industry market factors dominated (Rothwell et al., 1974). Mohr (1969) has also referred to a moderating effect of the size of the firm on the relative importance of its determinants of innovation. For example, top management characteristics and attitudes were found to be more important innovation determinants for small firms, due to the more active involvement of top managers in the innovation process (Carrier, 1994, Lefebvre et al., 1997).

To explain the inconsistency of results, some authors in the 1980s proposed taxonomies of firms with different determinants of technological innovation. Miller & Friesen (1984) identified two types of firm configurations with different innovation determinants, namely the 'conservative' firms with positive and significant correlation of innovation with information-processing, decision making and structural variables and the 'entrepreneurial' firms with negative correlation of innovation with information processing, decision making and structural integration variables. Goals and strategies, rather than structure were seen to be the key impetus to innovate. Also, Khan and Manopichetwattana (1989b) developed five clusters of small firms with different strategy, structure and managerial attitudes and showed that each cluster had its own specific factors determining innovation.

The taxonomies mentioned above had an indisputable pioneering value in the management literature. They accept that the characteristics of highly innovative firms are specific to particular conditions and attempt to identify clusters of firms with common important determinants of innovation. However, the proposed classifications were heavily based on perceptual criteria (such as the risk-taking, proactiveness, entrepreneurial strength and belief in luck) and less on factual measures such as size, industrial sector and common innovation type. There is still a need for the development of more clear-cut factual taxonomies, which could explain the conflicting research results on the determinants of innovation.

2.3) The aim of this paper: Pavitt's taxonomy as an integrative tool.

This paper proposes and tests the applicability of Pavitt's taxonomy (deriving from the economic school of thought) as an effective factual classification that could benefit the management literature searching for the determinants of innovation. Pavitt's taxonomy was selected for the test because it produced firm-classes with similar size, industrial sector and innovation type (the three important moderators causing result-instability in the organisational literature). The author expected that a simultaneous 'control' of all-three moderators would reduce the variation of the innovation determinants within classes and increase the variation across classes.

The research question was whether the rate of innovation and most importantly the differentiating characteristics of the highly innovative firms vary according to the technological trajectory. The following two research propositions were developed:

Proposition 1: 'Science based' and 'specialised supplier' firms have higher rates of innovation[1] than 'supplier dominated' and 'scale intensive' ones.

This proposition had a verification purpose. In a later paper, Pavitt et al. (1989) illustrated that the number of significant innovations, was higher in science based firms (given munificence in underlying technologies) and in specialised suppliers (given continuous pressures to improve production efficiency in user sectors), and was lower in supplier-dominated firms (given lack of in-house technological expertise). The author attempted to confirm these findings for the Greek industry.

[1] The rate of innovation was measured with a multi-indicator as described in section 3.2

Proposition 2: The determinants of innovation differ for firms in different technological trajectories.

This was the main proposition of this paper, aiming to contribute to two streams of thought:

a) The determinants of innovation literature, proposing Pavitt's taxonomy as a solution to the incompatibility of results issue and

b) The further development of Pavitt's taxonomy itself and in broader terms the economic perspective, focusing on a finer level of analysis, the individual firm within each sectoral-class. The identification of class-specific management-related characteristics of highly innovative firms within each class could enrich the theoretical and practical value of the taxonomy.

3. The portfolio model of starting variables

The routines associated with innovativeness are extensive and their strength of association is specific to particular conditions, but they tend to cluster around key themes. Table 2 demonstrates a comparative presentation of models in the literature that attempts to integrate the determinants of innovation. Common classes of factors appear throughout the different models focusing on 'context' (external environment and firm's profile), 'strategy', 'scanning external information' and 'organisational structure'.

Table 2 here

Despite the apparent similarity of integrative models of determinants of innovation at the aggregated level, there is more variety when it comes to operationalisation and empirical testing. The literature includes a large number of individual indicators falling into the above general variable-categories[2]; indeed too many to be incorporated into single questionnaires. Therefore, for practical reasons empirical researchers commonly employed and tested limited sets of potentially important indicators in particular contexts. Duchesneau et al. (1979) suggested that knowledge of the local industry is useful for selecting relevant starting variables. In this study a relatively large portfolio of 58 literature-derived indicators was selected and piloted with 8 senior Greek managers. The variables were categorised in four classes, in line with the integrative models of determinants of innovation reviewed previously (see table 2).

The portfolio model is shown in figure 1. Its presentation that follows covers two types of sources: a) Conceptual works that introduced the general themes and proposed their relationship with firm innovativeness and b) Studies (mainly empirical) that associated innovation rate with specific indicators, within the general themes.

Figure 1 Here

I) Contextual Variables

A number of theoretical perspectives view organisations as adaptive systems and suggest that contextual variables have a causal influence on strategy and structure. Some of these theoretical perspectives are contingency theory (Burns & Stalker, 1961), institutional theory (Parsons, 1966), resource dependence (Aldrich, 1979),

[2] Chiesa et al. (1996) and Souitaris (1999) offered detailed literature-based frameworks of operational indicators.

population ecology (Hannan & Freeman, 1977), and industrial economics (Freeman, 1982). A lively debate has evolved in the literature about the impact of environmental variables (Miller & Blais, 1992). Some schools of thought stress the dominant impact of the environment on the firm's strategy and behaviour (Weber, 1947) where other authors insist that organisations select and even structure their environment (Miller, 1989).

In this study, two types of contextual variables were incorporated in the portfolio model:

a) Firm's profile: The literature associated innovation with factors such as firm's age (Nejad, 1997), growth rate (Smith, 1974), profitability (Mansfield, 1971) and earnings from exports (Calvert et al., 1996).

b) Competitive Environment: There is evidence in the literature that a high rate of change of customer needs and intense competition are associated with highly innovative firms (Miller & Friesen 1984, Khan & Manopichetwattana, 1989a).

II) Strategy-related variables.

The management field views strategy as a network of choices to position the firm vis-à-vis its environment and to design organisational structures and processes. Since the emergence of the notion of corporate strategy in the 1960s, a debate has continued between two main schools of thought, the 'rationalist' school (Ansoff, 1965) and the 'incrementalist' school (Mintzberg, 1987). Porter (1980) made a major contribution to the analysis of innovation in corporate strategy, by explicitly linking technology to 'five forces' driving industry competition. Porter's 'rationalist' approach implies that managers have to analyse the external environment and, based on this analysis, determine a definite course of action. On the other hand, the 'incrementalists' Teece &

Pisano (1994) introduced a ‘dynamic capabilities’ approach to corporate strategy, which underlines the importance of dynamic change and corporate learning.

At the empirical level, Cooper (1984) was one of the pioneers to identify association between corporate strategy and innovation performance. Four subsets of strategy-related indicators were incorporated in the model:

a) *Innovation budget*. The literature indicated that the existence an innovation budget and its consistency during the years are factors related to innovation (Khan, 1990, Twiss, 1992).

b) *Business strategy*. Innovation rate was found to be higher in firms with well-defined business strategy, which included plans for new technology (Rothwell, 1992, Swan & Newell, 1995). Moreover, a well-communicated strategy (to the employees) with a long-term horizon was associated with innovation (Khan & Manopichetwattana, 1989a).

c) *Management attitude*. The literature indicated that top managers of innovative companies have internal ‘locus of control’ as opposed to external. In other words they believe that the company’s performance depends on manageable practices and not on uncontrollable environmental influences (Miller et al., 1982). Moreover, the top managers of innovative firms have a more favourable attitude towards risk (Khan & Manopichetwattana, 1989b) and perceive that the costs of new technology can be actually recouped in a period shorter than widely expected (Eurostat, 1996). Finally, innovative top managers believe that their firm could always perform better than it actually does and therefore there is a ‘performance gap’ which has to be filled in the future (Duchesneau et al., 1979).

d) *CEO's profile,* and more specifically age and status (owner vs. appointed). There is evidence in the literature that younger CEO's who also own the firm are more keen to innovate (Khan & Manopichetwattana, 1989b).

III) External Communications.

Various authors have found that acquiring and scanning information was positively associated with innovation (Tidd et al, 1997). Three subsets of innovation-related communications variables were incorporated in the model.

The first subset includes factors related to *communication with the firms' stakeholders* namely:

a) Customers: meeting them individually in person (Maidique & Zinger 1984, Rochford & Rudelius 1992, Chiesa 1996), discussing with them in panels (Chiesa et al., 1996), getting feedback through the post or telephone (Chiesa et al., 1996), or communicating with the broader customer base using quantitative market research (Khan & Manopichetwattana, 1989b).

b) Suppliers of machinery and equipment: (Duchesneau et al., 1979, Rothwell, 1992).

The second subset includes factors related to the *collection and scanning of information* from various sources such as public agencies (Carrara & Duhamel, 1995) and other firms (Alter & Hage, 1993, Bidault & Fiscer 1994). There are also more indirect ways of collecting innovation-related information including membership of professional associations (Swan & Newell, 1995), subscription to scientific and trade journals (Khan & Manopichetwattana, 1989b), attendance at trade fairs (Duchesneau et al., 1979), access and use of the internet, and use of electronic patent and research databases to search for new technology. The existence of a technology gatekeeper (a person who has a formal role to search for information on new technology) is another literature-derived determining variable (Allen, 1986; Rothwell, 1992). Finally, monitoring the competitor's activities can be a very useful way to identify crucial information (Chiesa et al., 1996).

The third subset goes beyond the collection of information and refers to the *co-operation of the firm with third parties* such as universities and research institutions (Bonaccorsi & Piccaluga, 1994, Lopez-Martinez et al., 1994); public and private consultants (Pilogret, 1993, Bessant & Rush, 1995); other firms in the form of joint ventures (Rothwell, 1992, Alter & Hage, 1993, Swan & Newell, 1995) or licensing (Lowe & Crawford, 1984); and financial institutions as a source of venture capital (EUROSTAT, 1996). The absorption of public technology funds is another potential determinant of innovation (Smith & Vidvey. 1992).

IV) Variables related to the 'organisational context'.

Organisational attributes are sometimes seen as the dominant influence of behaviours. Some classical schools of thought which emphasise the dominance of structural factors are bureaucracy theory (Weber, 1947), classical management (Gulick & Ulrick, 1938) and organisational sociology (Blay & Schoenherr, 1971). A double causality seems to be at work. Some schools observe that structural factors may thwart or stimulate innovation. Others argue that structure can be modified as a function of strategy to enhance the innovative potential of firms (Miller & Blais, 1992).

The organisational competencies incorporated in the portfolio model were grounded in the empirical literature and classified in 6 subsets.

a) *Technical competencies*. The intensity of R&D (Ducheneau et al., 1979; Ettlie et al., 1984) and the intensity of quality control (Rothwell, 1992; Zairi, 1996) were strongly associated with innovation.

b) *Market competencies*. Cooper (1984) and Maidique & Zinger (1984) associated innovation with an effective marketing programme and a broad distribution system, which can access distant markets.

c) *Education of personnel*. Highly educated and technically qualified staff was found to be more receptive to innovations (Carter & Williams, 1957, Nejad, 1997). Miller and Friesen (1984) suggested that the use of technocrats increased the production of innovative ideas.

d) *Breadth of experience of personnel*. A high proportion of employees with managerial responsibilities was related to the adoption of innovations (Becker & Stafford, 1967). Additionally, it has been argued that organisations whose staff have more diverse backgrounds (such as experience in other companies and/or abroad) will be more receptive to innovation, as their staff can generate a wider range of innovative suggestions (Carroll, 1967).

e) *Training*. Hage & Aiken (1970) and Dewar & Dutton (1986) presented evidence that knowledge depth, measured by the extent of professional training, was associated with innovation. On-the-job training was also associated with innovation by contemporary authors such as Swan and Newell (1995) and Nejad (1997). The latter distinguished two types of training: professional training given to the firm's engineers and managers and technical training offered to the production employees.

f) *Internal 'process' variables*. The literature indicated that innovative companies are less formalised than their non-innovative counterparts (Cohn and Turin, 1984). Also the 'slack' time (or thinking time) of engineers and managers can improve the business innovative performance (EUROSTAT, 1994). The literature also emphasised the need for cross-functional interdisciplinary teams, to ensure that customer needs remain the focus of R&D activity and that new products proposed by marketers can be efficiently and reliably manufactured. (Hise et al., 1990; Cooper, 1990, Clark and Fujimoto, 1991).

The presence of a ‘project champion’ was recognised by several authors as a crucial factor favouring innovation (Cooper, 1979 and Rothwell, 1992). The project champion is an individual who enthusiastically supports an innovation project and who is personally committed to it (Scon, 1973). A large number of authors, such as Burns & Stalker (1961), Rogers & Shoemaker (1971) and Rothwell (1992), have also identified an association between internal communication and technological innovation. Finally, authors such as Felberg & DeMarco (1992), Twiss (1992) and Chiesa et al. (1996) have argued that circulating new ideas and offering incentives to the employees to generate their own ideas enhances innovation potential.

The measures of the variables of the portfolio model were drawn from the literature and included both ratio measures and Likert scales. It is worth stressing again that the model of this study was not intended to be exhaustive. The factors that can be related to innovation are numerous and possibly changing over time as management practice is a dynamic process. The aim of this paper was not to offer a ‘complete guide’ to the determinants of technological innovation, but instead to test the applicability of 58 widely acknowledged factors for the different technological trajectories of the Greek industry.

4. Methodology

4.1) Research design

A sample of 105 companies was employed for the study's empirical test, representing almost 3% of the population of listed Greek manufacturing firms (the most accurate list of Greek manufacturing was the ICAP annual directory - ICAP, 1997- including 3600 firms). One respondent from each company completed a questionnaire during a face-to-face interview. A "snowballing" sampling technique was used: at the end of each interview the researcher was recommended to other managers who could be business partners, customers, suppliers or personal friends of the respondent. Despite the fact that the research was not based on a strictly defined random sample, the companies were chosen in a way that simulated random selection, according to whether someone in their firm happened to know a previous respondent. Therefore, the sample was not confined to one industrial sector or a vertical channel of trade but it was expanded to various industries, due to the complex web of personal networks that are dominant in Greek management culture (see following table 3).

Table 3 here

A chi-square test proved the sectoral representativeness of the sample, as the calculated actual chi-square value of 28.1 was lower than the critical chi-square value of 31.4 for 20 degrees of freedom, at 0.05 level of significance.

Pavitt (1984) gave detailed indicators for classifying firms into the technological trajectories (presented in table 1), namely the industrial sector, the source of technology, the type of user of technology, the means of appropriation, the relative balance between product and process innovation, the relative size of the firm and the intensity and direction of technological diversification. The 105 firms in the sample were classified according to the above indicators. The required information was collected from the respondents during the interviews. It could be argued that the classification was somewhat subjective and arbitrary, as the indicators were qualitative in nature. However, Pavitt's table was detailed enough to give a clear-cut decision in the majority of the cases. The classification gave the following results:

a) 56 firms were 'supplier dominated'. This sub-set of the sample, representing the majority of the Greek industry, included companies from a variety of traditional sectors such as food products, beverages, textile products, garments-underwear-accessories, tobacco, furniture, metal products and structures, footwear-leather goods, rubber and plastics, and paper and products.

b) 23 firms were 'scale intensive' coming from bulk material sectors such as petroleum and coal, non-metallic minerals, primary metal products, liquefied gas bottling and transportation means.

c) 15 firms were 'specialised suppliers' coming mainly from machinery and engineering.

d) 11 were 'science based' representing sectors such as chemicals, medicines, cosmetics, electrical and electronic equipment.

4.2) On the measurement of the rate of technological innovation

Several authors such as Tidd et al. (1996) have suggested that the rate of innovation of a company could vary substantially depending on the innovation measure used. Saviotti and Metcalfe (1984) argued that multi-indicators of innovation can offer a better understanding of innovation performance, shedding light on the problem from different angles and overcoming the incompleteness of the individual measures. In this study, the rate of innovation was measured with 7 variables drawn from the OECD's 'Oslo Manual' (1992):

1. Number of incrementally innovative products introduced in the last 3 years.

2. Number of radically innovative products introduced in the last 3 years. The decision on whether a new product was incrementally or radically innovative was left to the respondents and was based on clear definitions from OECD's Oslo manual (1992).

3. Number of innovative manufacturing processes introduced in the last 3 years.

4. Percentage of current sales due to incrementally innovative products introduced in the last 3 years.

5. Percentage of current sales due to radically innovative products introduced in the last 3 years.

6. Expenditure on innovation in the last 3 years over current sales (including R&D funding and capital expenditure on innovative manufacturing processes).

7. Number of patents acquired in the last 3 years (from Greece, Europe or the US)

The problem with multi-indicators is that they cannot offer an overall measure of innovation rate, as the partial variables are not directly comparable. The author attempted a methodological step in the innovation research and developed a combined proxy measure of innovation by standardising the seven individual measures and summing their standardised values. A standardised value was calculated by deducting the mean value from the observation-value and then dividing the difference by the standard deviation of all observed values. In simple terms, it measured the distance of each observation from the mean value in numbers of standard deviations. The standardisation is a statistical transformation that allows for comparison of heterogeneous variables (Norusis, 1994). Adding the 7 standardised variables in order to find ZTOTAL, implied that equal weighting were given to each of the individual measures for the calculation of the combined one. There was no obvious reason to favour one or other of the measures by giving them higher weighting, as all of them had strong and weak points (Hansen, 1992, Souitaris, 1998) and their 'predictive power' could not be quantified. As a result of the transformation, the ZTOTAL results were dimensionless.

4.3 Quantitative analysis

In the first phase of the analysis, the one way analysis of variance (ANOVA) was employed to test whether different trajectories had statistically significant differences between their means for any of the 7 partial innovation measures. The Duncan test (multiple comparison procedure) was used to specify pairs of trajectories with different means.

The second phase of the analysis was devoted to identifying association between the combined innovation measure ZTOTAL (dependent variable) and the potential determinants of the portfolio model (independent variables), within each of the four subsets of the sample. Pearson correlation coefficients were calculated between ZTOTAL and each one of the 58 determining variables.

4.4. Methodological limitations

There were two main methodological limitations of the empirical test:

a) The size of the sample (105) was small, particularly considering its subsequent classification into 4 groups. Multivariate stepwise regressions have been attempted, but with 27 independent variables and small sample sizes for the specialised-supplier (15) and science-based firms (11), the R-squares were too high and the results probably spurious. Consequently, the author decided to base the test on “indicative” Pearson correlation coefficients rather than causal multivariate analysis [3].

b) The fact that the firms were Greek might have influenced the results of the empirical test. The cultural and business environment in which a firm operates could also be a moderator of the determinants of innovation (Moenaert et al, 1994; Souitaris, 2001) and these ‘national effects’ are not captured by Pavitt’s taxonomy.

Therefore, this paper’s empirical work is an exploratory test of the proposition of different determinants in each trajectory, offering some hints on what these different determinants might be. It is not an absolute and final test aiming to confirm the exact determining variables for each trajectory.

5. Results and discussion

5.1) Differences in the innovation rate between trajectories (proposition 1)

Table 4 shows a comparison of means of the innovation rate variables for the four different trajectories. Table 5 presents the ANOVA and Duncan tests for the comparison of means of the above variables.

Tables 4 and 5 here

Important observations include:

The means of the innovation rate variables differed for different trajectories. Five out of the seven innovation measures had high F ratios in the ANOVA test and at least one pair of trajectories with statistical significant difference in the means (Duncan test).

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[3] The author would like to thank one anonymous referee for this suggestion

The ranking of the trajectories was the same for the number of incremental and radical products. Science-based firms produced the highest number of innovative products (incremental and radical), followed by the specialised suppliers. The other two sectoral trajectories produced far fewer innovative products with scale intensive firms having the lowest number. The order was also similar for the mean sales from incrementally and radically innovative products. This time the specialised suppliers had the highest percentage followed by the science based firms. The rest of the groups lagged behind.

The science-based firms had by far the highest mean number of patents, which would be expected since they belong to high technology sectors like pharmaceuticals and chemicals. Concerning the mean number of innovative processes and the mean ratio of investment over sales, there were no statistically significant differences in the groups. It was interesting, however, to note that the specialised suppliers had the lowest mean number of innovative processes (as they focus on product innovation) and the highest ratio of investment over sales (relatively high investment on innovation with relatively small size and sales).

Generally, the analysis indicated clearly that the science-based and the specialised supplier firms had higher rates of innovation than the supplier dominated and the scale-intensive. Therefore, the first research proposition was supported. The results did not indicate significant differences between the two ‘high-innovation’ trajectories (specialised suppliers and science-based firms), or between the two ‘low innovation’ trajectories (supplier-dominated and scale-intensive firms).

5.2) Differences in the innovation determinants between trajectories (proposition 2)

The results of the correlation analysis for each of the four trajectories are presented in tables 6 to 9.

Tables 6 – 9 here

In general, the significantly correlated variables were different for the four trajectories. Only five variables were associated with innovation in more than one sectoral class. Some observations from these results are as follows:

I) For *supplier dominated firms* (table 6) five types of factors proved important:

a) The competitive environment was particularly influential. The perception of intensity of competition and rate of change of customers' needs were both significantly correlated with innovation rate.

b) From the strategy-related variable group only two were relevant: the inclusion of new technology plans in the business strategy and the attitude towards risk. It was interesting that these variables had relatively low mean averages for the trajectory as a whole. In other words, the average supplier-dominated firm developed only short-term strategy and was risk averse. It appears that the innovative companies were those which used, to a higher extent, generally uncommon practises.

c) A significant number of external communication variables was associated with innovation rate - (consulting with panels of customers and suppliers of equipment; using market research; acquiring information from public agencies; having international contacts and monitoring the competitors) - indicating the importance of information for supplier-dominated firms.

d) Strength in marketing was also highly correlated to innovation rate.

e) Internal co-ordination proved particularly important. Formal internal communication and the existence of interdepartmental teams working on innovation projects were both associated with innovation rate.

Overall, the critical determining variables for this trajectory (competitive environment, external communication and marketing), indicated that the innovative supplier-dominated firms were market rather than technology driven.

II) Innovation in *scale intensive firms* was associated with three types of factors (see table 7)

a) The ability and willingness to finance innovative projects (co-operation with financial institutions, growth rate of profits, existence of an innovation budget).

b) The education of personnel (proportion of staff with a university degree and engineering or science degree).

c) The breadth of experience of personnel (proportion of staff with a managerial responsibility, proportion of engineers-scientists-managers with experience in other companies and abroad).

The above findings appear logical as the scale intensive firms tend to introduce expensive and technologically complicated process innovations (Pavitt, 1984). Therefore, they need investment capital and skilled personnel to implement them.

III) For *specialised suppliers:*

a) The factor with the highest association with innovation rate was growth rate in size (table 8). This finding could be explained by the fact that specialised suppliers were small manufacturers of machinery and instruments based on innovation and product customisation. For such firms, innovation brings success and growth.

b) Earnings from exports were also associated with innovation. It seems that the Greek ‘business’ markets were too small for innovative specialised suppliers.

c) Variables related to employee-motivation and development proved important (the presence of a project-champion, training for engineers and managers, and incentives to employees for contribute towards new ideas). Several respondents from specialised supplier firms reported during the interviews that they rely very much on their employees’ initiative and talent.

d) Searching for technology-ideas was also relevant (use of databases to search for new technology, co-operation with universities and research institutions). The findings appear logical, as specialised suppliers need technological input for the in-house design and development of innovative capital goods.

e) The importance of the definition of business strategy could be related to the fact that most of the specialised suppliers were small firms and their strategy was clear only in the mind of the owner-manager. A well-defined strategy distinguished the more innovative ones.

IV) For *science-based* firms (table 9) the important determinants of innovation were:

a) ‘Technology-related’ attitudes and practices (favourable attitude towards technology pay-back period and licensing) which seem logical considering the profile of the sectoral-class.

b) Growth rate of profit. The importance of this variable could be explained by the critical role of R&D (a generally expensive activity) for the innovation of science-based firms.

b) Education and experience of personnel (proportion of university graduates and engineers/ scientists and proportion of engineers and managers with experience abroad). These findings are also logical, as education and experience are important requirements for understanding and developing in-house technology.

c) Feedback from panels of customers. This result confirms earlier findings by Von-Hippel (1986, 1988) on the importance of lead-users in the innovation process of high-technology firms.

In general, different factors proved important for different trajectories. The only slight similarity was between the profile of scale-intensive and science-based firms, regarding the importance of education, the experience of personnel and profitability growth. A possible explanation could be the similarity between the profiles of these two groups as described by Pavitt, regarding their need for internal R&D and for high-cost innovations. However, this similarity could not justify a claim that the innovation determinants in the two trajectories were identical. Based on the above analysis of the results, the researcher accepted the study's second proposition that determinants of innovation differ for firms in different technological trajectories.

6. Conclusions

The main theoretical contribution of this study is the positioning of Pavitt's taxonomy as an integrative tool, bridging two distinct literature streams - the economic and management studies on technological innovation. To highlight this point, the author will return to these literatures to briefly revisit their main arguments and current progress.

The empirical economic literature searched for factors increasing ‘R&D intensity’. Economic researchers have concentrated on ‘industry-level’ factors (Cohen, 1995), such as firm-size and market structure (the ‘Schumpeterian’ view), market size and growth in demand (Schmookler, 1966) and -since the 1980s- technological opportunity and the ability to appropriate returns from new developments (e.g. Levin et al. 1987). Pavitt was in line conceptually and chronologically with the latter school of thought, basing the taxonomy on ‘technological regime’ variables. Cohen (1995) demonstrated with a detailed review of empirical literature in the economic tradition, that despite the consensus about the fundamental importance of ‘industry-level’ conditions, there is much less research and consensus on variables that distinguish firms within industries.

“*In comparison to our understanding of the influence of industry-level variables, our understanding of that of firm-level variables is more primitive still. Economists could still profitably refine empirical analyses of the role of easily measured firm characteristics such as cash-flow. There is, however, particular need to identify and analyse the effects of other less readily measured characteristics…*” (Cohen, 1995)

On the other hand, the management literature has studied the effect of such firm-specific characteristics on innovation[4], but with rather inconsistent results. The problem with this literature stream was the persistent attempt by researchers to generalise on the extent of association of firm-specific variables with innovation, underscoring, or just ignoring, the moderating effects of ‘industry-level’ conditions. Despite the acknowledgement by the literature (Khan & Mannopichetwattana, 1989b; Wolfe, 1994; Souitaris, 1999) of ‘moderating conditions’ such as the size of the firm, the industrial sector and the type of innovation involved, there was not enough comparative research contrasting the important determinants in different settings.

In 1999 a retrospective evaluation of Research Policy stated that the journal has accepted the major differences with respect to innovation in various sectors (recognised by Nelson and Winter, 1977 and Pavitt, 1984) and has published research in individual sectors and in multi-sector samples. A careful investigation of Research Policy revealed that apart from the SAPPHO study in the 70s (Rothwell, 1974 - chemicals vs. scientific instruments), there are no recent studies comparing sectors directly, using a variance methodology [5]. The determinants of innovation theme (variance approach) is still current but the studies either group industries together (e.g. Bughin & Jacques 1994; Baldwin & Johnson, 1996) or focus on one industry (e.g. Lee, 1995; Lal, 1999).

This paper has attempted to fill this gap, linking the economic and the management literature streams. The exploratory empirical test in Greece supported the research proposition that the important determinants of innovation differ in the four classes of Pavitt's taxonomy. Therefore, the study contributed to:

a) The economic perspective: Pavitt's taxonomy was developed further incorporating issues discussed in the management literature. Pavitt offered industry-level characteristics to cluster firms into wide sectoral-classes. This paper extended the argument and identified firm-level characteristics distinguishing the highly innovative firms within each class.

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[4] It is interesting to note that the dependent variable in the management literature was not the 'R&D intensity' (an input measure), but to the rate and success of innovation (output measures).

[5] There are comparative studies using a dynamic 'process' methodology such as Swann & Prevezer (1996) comparing the dynamics of industrial clustering in computing and biotechnology

b) The management perspective: Pavitt's taxonomy (derived from the economic literature) proved a useful tool to simplify the problem of multi-dimentional moderation, which management scholars faced. Size, industrial sector and type of innovation could be 'collapsed' into a single, general dimension: the 'technological trajectory'.

The author proposes a 'two-step' methodology to identifying the distinguishing characteristics of innovative firms in the future:

a) A classification of firms according to 'industrial-level' moderators. Pavitt's taxonomy has a high practical value at this level. It conveniently aggregated 'industrial-level' factors, producing four sectoral firm-classes, rather than a long list of sectors.

b) Identification of a set of management-related determinants of innovation specific to each sectoral class. In practice, Pavitt's typology offers the opportunity to customise innovation questionnaires and measure the right 'type' of variables according to the firm's class.

The empirical study in Greece was an exploratory test of this methodological approach. Despite the relatively small sample size and the uncertainty over the external validity of the results, the test offered some indication of the type of variables that are associated with innovation within each sectoral class.

Determinants of innovation for 'supplier dominated' firms were related to the competitive environment, strength of marketing, acquisition of external information, inclusion of technology plans in the business strategy, attitude towards risk and internal co-ordination. For 'scale intensive firms' the important variables were related to the ability to finance innovation projects and with the education and experience of personnel. The innovative 'specialised suppliers' firms had high growth rate and exports and were offering training and incentives to their employees to contribute towards new ideas. Also, important variables for this class were related to the search for technology ideas and with the definition of the business strategy. For the 'science based' firms important determinants of innovation included technology-related variables, education and experience of personnel, growth rate in profit and panel discussions with customers.

The author calls for more comparative empirical research in this direction in different contextual settings and with large samples, which can confirm and potentially finalise the important determining variables for each trajectory.

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Table 2: A comparison of 'integrated' models of determinants of innovation

D. Miller (1984)	Khan & Manopichet--wattana (1989)	R. Miller & Blais (1992)	Rothwell (1992)	Tidd, Bessant & Pavitt (1997)	Portfolio for Greek firms
Environment	Competitive Environment	Context	Corporate conditions		***Context***
	Firm's profile				
Decision Making	Strategy Entrepreneurial Attitudes	Strategy		Strategy[6]	***Strategy***
	Functions	Process	Tactical variables	Implementation mechanisms	***External communications***
Information processing				External communications	
Structure	Structure	Structure		Organisational context	***Organisational context***

Table 3 Sectoral comparison of companies in the sample and the population

Sector	**n sample**	**n population**	**% sample**	**% population**
Food and beverages	29	686	27.62	19.06
Tobacco and products	2	31	1.90	0.86
Textiles	9	331	8.57	9.19
Wearing apparel and fur	6	336	5.71	9.33
Footwear-leather goods	1	71	0.95	1.97
Wood-cork products	1	69	0.95	1.92
Pulp, paper and products	2	87	1.90	2.42
Publishing, printing	3	242	2.86	6.72
Coke, refined petroleum products	2	20	1.90	0.56
Chemicals	7	153	6.67	4.25
Pharmaceuticals	4	90	3.81	2.50
Rubber-plastics	4	221	3.81	6.14
Non metallic mineral products	5	377	4.76	10.47
Basic metals	2	34	1.90	0.94
Fabricated metal products	10	277	9.52	7.69
Machinery	8	129	7.62	3.58
Electric appliances	2	58	1.90	1.61
Electronic equipment	3	92	2.86	2.56
Transportation means	1	84	0.95	2.33
Furniture	2	104	1.90	2.89
Miscellaneous	2	108	1.90	3.00
Total	105	3600	100	100

[6] Contextual variables included in the 'strategy' theme

Table 4: Comparison of means of innovation output measures in the different sectoral classes

Sectoral class		Mean of incrementally innovative products	Mean of radically innovative products	Mean of innovative manufacturing processes	Mean of patents
1	Supplier dominated	5.89	2.16	6.09	0.71
2	Scale intensive	3.91	0.87	6.52	0.26
3	Specialised suppliers	15.40	6.53	4.07	1
4	Science based	28.09	10.82	8.91	14.54

Sectoral class		Mean of sales due to incrementally innovative products	Mean of sales due to radically innovative products	Mean of investment on innovation over sales
1	Supplier dominated	17	13.25	.3507
2	Scale intensive	23	9.54	.1343
3	Specialised suppliers	54	27.33	1.5419
4	Science based	48.18	18.64	.1329

Table 5: ANOVA and Duncan Tests for comparison of means of innovation output measures in the different sectoral classes

ANOVA STATISTIC	Mean of incrementally innovative products	Mean of radically innovative products	Mean of innovative manufacturing processes	Mean of patents
F ratio	4.3537	3.7624	0.3610	7.1245
F probability	0.0063	0.0131	0.7813	0.0002
Duncan test: significant differences in means of groups	1 and 4 2 and 4	1 and 4 2 and 4	None	1 and 4 2 and 4 3 and 4

ANOVA STATISTIC	Mean of sales due to incrementally innovative products	Mean of sales due to radically innovative products	Mean of investment on innovation 1993-96 over sales 1996
F ratio	11.6127	2.0216	1.5890
F probability	.0000	0.1156	0.1969
Duncan test: significant differences in means of sectoral classes	1 and 3 1 and 4 2 and 3 2 and 4	2 and 3	None

Table 6: Significantly correlated independent variables to the combined-standardised innovation measurement Ztotal for the **supplier dominated firms**

Variable	Pearson's Correlation Coefficient[7]
Perception of intensity of competition	0.4760**
Inclusion of new technology plans in the business strategy	0.4290**
Perception of rate of change of customer needs	0.4139**
Strength in marketing	0.3784**
Acquiring information from public agencies	0.3527**
Use of market research	0.3456**
Interdepartmental teams working on innovation projects	0.3196*
Consultation with panels of customers	0.3015*
International contacts	0.2996*
Consultation of suppliers of equipment	0.2907*
Monitor the competitors	0.2845*
Formal internal communication	0.2751*
Management attitude towards risk	-0.2705*

Table 7: Significantly correlated variables to Ztotal for the **scale intensive firms**

Variable	Pearson's Coefficient
Co-operation with financial institutions (borrowing for R&D)	0.6189**
Proportion of staff performing a managerial role	0.5904**
Existence of innovation budget	0.5654**
Proportion of staff with engineering or science degree	0.5182*
Proportion of engineers-scientists-managers with experience in another company	0.4929*
Growth rate of profits	0.4899*
Proportion of staff with a university degree	0.4605*
Proportion of engineers-scientists-managers with experience abroad	0.4541*

Table 8: Significantly correlated independent variables to Ztotal for the **specialised supplier firms**

Variable	Pearson's Coefficient
Growth rate of size	0.8803**
Existence of project champion	0.8606**
Earnings from exports	0.7283**
Intensity of training of engineers and managers	0.6359*
Intensity of use of databases to search for new technology	0.5677*
Incentives for the employees to contribute towards new ideas	0.5645*
Definition of business strategy	0.5618*
Intensity of co-operation with universities and research institutions	0.5363*

[7] For all correlation tables:
*   indicates a correlation coefficient with a two tailed observed significance level less than 0.05
** indicates a correlation coefficient with a two tailed observed significance level less than 0.01

Table 9: Significantly correlated independent variables to Ztotal for the **science based firms**

Variable	Pearson's Coefficient
Attitude towards new technology pay-back period	0.8513**
Growth rate of profit	0.8155**
Proportion of staff with engineering or science degree	0.8058**
Licensing	0.7741**
Consultation with panels of customers	0.7307*
Proportion of staff graduated from a university	0.7193*
Proportion of engineers-scientists-managers with experience abroad	0.6875*

Figure 1: The portfolio model of determinants of innovation *

Contextual variables

Firm's Profile
- years of operation
- growth rate of size
- growth rate of sales
- growth rate of profits
- earnings from exports

Competitive environment
- perception of rate of changing customer needs
- perception of intensity of competition

External communications

Communication with the stakeholders
- consultation with customers in person
- consultation with panels of customers
- feedback from customers through post or phone
- consultation of suppliers of raw materials
- consultation of suppliers of equipment
- use of market research

Networking - Scanning external information
- acquiring information from public agencies
- exchange information with other domestic firms
- international contacts
- membership of professional associations
- subscription to scientific and trade journals
- attendance of trade fairs
- access and use of the world wide web
- use databases to search for new technology
- existence of technology gatekeeper
- monitoring the competitors

Co-operation with external organisations
- universities and research institutions
- public and private technology consultants
-Other firms (joint R&D projects)
-Licensing
-financial institutions (borrowing for R&D)
-absorption of public technology funds

Rate of technological innovation

Strategic variables

Innovation budget
- existence of an innovation budget
-consistency of the innovation budget

Business strategy
- definition of the business strategy
- communication of the business strategy
- inclusion of new technology plans in the strategy
- horizon of the strategy

Management attitudes
- locus of control
- attitude towards risk
- attitude towards new technology pay-back period
- perception about performance gap

CEO's profile
- age
- owner vs. Appointed

Organisational Competencies

Technical competencies
- intensity of R&D
- intensity of quality control

Market competencies
- strength in marketing
- breadth of distribution system

Education of personnel
- proportion of staff with a university degree
- proportion of staff with engineering or science degree

Breadth of experience of personnel
- proportion of staff performing a managerial role
- proportion of engineers-scientists-managers with experience in another company
- proportion of engineers-scientists-managers with experience abroad

Training of personnel
- intensity of training of engineers and managers
- intensity of training of production employees

Internal Processes
- degree of formalisation
- slack (thinking) time of engineers and managers
- interdepartmental teams working on innovation projects
- existence of project champion
- extent of formal internal communication

Adopted from Souitaris (2002)

Table 1: Sectoral technological trajectories (source Pavitt, 1984)

		Determinants of technological trajectories			Technological trajectories	Measured characteristics			
Category of firm	Typical core sectors	Sources of technology	Type of user	Means of appropriation		Source of process technology	Relative balance between product and process innovation	Relative size of innovating firms	Intensity and direction of technological diversification
Supplier dominated	Agriculture; Housing; Traditional manufacture	Suppliers, Research extension services, big users	Price sensitive	Non-technical (trademark, marketing, advertising, aesthetic design)	Cost-cutting	Suppliers	Process	Small	Low vertical
Scale intensive	Bulk materials (steel glass); assembly (consumer durables & autos)	PE suppliers; R&D	Price sensitive	Process secrecy and know-how; technical lags; patents; dynamic learning economies	Cost-cutting (product design)	In-house; Suppliers	Process	Large	High vertical
Specialised suppliers	Machinery; Instruments	Design and development users	Performance sensitive	Design know-how; knowledge of users; patents	Product design	In-house; Customers	Product	Small	Low concentric
Science based	Electronics/ electrical; chemicals	R&D; Public science; Product engineering department	Mixed	R&D know-how; patents; process secrecy and know-how; dynamic learning economies	Mixed	In-house; Suppliers	Mixed	Large	Low vertical; High concentric