INNOVATION AND TECHNOLOGY TRAJECTORIES IN A DEVELOPING COUNTRY CONTEXT: EVIDENCE FROM A SURVEY OF MALAYSIAN FIRMS

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INNOVATION AND TECHNOLOGY TRAJECTORIES IN A DEVELOPING COUNTRY CONTEXT: EVIDENCE FROM A SURVEY OF MALAYSIAN FIRMS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

This thesis investigates the relevance of currently used firm-level innovation concepts in a developing country context. I draw on the results of a comprehensive survey of manufacturing and service firms instrumented to assess the knowledge-capabilities of the economic sectors in Malaysia. The thesis presents a discussion of the extant literature on firm-level innovation and tests hypotheses regarding the impact of firms' organizational structure, strategies, resources and environment as determinants of product, process and organizational innovations. These are examined from the classifying framework provided by Keith Pavitt's model of technology trajectories to better understand the nature of innovation and its production determinants. I find that Malaysian firms -- across all sectors -- show a greater propensity to make process and organizational innovations as against product innovations. Soft factors like training, knowledge management practices and collaboration with market actors are used as significant inputs in their innovation process.

CHAPTER 1

INTRODUCTION

It is now a commonplace that the competitive advantage of nations and their resident firms is derived not so much from their size, labor or capital assets *per se* but from the ability to continuously harness these endowments to innovate. The notion of the knowledge-based economy is derived from the existence of innovative organizations that mobilize a variety of factor inputs to create new products, processes and services (Tidd, et al., 2001). As developing countries focus their efforts on transitioning to knowledge economies and developed countries on furthering their relative position, creating and managing innovation has become a prime concern of public policy. This thesis presents an empirical analysis of the determinants of innovation in a developing country context. I tap on the results of a comprehensive survey of Malaysian firms to investigate their knowledge and innovative abilities. The data is rich in its coverage of firms' business practices during the period 2000-2002 and allows an analysis of both manufacturing and service sector establishments.

My effort is organized as follows. Chapter 2 presents a survey of the extant literature on various innovation determinants. I also review work on the idiosyncrasies of innovation as a function of sectoral conditions and in developing-country settings. Chapter 3 describes the dataset I use, focusing on various aspects of innovation and presents an extension of Pavitt's model of technology trajectories. This sets the stage for Chapter 4, where I hypothesize and test the impact of various explanatory variables on product, process and organizational innovations. By using iterative logistic regression models, I examine if firms from different technology classes use inputs to innovation differently. Chapter 5 concludes with a discussion of main findings and their implications for public policy. The thesis adds to the body of empirical work on firm-level innovation dynamics. More specifically, it is intended to contribute towards a sectoral understanding of innovation in a developing country setting.

CHAPTER 2

WHAT DO WE KNOW ABOUT INNOVATION? A LITERATURE REVIEW

This chapter surveys the relevant literature on firm-level innovation studies with an objective of summarizing the state of the art. While the effort can by no means be complete and comprehensive, I attempt to synthesize economic, business and the more recent National Innovation Systems literature to arrive at a portfolio of potential innovation determinants that are used in the development of my hypotheses.

2.1 The measures and means of innovation

Schumpeter (1934) distinguishes between *invention*, the generation of new knowledge, and *innovation*, the entire process by which new knowledge is generated and diffused into the market. Innovation is hence a broader concept that is seeded by invention and dispersed by successful commercialization. Innovation can be a new product, process, raw material, market or industrial organization. The Oslo Manual (OECD, 1997) recognizes the *technological innovation* of products and processes as covering methods that change a firm's actions, and *organizational innovation* as the introduction of changes in organizational structure, implementation of advanced managerial techniques and implementation of changes (Jaramillo et al, 2001). A firm might choose to compete by developing new products, processes, organizations or a combination of the three. While new products are cutting edge and provide innovating firms the advantage of first mover, process innovations provide strategic and cost advantages to the innovators. As Tidd et al (2001) note, the success of the Japanese automobile firms during the late twentieth century was mostly derived from process innovations. Similarly successful service sector firms -- not constrained by having to produce tangible goods -- continuously and rapidly incorporate new ideas in their organization to provide better, faster, higher quality service to customers (Stigler, 1956).

Ideas or new knowledge are embedded in new products, processes or routines (OECD, 1996b). Patents provide direct, public and verifiable evidence of the existence of a new and non trivial invention. Hence, patents are both a good proxy as well as "correlate indicators" of useful inventions (Jaffe, 1999). Coombs, et al. (1996) provide a good summary of the innovation measurement problem in their advocacy of Literature-based Innovation Output indicators (LBIO). Specifically, the authors criticize the use of patents as innovation output indicators since they only indicate inventions or mere technical activity. Also, the most significant technological advances may not even be patented, since patenting is a discretionary activity and companies resort to other methods to protect their competitive advantage. Still, the number of patents has been widely used by economists because of reasons ranging from their ease of use to availability of associated information in aggregate form (Pavitt, 1985; Trajtenberg, 1987; Griliches, 1990). However, surveys of firms remain the most consistent method to systematically collect information about different kinds of innovation, since patents discount or completely ignore process and organizational innovations (Archibugi, 1992). Moreover, such surveys are useful in simultaneously capturing information about other factors related to innovations like firm employment, ownership, size and other relevant financial and business details (Roper and Love, 2002).

(a) Firm Size

The relationship between firm size and innovation has generated one of the largest yet most inconclusive bodies of literature in innovation studies. The opposing poles of thought in this school can be summed up in two words. *Schumpeter* (1934) and *Schumpeter* (1950). The first Schumpeterian regime (colloquially referred to as Mark 1; more formally as the theory of *creative destruction*) posits a model wherein innovation is a highly competitive process and the dynamism is best captured by small, new firms which continuously displace incumbent firms at the frontiers of technology (Malerba, Orsenigo and Peretto, 1997). However, in his second coming, Schumpeter envisions a dominant role for large firms which continuously innovate, drawing from their pool of cumulative knowledge and acquired technological capabilities over time (the *creative accumulation* or Mark 2 school of thought). The issue has not seen a conclusive settlement with various theoretical and empirical studies providing arguments and evidence advancing both sides.

Among the arguments that large firms are more innovative and successful are natural economies of scale and scope of investments. Large firms have superior access to finance and ability to spread risk in diverse portfolios (Holmstrom; 1989). Other supporting functions to develop and commercialize innovations are better developed in the large firms (Cohen, Levin, & Mowery; 1987). Recent empirical studies show that the number of innovations per dollar of R&D is inversely related to firm size, and that the contribution of smaller firms to innovations is often understated (Bound et al 1984; Acs & Audretsch, 1988, 1991a; Cohen & Klepper, 1996). Small firms have also been shown to be more efficient in their use of capital and labor resources in producing innovation

(Acs & Audretsch, 1991b). Besides, small firms are more likely to participate in the market for technologies (Hicks, et al. 2003). In an attempt to reconcile the contradicting view points over the question of size, Nelson and Winter (1982) argue that both possibilities can be true. Circumstances that favor small firms over large firms are generated by a mix of factors specific to the nature of the industry they operate in.

(b) Research and Development Expenditures

Studies linking the size of organizations to innovation are based on an analysis of Research and Development inputs and outputs of firms in one form or the other. The issue of scale and returns to capital were primary to early economists and hence the focus on Research and Development investments. Pakes and Griliches (1984) were among the foremost to operationalize a production function for knowledge to formally estimate the causal dependence of knowledge outputs on knowledge inputs. Since outputs of innovation activity were not directly observable, Pakes and Griliches used the count of patents assigned to firms as a proxy for knowledge capital. A cumulated value of lagged and current Research and Development investments was used as the key explanatory variable. A chief problem of the Pakes-Griliches *Knowledge Production Function* (K.P.F) was that R&D expenditures were treated as endogenous. This assumption allows no causal relation between factors like innovative success, productivity and R&D investment. In an attempt to remedy this problem, Crépon, Duguet and Mairesse (1998) proposed a model where the factors that have an influence on the estimated probability of being engaged in R&D also influence the estimated elasticity of productivity, and vice versa. They demonstrated that the assumption of R&D investment as a stochastic process was tenuous and that the probability of R&D is a function of several previously omitted factors like a firm's size, market share and diversification, and other external factors like demand pull and technology push. However, confirming the basic results of Pakes-Griliches, they still found robust causal relationships between the innovation outputs of firms, and the extent of their R&D investments.

Since then various studies have utilized modified versions of the K.P.F. to estimate the expected or realized benefits from invention such as growth, profitability, productivity, or the stock market value of the firm or industry (Hall, et al. 2003). However, there is increasing criticism of the use of patents and R&D expenses as proxies for innovation & knowledge inputs (OECD, 1994).

While Research and Development expenditure has been a consistently good estimator of innovation, some studies, predominantly ones involving developing country firms and the service sector, find only a weak association between R&D expenditure and innovation. Hence a valid and important criticism of a sole R&D investment focus in innovation studies is that they do not account for sectoral heterogeneity and are too blunt in their industry-level aggregations (Teece et al., 1994). Also, they adopt a restrictive (if rigorous) production focus, and attention on patents/R&D inputs cannot completely capture the highly complex and diverse nature of innovation. Also, as Richard Nelson (1996) points out, R&D does not encompass all the efforts of firms and governments to innovate, as there are other sources of technical change, such as learning by doing, informal R&D which are not captured by this narrow definition.

(c) Human Capital

The insufficiency of R&D capital in explaining new knowledge and a variety of factors -- the accumulative nature of innovation, the tacit nature of knowledge and the growth of the services sector to name a few -- have focused attention on the role of human capital. OECD (2001 a) recognizes that a chief characteristic of the knowledge-based economy is the high demand for skilled technical workers who are above average in their qualifications and can be identified as performing knowledge-rich jobs. Recent business literature lays particular emphasis on the role and nature of human capital in knowledge based organizations. Highly qualified workers add great value to any firm and are hence acquire significant weight in the intangible assets measurement literature (Edvinsson and Malone, 1997, Boudreau, 2002, Sveiby, 1998). The possession and retention of high quality workers is also exceedingly important, especially when innovation is viewed as a cumulative process, critically dependent of tacit knowledge (Galende and Fuenteb, 2003).

To define knowledge workers, Lavole et al. (2002) reformulate occupational categories based on the use and production of knowledge and reclassify economic activities according to tasks performed by workers. Cervantes (1999) combines the education and skill qualification needed for different types of jobs and identifies science and technology personnel as typically highly educated and more likely to be employed in occupations requiring at least a first university degree. Miller and Friesen (1984) also suggest that the use of technocrats increases the production of innovative ideas. Highly educated and technically qualified employees are also more receptive to innovations (Carter and Williams, 1957). Jacobsson, et al. (1996) use proportion of employees with engineering and science backgrounds as a technological innovation indicator. They argue that scientists and engineers are the main carriers of innovation and their proportion can better capture information on process engineering and informal innovations neglected by indicators like patents and formal R&D measures.

(d) Training

Continuous upgrading of skills is essential to leverage a qualified work force to adapt to the demands of market and remain innovative. Hage & Aiken (1967) and Dewar & Dutton (1986) show that knowledge depth, as measured by the extent of professional training, is positively correlated with innovation. Later studies, by Swan and Newell (1995), for example, show that on-the-job training is positively associated with innovation.

(e) Technology Adoption

The development and diffusion of information and communication technologies (ICT) is believed to have had a major impact on patterns of innovation and productivity across a wide range of sectors (Brynjolfsson and Hitt, 2003). Information and communication technologies (ICT) are ubiquitous, creating new needs and requiring appropriate organizational structures, facilitating the automation of some tasks and the outsourcing of others, supporting technological watch and improving access to external knowledge. Firms have to react faster to keep their competitive edge and to be able to build on all or part of their past experience (Kremp and Mairesse, 2004).

(f) Collaboration with external sources

Innovative firms are more likely to use external sources of knowledge either as supplements or complements to their own knowledge endowments. The role of external sources assumes greater importance for small and developing country firms which may not have formal institutional arrangements to conduct research and development (Becker and Dietz, 2003). Also, firms that value innovation and R&D also attach greater importance to external knowledge sources (Arvanitis and Hollenstein, 1994, Gambardella, 1992). While recent literature focuses on the augmented role of universities as external providers of research to firms (see Rosenberg and Nelson, 1994 for an excellent overview of university contributions to American industry), government organizations, customers and sometimes even competitors can provide inputs to the innovation process of a firm.

(g) Presence of Knowledge Management Practices

A recent trend in organizations is to coordinate their tasks and activities in the framework of a formal knowledge management system (Boudreau, 2002). In modern knowledge-driven economies, firms are increasingly aware that individual and collective knowledge is a major factor of economic performance. The third French leg of the supplementary community innovation surveys (CIS3, 1998-2000) conducted to assess the knowledge management policies of firms asks questions about the presence of KM practices such as promoting a culture of information and knowledge sharing, motivating employees and executives to remain with the firm, forging alliances and partnerships for knowledge acquisition and implementing written knowledge management rules. Kremp and Mairesse (2004), in their micro econometric analysis of the survey, confirm that the presence of these knowledge management practices contributes significantly to firm innovative performance and to its productivity. While it is hard to argue that the presence of a Knowledge Management practice itself will directly lead to a firm being innovative, it might serve as a good proxy for a variety of activities that contribute to the generation and utilization of new knowledge.

(h) Export Orientation

The export-orientation of firms has been widely studied in its association to innovation. A study of Italian firms found that the export intensity of innovating firms is systematically higher than that of non-innovating firms (Basile, 2001). However, there is some disagreement about the causality direction between innovation and the exporting behavior of firms. Some scholars hypothesize that innovative firms are more likely to export and regress different indicators of innovation on export performance (see Wakelin, 1998 for a good review). Others argue that exposure to international markets makes the firms more innovative. This appears to be a particularly reasonable position to take, especially where the firm concerned is from a developing country. Exposure to competitive international markets is more likely to force firms to make product and process improvements to meet the demands of global consumers. The idea that export-oriented policies expand technological frontiers (especially in the case of developing countries) provides a rationale for this domain of research. The so-called "learning-by-exporting" literature has been developed in that context and has been used by Dahlman and Westphal (1982) and more recently by Emre and Taymaz (2003) to examine the role of exporting on innovativeness of Turkish firms. The former provide evidence that

Korean firms actively engaged in exports were better at generating improvements in product quality, design and productivity.

2.2 The odds and ends of innovation in developing countries

A huge volume of data regarding innovation is collected and analyzed in the developed countries. Consistency of results and benchmarking exercises (like the Community Innovation Surveys) have made comparability of estimates possible. However, in developing countries where innovation surveys are conducted sporadically, and the characteristics and scope of processes of technological change remain largely unknown. One of the most striking weaknesses of developing countries is that they exhibit only a fragile linkage between the knowledge production and economic systems (Nelson, 1993). In their analysis of Thailand's system of national innovation, Intarakumnerd, et al (2003) conclude that local firms have mostly grown without deepening their technological capabilities and where technological learning has existed, has been very slow and passive. Also, they notice weak to absent linkages between the various actors (government, university, industry) necessary to stimulate a culture of innovation, especially where individual R&D capabilities are lacking.

Forbes and Wield (2000) examine the differences in the nature of innovative activity in developed and transitional countries. They note that developed country firms are *technology leaders*, and developing country firms are *technology-followers*. They identify some basic differences between the innovation paths of the two. Specifically, for technology followers, (i) *Incremental innovation* is key: Technology leaders are capable of making the leap to a new technological paradigm but, for followers any change is new to the firm. As the technology-leader continues to improve the technology, keeping up requires only incremental innovation, while catching up requires incremental innovation at a faster pace than in the leader. Incremental innovation is thus the primary source of long-run competitiveness in technology-followers. (ii) *Process innovation*: Technology-followers mature when innovation drivers change to cost competition. Cost competition induces process innovation (iii) *Shop-floor innovation* arising in day-to-day operations, is the major source of cost-saving on the shop-floor and is not captured by formal innovation indicators. However, it contributes significantly to the competitiveness of technology followers in cost-sensitive markets (iv) *Organizational, cultural and managerial changes*: For any innovation to be successful, it has to be widespread, continuous and accompanied by changes in supportive functions.

Arocena & Sutz (2000a) offer a comparison of industrial innovation surveys in several Latin American countries. They argue that national spending on innovation in developing countries is relatively low, evidenced by the fact that investing in R&D is below the threshold of 1% of GDP in the Latin American developing countries. They note that industrial innovation is highly informal and even when firms perform product and process innovation, R&D activities are not clearly and formally articulated with the enterprise strategy. However, entrepreneurial innovation is not necessarily of a low level of complexity and the proportion of professionals in R&D is consistently higher than in other firm activities. Innovative firms have a comparatively important number of qualified technicians and that in such a situation, their number, salaries and size are the only indicators related to level of innovation performance that surveys can capture.

Alcorta and Peres (1998), Arocena and Sutz (2000a) note that the lack of qualified personnel in medium and small enterprises of developing countries is not compensated by use of external advice. Developing country firms consider the ideas for innovation as well as the concrete implementation of innovations mainly as an internal affair. Most of these firms, in their quest for innovation, see augmenting investment in machinery and equipment as the best strategy. In summary, the authors find low spending on R&D, low reliance on local knowledge institutions and high reliance on foreign embodied science and technology as the distinctive characteristics of the more innovative firms in developing countries. Further, most innovative activity in developing countries consist of minor innovations (modification or improvement of existing technologies). There are relatively few firms with 'linkage capabilities', that is, the capabilities required to receive and transmit information, experience and technology from components and raw material suppliers, subcontractors, consultancy firms, service firms and technological institutions. (Arocena and Sutz, 2001a).

Jaramillo et al (2001, p18-22) make an effort to adapt the guidelines of the Oslo manual in conducting innovation surveys in developing countries, specially the Latin American countries. They note that, despite greater international integration and an increasing interest in technological improvement, Latin American firms exhibit key differences with regard to the nature and intensity of their efforts aiming at technological innovation in comparison to the developed countries. Specifically, they note that a much smaller percentage of firms' efforts correspond to R&D activities, while other innovation activities, particularly organizational change, administrative reorganization, and new product marketing have increased in relative importance. The authors note that since:

> "..(local firms) often choose to glean technological knowledge from international sources is related to an urgent need to realize immediate competitive improvements (without having to wait for their endogenous efforts to mature), thus enabling them to improve their domestic and, in all probability, foreign market positioning. "

In their study regarding the innovation activities of small and medium sized manufacturing firms in India, Kumar and Saqib (1996) note that competitive pressures, export-orientation and vertical integration influence the firms' inclination to undertake R&D and be innovative favorably. They also note that firms in chemicals and capital goods industries appear to attach the greatest importance to R & D because of the opportunities available to them for adaptation.

2.3 Sectoral patterns of innovation

The OECD's latest version of the Oslo manual (2000, pp 30) recognizes the sectoral dependence of innovation but focuses on the broad distinction between manufacturing and service firms. Underlining the differential nature of innovation in services and manufacturing, the manual advances the following four important points:

- The characteristics of innovation in the service industries are different from those in manufacturing industries. Service innovation is often immaterial in nature and therefore difficult to protect. Services have a higher degree of customization. There is a closer interrelationship between the development of new services and the processes to produce them.

- There are differences in the statistical context. There are well-established statistical programs for the goods handling services, including wholesale and retail trade, freight and transportation. This means that there are robust measures of production, investment, prices and financial activity for these industries that make it easier to distinguish differences between innovators and non-innovators and to draw policy inferences.
- Service industry firms tend to be smaller than those in manufacturing, and less concentrated. This has methodological implications for sample surveys and industry estimates.
- Service industries vary in their requirements of different skills, organize their production and marketing functions differently, make use of different levels of technology and serve different markets. They may have different propensities to engage in international trade, and to innovate, and they respond differently to economic conditions.

Galende and Fuenteb (2003, p 717) set the stage for their analysis of Spanish firms by summarizing the anticipation and approach of economic theories towards innovation. According to them, prior work can be compartmentalized to be deriving from two characteristic categories.

> "The *industrial organization* approach is a linear analysis of technology, attributing it with a strong information component and considering it as a direct line between science and innovation. From this approach, innovation is fundamentally determined by a firm's external factors and companies are characterized by their passive behavior. On the other hand,

the *evolutionary* model considers the process of innovation as a diverse, dynamic, continuous and accumulative process, with knowledge as its main component. The tacit, complex and systemic character of innovation is highlighted. It undergoes a past-dependent process and has a certain irreversibility with regard to the technological path followed" (emphasis added and structure changed).

Franco Malerba (2002, p251) underpins the contributions of the evolutionary theory (Nelson, Metcalfe, Freeman and Dosi) as the bases for his framework of sectoral systems of innovation. He notes that:

"The evolutionary literature has proposed that sectors and technologies differ greatly in terms of the knowledge base and learning processes related to innovation. Knowledge differs across sectors in terms of domains. One knowledge domain refers to the specific scientific and technological fields at the base of innovative activities in a sector (Dosi, Nelson and Rosenberg, 1993). The second domain regards applications, users and demand for sectoral products. In addition, other dimensions of knowledge may be relevant for explaining innovative activities in a sector".

Pavitt (1984)'s taxonomy of the technology trajectories of firms is rooted in the premises of evolutionary thought. Evolutionary theory anticipates that changing technological opportunities along trajectories, governed by paradigms, is a central regulating variable in the economy and the society (Andersen, 1998). Pavitt refined the idea 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. His systematic method of sectoral classification was based on this premise and was first tested 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 was able to confirm what to this day remains an elegant and practical classification of sectors. His original categorization identified four broad “trajectories” or “paths” that firms could take:

1. *Supplier dominated firms* are found mainly in traditional sectors of manufacturing like agriculture and textiles. The firms are generally small with weak R&D and engineering capabilities. Technical change is affected mostly by suppliers of machinery, equipment and other production inputs.

2. *Scale intensive firms* are producers in sectors of extraction and processing of bulk materials, automobiles and large scale engineering products. The risk of adopting radical innovations makes changes in this sector incremental and cumulative. The firms produce a high proportion of their process technologies to which they devote a high proportion of their resources. Product and process innovations go hand and hand, the source of most of which are internal engineering departments and experience.

3. *Specialized suppliers* are small and provide high-technology inputs in the form of machinery, components, instruments or software. These firms can be found in the machinery and instrumental engineering firms. They 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.

4. *Science-based firms* belong mostly to the chemical, pharmaceutical and electronic sectors. They are involved in making fundamental discoveries and contribute to emerging markets. Their main source of technology is internal R&D and often work closely with academic inventions. 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.

Tidd et al. (2001) extended Pavitt's model to include a fifth category, \`*information intensive firms*', to accommodate the emerging service industries such as finance, retailing, publishing, telecommunications, and travel. The focus of new products, processes and services of these firms is to adapt to new customer demands.

Archibugi, et al. (1991) categorized 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 specialized suppliers, selling their products to other companies and receiving information through this channel (Souitaris, 2002). De Marchi et al. (1996) empirically tested Pavitt's model by using a dataset of Italian manufacturing firms. They investigated the relevance of the model by first transforming Pavitt's qualitative assessments into quantitative associations. They then tested the predicted associations between industrial sectors and patterns of technical change, and the predictive power of the model by comparing the variance in innovative characteristics accounted for by the model v/s the total variance. Their results, aligned consistently with the predictions of the model. The advantage of Pavitt's framework is that it allows the reduction of sectoral diversity with respect to the nature, sources, directions and strategic implications for innovation into five generalized classes. However, Niosi (2000) notes that heterogeneities persist among firms within Pavitt's sectoral classes. The classification suits us, in that although Pavitt used the firm as his unit of analysis, he identified common technological patterns at the level of the sectoral class (as noted by Souitaris, 2002). Souitaris uses Pavitt's taxonomy, positing that it integrates the economic and business approaches of studying industries and firms respectively. Freel (2002) applies Pavitt's framework to study the impact of networking and proximity on innovation in a survey of small and medium firms in Scotland and Northern England. He demonstrates that the model is useful in reducing "sectoral noise" and produces results consistent with the expectations of the model.

2.4 Summary

The preceding sections focused on four broad themes. *Firstly*, they clarify the different *types* of innovation (product, process and organizational innovation), their sources and circumstance. The strengths and weaknesses of different indicators (like patents) of innovation were discussed. This will guide in selecting and interpreting different measures of innovation in the following empirical chapters. *Secondly*, factors like R&D activity, human capital, training, technology adoption, firm size, collaborative efforts and knowledge management practices were surveyed for their impact on innovation. This is intended to guide the selection of innovation-explanatory variables for my study. *Thirdly*, I emphasized the technology-dependence of innovation and presented Pavitt's taxonomy of technology trajectories as a model capable of providing an organizing framework for sectoral explorations in the succeeding chapters. *Lastly*, developing country firms are unique in their behavior and use of inputs to innovate. An awareness of country-specific factors is essential to make better sense of innovation estimations and determinants.

CHAPTER 3

A TAXONOMY BASED ON FIRMS' TECHNOLOGY TRAJECTORIES

Keith Pavitt (1984) bases his model of technology trajectories on the premise that industrial sectors differ in the nature, sources, methods and users of their innovative activities. The research was based on the Science Policy Research Unit (Sussex University) database which included data on about 2000 significant innovations in Britain since 1945 (Souitaris, 2003). Pavitt subsequently applied the model in a test on a data set of U.S firms. The taxonomy, as surveyed in the previous section, comprises of four base categories and a later category appended by Tidd and colleagues (2001).

In this chapter, I apply an extended model of Pavitt's technology paths on a comprehensive dataset of Malaysian firms. The primary purpose of this exercise is to demonstrate that the classes are significantly different from each other in their nature of innovation (product, process, organizational), the competitive strategies they adopt (price, quality), their sources of technical change (internal, market, external institutions) and size. The rest of the chapter is organized as follows. Section 3.1 presents expectations of Pavitt's main technology categories (in reprise) and discusses new extensions. Section 3.2 describes a data classification exercise. Section 3.3 concludes the chapter by discussing patterns in the data and their conformance to the expected features of different technology classes.

3.1 An extended model of Pavitt's technology trajectories

1. Supplier dominated firms (SD) are traditional manufacturing sector firms like textiles, rubber, food, wood-based industries and plastics. They are characterized by a low propensity to perform research and development activities. Innovation in these small firms is mostly targeted at cost-saving improvement which is seen as the primary strategy to compete in a market where competition is intense and customers are price sensitive.

2. *Scale intensive firms (SI)* are large manufacturing firms operating in the increasing returns to scale industries. They are to be found in the automobile and transportation equipment sector. Most of their innovations involve process and engineering redesign. Product innovation in this sector is mostly incremental and cumulative. Consequently, the source of innovation arises out of experience and is mostly internal.

3. *Specialized suppliers (SS)* are small, technology intensive firms that provide machinery, component and instrument inputs to other firms. These firms can be found in the machinery and instrumental engineering firms. Fabricated metals, electrical and electronics firms as well as specialized instrument manufacturers comprise this class. They typically innovate in products, and view innovation, high quality and customization as sources of competitive advantage. They hire a high proportion of skilled and qualified labor and when the need arises collaborate with market and external sources for their R&D needs.

4. *Science-based firms (SB)* belong to the chemical, pharmaceutical and electronic sectors. As the name suggests, they are primarily involved in making fundamental, science based discoveries and compete in nascent markets. Hence, they seek to collaborate with

universities and R&D institutions and are less concerned with price-based competition. The firms are typically small and operate in niche markets.

5. *Information-intensive firms (II)* represent the extension of Tidd, et al. (2001) to incorporate the burgeoning *new service*s of telecommunications, information technology and other business services. The firms are small, innovative and somewhat correspond to the specialized suppliers in their nature of innovation and strategies, except that they primarily deal with information which is an intangible good.

6. *Primary-services (PS)* I have extended the basic taxonomy to better differentiate the services industry by exploiting the richness of sectoral data available from the MyKE survey. This sector includes firms from the traditional services economy - like education, finance, transportation, tourism and health. Since customization, flexibility and cost are determining factors of success in this class, I expect the firms to adopt a mixture of price and quality-based strategies to compete. Also, they should be more likely to make organizational changes to adapt to changing customer and market demands.

To supplement the above discussion, table 3.1 presents a summary of the final technology classes, the sectors they comprise of and their defining attributes. I hasten to note that the correspondence between Pavitt's assignment of sectors to his four broad classes and my assignment is not exact. For example, the petroleum industry in Pavitt's original taxonomy is suggested to be scale-intensive. However, the survey I use aggregates chemical and petroleum into a single sector. They have hence been included under the science-based category. Otherwise, I have tried to maintain the conceptual integrity of Pavitt's model to an extent permitted by the organization of my data.

Table 3.1 A modified version of Pavitt's sectoral taxonomy and its expectations

Sector characteristics	Core Sectors	Firm size	Type of Innovation	Strategy	Sources of Innovation
Supplier dominated	Agriculture, food, wood-based, textiles, rubber & plastics	Small	Process	Price	Specialized suppliers
Scale intensive	Automotive, transport equipment	Large & Medium	Process	Price, quality	Internal
Specialized Suppliers	Fabricated metals, machinery, instruments, electrical, electronics	Small	Product	Quality, Performance, Customization	Market
Science based	pharmaceuticals, drugs, chemicals, microelectronics	Medium & Large	Product & Process	Innovation, Quality	Research centers, universities
Primary Services	education, transportation, finance, tourism, health	Small & Medium	Organizational	Mixed	Mixed
Information Intensive	All services	Small	Product & Process	Quality, Price, Customization, Quick delivery	Market, External

3.2 Data and descriptives

The principal source of data for this study is a nationwide survey (Malaysian Knowledge Content Survey 2002) of private enterprises in eighteen manufacturing and services sectors of Malaysia. Researchers from The Georgia Institute of Technology (Shapira et al, 2003) designed and instrumented the survey. The questionnaire was administered to senior managers of randomly selected manufacturing and service establishments by the Malaysian Department of Statistics (DOS) in conjunction with the DOS Annual Survey (of Manufactures or Services). Only those respondents with at least 10 employees (or at least 20 employees for manufacturing establishments) and belonging to one of 18 designated study sectors qualified. A stratified random sampling technique based on establishment employment size and industrial classification within the sampling frame was used to represent the overall composition of the Malaysian economy (MyKE, 2003). The final cleaned dataset comprises of 1819 respondents.

Table 3.2 Number of firms in each technology class & comprising sectors

	Class	**Sectors**
Food processing		142
Rubber and Plastics		134
Wood-based		127
Textiles and apparel		112
Supplier-dominated (SD)	**515**	
Automotive		82
Transport equipment		67
Scale-intensive (SI)	**149**	
Fabricated metals		119
Electrical & Electronics		120
Machinery & Instruments		106
Specialized-supplier (SS)	**345**	
Chemicals & petroleum		110
Science-based (SB)	**110**	
Education		80
Transportation		125
Finance		65
Tourism		133
Health		91
Primary-services (PS)	**494**	
Telecom		41
Info Tech		76
Business services		89
New-Services (Info Intensive)	**206**	
Total	**1819**	

The detailed sectors that comprise each class and the number of firms under each are presented in table 3.2. Clearly, supplier-dominated firms and primary services are the dominant technology classes by number of firms they represent. Since the survey was conducted by sampling firms to represent Malaysia's sectoral composition, the same can be assumed to be representative of Malaysia's overall economy.

The variables that depict the nature of innovation are product innovation (*prodinn*), process innovation (*procinn*) and organizational innovation (*orginn*). Each of these variables is cast as binary with the value of the variables set to '1' if the firms reported innovating in the respective dimensions. Firm strategy to compete in the market is also represented by a binary variable (*quality*) that is set to '1' if it reported that price was *not* its most important source of competition(respondents were asked to choose among a variety of options including price, quality, innovation and customization as their primary strategy). Further, firms were asked about the main sources of knowledge they utilized in their innovative efforts. Respondents who accorded high importance to internal resources (staff within the establishment, or other units within the establishment) were marked '1' on the corresponding dichotomous variable (*internal*). Similarly, firms that considered suppliers, competitors or customers an important source for innovation ideas were set to high on the respective binary variable (*market*). Firms that tapped on universities, government research organizations and other public R&D institutes were marked '1' on a variable labeled 'external'. Per size, firms were divided to fall into one of the three broad categories depending on whether they had less than a 100 employees (*sizecat=1*), between 100 and 500 employees (*sizecat=2*) or greater than 500 employees (*sizecat=3*). About 58% of the firms in our sample of 1819 are small and about 34% are of intermediate size.

Science-based firms are the most likely to innovate in products with 29% of them reporting such innovations followed by firms belonging to the information-intensive industry (26%) and specialized suppliers (25%). There is little to distinguish between scale-intensive firms and supplier-dominated firms from their innovation descriptives. A great proportion of service sector firms report organizational innovations (61% of the information intensive and 50% of the primary services sectors). The information intensive sector is the most likely to compete on quality (in other words, the least likely to compete on price). The service sectors and the specialized-services depend on internal sources to innovate (existing staff within establishment, newly-hired professionals or other associated business units within the establishment). Primary services also depend on external sources (universities, governments, other R&D enterprises and organizations) to a greater extent than the other sectors. Firms in the most innovative sectors (science-based and services) are more likely to be small in size as compared to the supplier-dominated and scale-intensive firms.

Table 3.3 Descriptives and Pavitt's expectations

	Supplier-dominated	Scale-intensive	Specialized-suppliers	Science-based
product innovation	14%	19%	25%	29%
process innovation	34%	38%	46%	48%
organizational innovation	37%	43%	47%	51%
quality as primary strategy	75%	72%	68%	76%
internal - source of knowledge	23%	26%	36%	32%
market - sources of knowledge	33%	39%	39%	38%
external - sources of knowledge	11%	11%	11%	19%
less than 100 employees	53%	54%	55%	58%
between 100-499 employees	40%	33%	33%	39%
greater than 499 employees	7%	13%	12%	3%

Table 3.3 (continued)

	Primary-services	New-Services	Total
product innovation	19%	26%	20%
process innovation	31%	49%	38%
organizational innovation	50%	61%	47%
quality as primary strategy	79%	89%	76%
internal - source of knowledge	33%	41%	31%
market - sources of knowledge	32%	43%	36%
external - sources of knowledge	17%	18%	14%
less than 100 employees	59%	70%	58%
between 100-499 employees	33%	21%	34%
greater than 499 employees	8%	9%	9%

3.3 Discussion and conclusions

The previous section described broad differences between the sectors of Malaysia's economy – by using an extended model of technology trajectories to assign firms to one of the six broad categories. Basic descriptives indicated that supplier-dominated firms are very limited in their innovative capabilities. Pavitt (1984, p. 356) explains that this is because traditional manufacturing firms that comprise the class focus on cost reducing process technologies to meet the demands of price-sensitive customers. Because of their weak internal R&D and engineering capabilities, markets including customers, suppliers and competitors are the likely source of new or improved process technologies.

For the scale intensive firms -- like large automotive and equipment manufacturers -- we can expect in-house capabilities to make a greater contribution to both product and process innovations. However a high proportion of resources are likely to be devoted to less risky improvements/changes in their process technologies. We see this in the low number of product innovators (19%) and average number of process innovators (38%) for the scale-intensive sector. On the other hand, specialized suppliers are small, specialized firms operating in markets for technology (Hicks, et al, 2002). They are usually electronics and instrumental engineering firms which produce a high proportion of their own product technologies.

Science-based establishments like chemical and pharmaceutical firms are distinguished by their focus on product innovation. They are likely to employ a high proportion of skilled and qualified labor. They are also expected to use external inputs and collaborate with universities and other organizations for their innovation needs. Since, they operate in situations where consumers and markets are not very well developed, price is of little concern for their survival or growth strategies. The information intensive sector (used interchangeably with “new services” here) has firms that are similar to their counterparts in the science-based class in many ways. They develop and rapidly bring t radically new services to market, *i.e* they product innovate. Quality and innovation are main sources of competitive advantage and not price. Firms are often small and specialized and their main purpose is to design and operate complex information systems (Tidd et al, 2001).

Primary service firms comprising education, health, transportation and finance among others while not subject to the same pressures of their information-intensive counterparts face a competitive market where along with price, factors like rapidity and newness of service and customization play a huge role in profitability and growth. Customers are hence an important source of innovations and adaptability to the dynamic market situation is ensured by continuous improvements in organizational and business practice improvements.

Overall, patterns evidenced by key variables fold along the lines of technology classes as predicted by Pavitt. The spirit of this exercise was broad and exploratory. While no rigorous statistical testing methods to test the robustness of my classification scheme were employed, a simple examination of proportions suggests considerable heterogeneity across different technology classes. While scale-intensive and supplier-dominated firms appear similar in aspects of their innovation propensities, collaboration and size, the remaining classes were distinct from each other. The next chapter builds on the results of this classification exercise and investigates the contribution of various factors like research and development, human capital, training, technology adoption, firm size, collaboration patterns, export orientation, knowledge management practices and firm size on innovation in the various technology classes. Formal statistical methods are employed to test the sectoral dependence of innovation.

CHAPTER 4

DETERMINANTS OF INNOVATION

This chapter applies concepts from the innovation literature (surveyed in chapter 2) on the database of Malaysian firms to investigate the impact of various factors on their innovation propensities. In an earlier chapter, I argued that the nature and type of innovation in firms is a function of sectoral characteristics. Further, an extended model of Pavitt’s technology trajectories was used to categorize (into six manageable classes) and describe firms.

In this chapter, I formally test the economic and statistical significance of variables like R&D, education of the workforce, collaboration strategies, technology adoption, export intensity, firm size and ownership on product, process and organizational innovation. Firstly, Section 4.1 presents three baseline models where product innovation, process innovation and organizational innovation (binary dependent variables) are each regressed on the above set of independent variables. Section 4.2 examines if adding sectoral indicators (represented by the six technology classes) to the baseline models enhances their explanatory power. If the “technology trajectory” of firms influences the nature of their innovation, it can be hypothesized that firms differ significantly -- in their choice and combination of inputs to innovate -- depending on the sector they belong to. I test this notion by estimating models where innovation is regressed on each of the explanatory variables, sectoral indicators *and* variables representing interactions between the two. Section 4.3 concludes the chapter by discussing the results and policy implications.

4.1 The baseline innovation model

The baseline innovation models test hypotheses regarding the impact of various innovation inputs on innovation. At this stage, no sectoral distinctions are made. The set of models in this section comprises of three logistic regression estimations. "*INNOVATION*" -- the dependent variable -- is distinguished as product innovation, process innovation and organizational innovation. Each is represented by a binary term set to '1' if the firm reported the corresponding type of innovation. The probability of innovating along each of the three dimensions -- given the explanatory variables -- is then estimated using three separate equations by means of standard logistic regressions. The baseline model can be formally stated as:

$$\Pr(INNOVATION = 1 \mid x) = f(\beta_0 + \beta_1 randd + \beta_1 humancap + \beta_2 training + \beta_3 techadopt + \beta_4 collab + \beta_5 kmgmt + \beta_6 \exp ort + \beta_7 foreign + \beta_8 age + \beta_9 sizecat) \quad (1)$$

I have been guided by previous studies in the selection of explanatory variables. The literature surveyed in chapter 2 explains the rationale and expectations of these factors (on innovation). Table 4.1 presents summary statistics for the variables, both for the entire dataset, and by technology class. Expectations regarding the direction of influence of the explanatory variables can be briefly summarized as below:

- Research and Development (*randd*): I operationalize this as a binary variable set to "1" if the firm reported any spending on research and development during the year 2002. I expect *research and development to have a positive impact on product innovation and process innovation but less impact on organizational changes*.

- Human Capital (*humancap*): This is calculated as the proportion of employees of a firm with a university degree or higher in science and engineering fields. *Humancap is expected to have a positive impact on all types of innovation.*
- Training (*training*): Dichotomous variable set to "1" if the respondent answered positively to having trained employees during 2002, "0" otherwise. *Should also have a positive impact on innovation – although it is not clear if training impacts different types of innovation differently*.
- Technical adoption (*techadopt*): This is also operationalized as a binary variable and is turned on for firms that reported having computers that were both internally and externally networked. *Can be expected to have a positive impact on process and organizational innovations.*
- Collaboration (*collab*): This is set to "1" if the firm responded positively to having collaborated with external sources. *This should be positively related to product and process innovation across all sectors*, but particularly so for sectors where trade secrets is not a vital concern. *I expect collaboration to have a less significant impact on product innovations since most firms prefer to develop products internally*.
- Knowledge management (*kmgt*): Firms responding positively to the question on operation of formal procedures for aquiring, sharing or using knowledge were marked high on this binary variable. Knowledge management has been shown to improve decision-making by improving information availability in organizations. *Knowledge management practices should positively predict organizational innovations*.

- Export intensity (*export*): is the proportion of sales from exports. Theory predicts that exposure to export markets makes firms innovative. However, developing countries export based on low-cost strategies. Hence, it will be interesting to observe the relation between export-intensity and innovation across various technology classes.
- Foreign firm (*foreign*): This is included as a control variable and provides suffers from the same ambiguity as the export variable in developing expectations in relation to innovation. Age (*age*) of firms and the size category (*sizecat*) they belong to are included as control variables.

Results of the estimations are presented in table 4.2. R&D and proportion of workers with science and technology degrees are among the most significant predictors of product innovations. Firms use collaboration with external sources and training to effect their process improvements. Knowledge management, collaboration and education (human capital) are significantly important inputs to the organizational innovation process. Age has a negative impact on product innovations, while medium sized firms (that employ between 100 and 500 workers) innovate more than their larger counterparts (greater than 500 employees).

Table 4.1 Explanatory variables – descriptives

Technology Class	Supplier-dominated	Scale-intensive	Specialized-supplier	Science-based
R & D in 2002	22%	26%	27%	45%
Trained employees	34%	48%	54%	69%
Networked computers	52%	68%	69%	83%
Collaborate with external sources	34%	41%	40%	42%
Engage in knowledge management	29%	38%	41%	46%
Foreign establishment	8%	9%	30%	33%
% of workers with S&T degrees	5%	8%	9%	13%
	(5.7)	(7.8)	(9.7)	(13.6)
Export intensity	33%	17%	39%	29%
	(39.8)	(30.4)	(41.5)	(33.3)
Age	17.3	15.6	14.0	17.4
	(9.9)	(8.6)	(8.3)	(10.3)
Number	515	149	345	110

Table 4.1 (continued)

Technology Class	Primary-services	New-Services	Total
R & D in 2002	13%	25%	22%
Trained employees	47%	46%	46%
Networked computers	65%	85%	66%
Collaborate with external sources	35%	46%	38%
Engage in knowledge management	37%	49%	38%
Foreign establishment	6%	10%	13%
% of workers with S&T degrees	16%	33%	13%
	(17.7)	(28.3)	(17.0)
Export intensity	3%	4%	21%
	(13.3)	(14.8)	(34.9)
Age	15.8	14.2	15.8
	(12.5)	(10.7)	(10.5)
Number	494	206	1819
(Standard errors in parenthesis)			

Table 4.2 Baseline model results

	Product innovation	Process innovation	orgnzl. Innovation
r & d	2.68	2.07	1.3
	[0.39]***	[0.29]***	[0.19]*
% workers with s&t degrees	3.866	2.644	2.924
	[1.402]***	[0.932]***	[1.064]***
employee training	1.45	1.26	1.85
	[0.22]**	[0.16]*	[0.23]***
networked computer	1.17	1.19	1.45
	[0.20]	[0.16]	[0.19]***
Collaborate	2.59	5.59	6.34
	[0.35]***	[0.65]***	[0.76]***
knowledge management	1.61	1.66	2.1
	[0.23]***	[0.20]***	[0.26]***
export intensity	1	1	1
	[0.00]	[0.00]	[0.00]*
foreign firm	1.42	1.45	0.87
	[0.26]*	[0.26]**	[0.15]
Age	0.98	1	1
	[0.01]**	[0.01]	[0.01]
medium-sized(100-499 employees)	1.48	1.34	1.41
	[0.23]**	[0.18]**	[0.19]**
large-sized(499 employees)	1.77	1.36	1.32
	[0.41]**	[0.30]	[0.30]
Observations	1819	1819	1819

Standard errors in brackets
* significant at 10%; ** significant at 5%; *** significant at 1%
Reference group is small (<100 employees)

4.2 Sectoral innovation models

In this section, I investigate if the explanatory variables' impact on different types of innovation is moderated by sectoral characteristics. As a first step, I extend the baseline model in the previous section to include binary dummies for each technology class. The supplier-dominated class is treated as the reference group since it is the least innovative of all classes and has the largest number of firms of any class. In addition to the expected significance on the explanatory variables (which was tested in the previous section), I expect the coefficients on all classes to be positive and significant in the regression that employs product innovation as the dependent variable. However, *scale-intensive firms are expected to be more likely to process-innovate and the two service sectors are more likely to be positively associated with organizational innovations.*

$$\Pr(INNOVATION = 1 \mid x) = f(\beta_0 + \beta_1 randd + \beta_1 humancap + \beta_2 training + \beta_3 techadopt + \beta_4 collab + \beta_5 kmgmt + \beta_6 \exp ort + \beta_7 foreign + \beta_8 age + \beta_9 sizecat + class\_dummies) \quad (2)$$

Table 4.3 presents results of the logistic regressions. As against expectations, the scale-intensive sector is not significantly different from the base class in respect to any of its innovation propensities. Specialized-suppliers as well as science-based firms are more likely to have product innovations. Both the services sectors are significantly better predictors of organizational innovations. There is no statistical evidence to differentiate the sectors in their process-innovation propensities. In summary, all the technology classes (except the scale-intensive sector) are significantly different from the supplier-dominated firms in respect of their propensities to innovate along at least one dimension (product, process or organizational).

Table 4.3 Results of models with class dummies

	product innovation	Process innovation	orgnzl. Innovation
r & d	2.78	1.98	1.43
	[0.42]***	[0.29]***	[0.22]**
% workers with s&t degrees	3.21	2.608	1.648
	[1.342]***	[1.037]**	[0.663]
employee training	1.4	1.28	1.84
	[0.21]**	[0.17]*	[0.24]***
networked computer	1.12	1.16	1.37
	[0.20]	[0.16]	[0.19]**
Collaborate	2.62	5.6	6.52
	[0.36]***	[0.65]***	[0.79]***
knowledge management	1.59	1.67	2.04
	[0.23]***	[0.21]***	[0.25]***
export intensity	1	1	1
	[0.00]	[0.00]	[0.00]
foreign firm	1.3	1.33	0.87
	[0.25]	[0.24]	[0.16]
Age	0.98	1	1
	[0.01]**	[0.01]	[0.01]
medium(100-499 employees)	1.51	1.41	1.4
	[0.23]***	[0.19]**	[0.19]**
large(> 499 employees)	1.78	1.44	1.23
	[0.42]**	[0.32]	[0.28]
scale-intensive	1.21	0.96	0.93
	[0.34]	[0.22]	[0.22]
specialized-supplier	1.53	1.34	1.2
	[0.32]**	[0.23]*	[0.21]
science-based	1.62	1.12	1.05
	[0.46]*	[0.29]	[0.27]
primary-services	1.51	0.78	1.67
	[0.33]*	[0.14]	[0.29]***
new-services	1.46	1.25	1.92
	[0.41]	[0.29]	[0.45]***
Observations	1819	1819	1819

Standard errors in brackets
* significant at 10%; ** significant at 5%; *** significant at 1%
Reference group is supplier-dominated, small (<100 employees)

The next step in examining sectoral impacts on innovation is to test if the effect of explanatory variables on innovation is different for different sectors. Since I find no evidence to distinguish the supplier-dominated and scale-intensive sectors, firms originating from the two are treated as belonging to the same broad technology class. This has the effect of reducing the number of technology classes to five. It also simplifies estimation and interpretation of model coefficients by reducing the number of variables. Now, for each of the five classes, I examine the impact of various explanatory variables on product innovation, process innovation and organizational innovation. To test if the impact of different explanatory variables on different types of innovation is moderated by technology classes, I interact each of the explanatory variable with dummies representing the five technology classes. The model hence comprises of both main and interaction effects of all the innovation determinants and technology sectors. The model can be formally represented as follows:

$$\begin{aligned}\Pr(INNOVATION = 1 \mid x) = f(&\beta_0 + \beta_1 randd + \beta_1 humancap + \beta_2 training + \beta_3 techadopt \\ &+ \beta_4 collab + \beta_5 kmgmt + \beta_6 \exp ort + \beta_7 foreign + \beta_8 age + \beta_9 sizecat + class\_dummies \\ &+ class\_dummies * randd + class\_dummies * humancap + class\_dummies * training \\ &+ .....)\end{aligned} \quad (3)$$

Results of model-3 regressions are tabulated in table 4.4. Interpretation of all coefficients is with respect to the reference group (the small, supplier-dominated/scale intensive firm). Strikingly, R&D does not appear to be a statistically significant determinant of organizational innovations any more (controlling for sectoral and other effects). Also, R&D appears to be a less significant predictor of process innovations. The high magnitude of the coefficient on the interaction term of primary-services with R&D suggests that firms of that sector uniquely use R&D as an input to organizational innovations. Interestingly, human capital (proportion of employees with S&T degrees) does not show up as significant either individually or interacted. Other noteworthy results include: the increased likelihood of firms in the information-intensive sector to make use of training as an input to product innovations; the significance of training as an input to process and organizational improvements across all sectors. It is somewhat baffling that knowledge-management activities seem to hinder rather than foster innovations among science-based firms. Overall medium-sized firms and especially science-based, medium-sized firms appear to be the most likely to be product innovators. Age has a weakly significant negative relationship with the propensity to innovate.

Table 4.4 Results of class dummies interacted with innovation determinants

	product innovation	process innovation	orgnz. Innovation
r & d	2.57	1.58	0.91
	[0.72]***	[0.40]*	[0.23]
(specialized-supplier)*randd	1.22	1.23	2.11
	[0.50]	[0.49]	[0.85]*
(science-based)*randd	1.33	3.24	1.61
	[0.82]	[2.08]*	[0.94]
(primary-services)*randd	1.08	2.12	3.3
	[0.46]	[0.89]*	[1.57]**
(new-services)*humancap	0.9	2.42	0.05
	[1.75]	[4.37]	[0.09]*
employee training	0.91	1.89	1.86
	[0.25]	[0.43]***	[0.41]***
(specialized-supplier)*training	1.39	0.48	0.89
	[0.61]	[0.18]*	[0.33]
(science-based)*training	3.25	0.6	3.83
	[2.61]	[0.39]	[2.72]*

Table 4.4 (continued)

(primary-services)*training	1.88	0.56	0.79
	[0.77]	[0.19]*	[0.26]
(new-services)*training	3	0.87	1.49
	[1.51]**	[0.37]	[0.68]
(new-services)*techadopt	1.07	3.07	1.4
	[0.77]	[1.76]**	[0.80]
Collaborate	2.85	7.48	6.4
	[0.73]***	[1.51]***	[1.26]***
(primary-services)*collab	0.62	0.54	0.91
	[0.23]	[0.17]**	[0.29]
knowledge management	1.76	1.77	2.2
	[0.47]**	[0.39]***	[0.47]***
(science-based)*kmgt	0.64	0.15	0.38
	[0.40]	[0.09]***	[0.23]
(specialized-supplier)*export	1	1.01	1
	[0.01]	[0.00]*	[0.00]
(science-based)*export	0.99	1.01	1.02
	[0.01]	[0.01]	[0.01]**
(primary-services)*export	0.98	1.01	1.02
	[0.01]	[0.01]	[0.01]*
Age	0.98	1	0.98
	[0.01]	[0.01]	[0.01]**
(primary-services)*age	1	1.01	1.03
	[0.02]	[0.01]	[0.01]**
(new-services)*age	1	1.01	1.04
	[0.02]	[0.02]	[0.02]
medium-sized	1.05	1.66	1.49
	[0.29]	[0.38]**	[0.33]*
science-based & medium-sized	4.08	0.41	0.69
	[2.58]**	[0.25]	[0.40]
specialized-supplier	0.78	1.03	0.47
	[0.48]	[0.50]	[0.23]
science-based	0.8	5.29	0.28
	[0.91]	[4.67]*	[0.28]
primary-services	1.13	0.57	0.69
	[0.58]	[0.24]	[0.27]
new-services	0.508	0.647	0.767
	[0.437]	[0.440]	[0.509]
Observations	1819	1819	1819

Standard errors in brackets
* significant at 10%; ** significant at 5%; *** significant at 1%
Reference group is supplier-dominated, small (<100 employees)

4.3 Discussion and recommendations

Supplier-dominated firms include food processing, rubber and plastics, wood-based, textiles and apparels. Scale-intensive firms comprise of automotive and transport equipment manufacturers. The combined class of supplier and scale firms comprises the largest technology class with about 37% of firms in the entire dataset. Figures 4.1, 4.2 and 4.3 further clarify the role of these technology classes in the overall economy (the survey-sample was chosen to be representative of Malaysia's overall economic sectoral composition; further response rates were very high and neared unity and hence it is quite reasonable to assume that the dataset is representative of the overall economy). They provide about 32% of the employment but only contribute to 17% of the overall value-added for 2002. Not surprisingly, they also rank the lowest in terms of value-added per employee (Figure 4.3). Firms belonging to these classes have the lowest intensities of product, process and organizational innovations and use unconventional factors like training, collaboration with external sources of knowledge and knowledge management practices as inputs to their process and organizational innovation process. As Tidd, et al (2001) note, despite technological advancements in the past decades, innovation-options available to firms belonging to these classes remain modest. Targeted policies to enhance innovation in this class will be limited to cost-pruning and minor technological advancements. It is partly because of the low potential of these classes to add value that developed country firms continue to outsource such operations to low cost locations.

Specialized supplier firms comprise of fabricated metals, electrical & electronics and machinery & instruments. They are characterized by the maximum export intensity of any class (the mean firm of this class derives about 40% of its sales from exports).

Unlike scale-intensive and supplier-dominated sectors, firms in this sector appear to innovate in products and use R&D as an input. They also use a mix of collaboration and knowledge management activities to process and organizational innovation ends.

However, the innovation intensity of these firms is by no means outstanding. They appear to be only 1.5 times as innovative (in products, controlling for other factors) as their dismal supplier-dominated counterparts, which are hindered in their innovation intentions by the nature of areas they operate in. It will be a challenge and opportunity for policy-makers to investigate constraints to innovation in this important technology class. In this respect, it will be important to target firms in the electrical, electronic, machinery and instruments sector for further improvement.

Science-based firms belong to the chemical and pharmaceuticals sector. They have the highest innovation intensities, rank among the top on mean measures of technology adoption (measured as the presence of externally and internally networked computing power) and training. On average, these firms are also the oldest (mean age of 17 years) and most likely to be headquartered outside Malaysia. The firms are characterized by their use of conventional sources like R&D and S&T human-capital to innovate. The key to improving the innovation performance of the economy as a whole will be to augment the role of science-based firms in the economy. In the current dataset, science-based firms account for a tiny 4% of the employment while contributing 21% to overall value-added. However, this sector presents a mystery to the author by evidencing a negative association between knowledge management practices and innovation.

The primary services sectors comprises of firms from education, transportation, finance, tourism and health sectors. This class shows a great deal of variation in its innovation characteristics and explanatory variables. Firms of intermediate and larger size in are positively linked to innovation. They are also characterized by the use of R&D to make organizational improvements. Knowledge management significantly contributes to product, process and organizational innovation, as does collaboration, training and S&T capital.

Finally for the information intensive sector (Telecom, Info Tech and Business services), research and development significantly contributes to product innovation. Training is a significant predictor of product and organizational innovation. Knowledge management contributes significantly to product and organizational changes and technology adoption predicts process improvements. The sector reported the highest mean values of value-added per employee and contributed slightly more than a fourth to overall value-added.

In summary, Pavitt's model of technology trajectories provided a useful framework to examine similarities and differences in the innovation characteristics of firms. Science-based and specialized-supplier firms were found to be among the most likely to product-innovate. The service sectors on the other hand were distinguished by their high organizational innovation propensities. An interesting pattern was that firms across all sectors use R&D inputs to product innovate, whereas factors like training, knowledge management, and collaboration are important inputs to process and organizational innovations. Lessons for the policy-maker include focusing on augmenting the weight and role of science-based and information-intensive sectors in the overall economy. Further, specialized-supplier firms have to be targeted in their significantly untapped potential to be innovative.

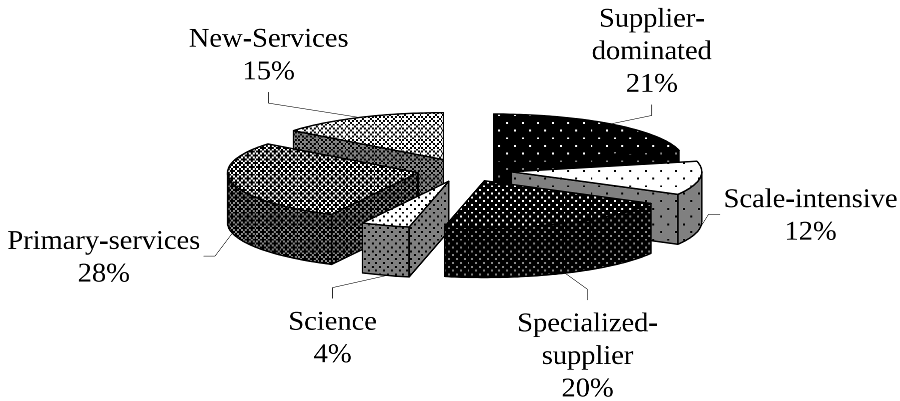

Figure 4.1 Employment by technology class

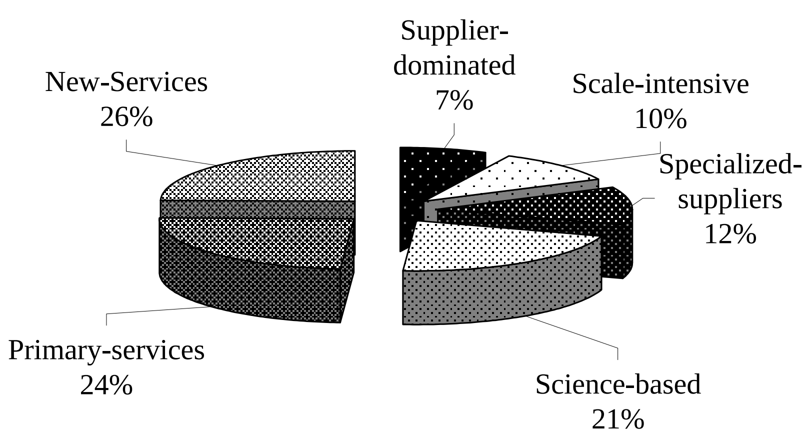

Figure 4.2 Value-added by technology class

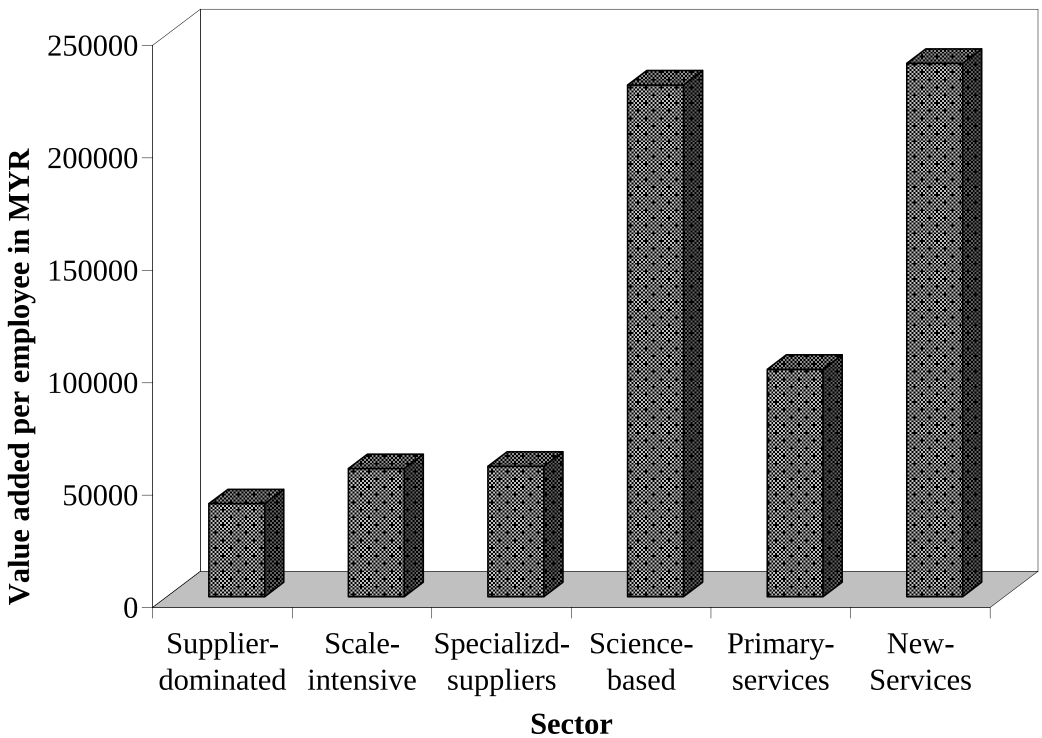

Figure 4.3 Value-added per employee by technology class

CHAPTER 5

CONCLUSIONS

Technical change is a complex and diverse phenomenon. Aggregate firm-level studies investigating this process can be better served by classification models that integrate commonalities among myriad sectors without compromising on their definitive features. Such models should also be rooted in theory and allow researchers to form reasonably accurate and testable expectations about innovation characteristics of firms given their broad technological affiliation. Pavitt’s model of technology trajectories is one of very few frameworks (known to the author) that compress the vast deal of heterogeneity among firms into a few manageable classes. It is grounded in conventional economic theory with a strong evolutionary influence (depending on the extent to which one is willing to entertain the notion). The model is not *ad hoc* in the sense that it has been tested in different settings, scales and economies. Pavitt (1984) himself tested the model on datasets of the U.K and U.S. economies, Souitaris (2002) applied the model to a data set of Greek manufacturing firms, De Marchi (1996) tested the predictive relevance of the model and its implications on Italian manufacturing sectors, and OECD studies acknowledge the model’s implications in their innovation surveys and studies (Malerba, 2001).

In this thesis, I extended the model by distinguishing between the primary services sector (comprising tourism, education, health, transportation and finance services) and the information intensive service sector (telecommunication, information technology and business consultancy services). They were shown to have peculiarities in their innovation characteristics. Primary-service sector firms were mainly organizational innovators and used a combination of soft-factors like training and knowledge management strategies to effect changes. They were also distinct in using R&D to effect organizational improvements. The information-intensive sector firms used research and development to effect product and process. Interestingly, foreign firms or firms that reported high export intensities fared no better than local firms and firms which catered to local markets as innovators. This should sound a cautionary note to developing country planners who traditionally view foreign firms as innovative and favor them with various investment incentives.

This study also acknowledged that product, process and organizational changes are very different in their nature and sources. Malaysian firms appear to be strong organizational and process innovators. This is consistent with the findings about innovation patterns in other developing countries. Jaramillo, et al (2001) argues that the predominance of innovations in organizational areas among developing country firms may be due to a preponderance of 'defensive' strategies. This in turn maybe due to the weak links between the scientific/technical system and the socio-economic system. Also, technology followers are more likely to innovate organizationally as compared to leaders who couple product and process improvements with changes in business practices (Forbes and Wield, 2000).

Although this study was carried out in a developing country context, some of the results were reassuring. Traditional research and development is important and shows up as an indispensable input to product innovation across all technology classes. On the other hand, firms use practices like training, knowledge management practices and collaboration with external and market sources to realize their process and organizational improvements. The only factor that consistently and overwhelmingly trumped research and development as an innovation predictor was collaboration with external sources. Primary services appear to favor a high proportion of science and technology workers while the information intensive sector appears to favor training them as a means of realizing innovation. Again, this shows that developing country firms may be more likely to use informal research strategies like knowledge sharing via collaboration.

In summary, my effort is different from three distinct perspectives. Primarily, it is the first such study that applies Pavitt's model in a diverse, developing country context. Secondly, unlike previous authors who adopt a more exploratory approach to test Pavitt's model, I use the expectations provided by the model to explore the determinants of innovation across different technology categories. Finally, this thesis confirms that the sources and means of product, process and organizational innovations are different. Innovation types, their intensities and efficiency are influenced to a great extent by country and sector-specific factors.

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