Technological Diversification, its Relation to Product Diversification and the Organisation of the Firm

Felicia Fai
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University of Bath School of Management
Claverton Down
Bath
BA2 7AY
United Kingdom
Tel: +44 1225 826742
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2004.11	Felicia Fai	Technological Diversification, its Relation to Product Diversification and the Organisation of the Firm.

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Felicia Fai

School of Management, University of Bath, Claverton Down, Bath, BA2 7AY, UK.
Tel: +44 (0)1225 384604
Fax: +44 (0)1225 386473
E-mail: mnsfmf@management.bath.ac.uk

Introduction

This paper studies the issue of technological diversification at the firm level through the theoretical foci of evolutionary economics and resource-based theory. Despite empirical observations of our increasingly technologically complex world, technological diversification is little studied. Traditional researches into diversification and the firm have tended to focus on diversification at the levels of products and regions for the motives of risk diversification and the exploitation of economies of scale and scope. Technological diversification has generally been subsumed into such discussions and has implicitly been assumed to follow diversification at the product level. However, more recent work on large firms examining technological scale and scope, and the relationship between the breadth of the product base relative to the firm's technological base, has stimulated the need to look at technological diversification in its own right. As such, I examine the nature of technological diversification and outline the ways in which this, as a process, may relate to diversification at the product level. In turn, these relationships help to explain how new technologies may be absorbed via different organisational forms and hence why technological diversification is a phenomenon that has important implications for the organisation of competencies within firms and between firms.

Background

This paper considers technological diversification and its implications for the firm. Neo-classicists traditionally study the behaviour of firms with respect to input factors of production; the quantity of goods produced and the price at which they should be sold in order to maximise profit. The consideration of these decisions is subject to any number of limiting assumptions, many of which are highly remote from reality. In the neoclassical perspective, it is merely the combination and recombination of land, capital and labour ratios that determines what to produce, how to produce it, and in what quantities to maximise profits at the margin. There is no suggestion that how these factors relate to one another might be important in the production process or for the growth of the firm.

Nelson and Winter's "An Evolutionary Theory of Economic Change" (1982) arose from their frustration with the limitations of the orthodox economic approach. They recognised that processes of economic change were much more subtle involving the combination of firm-specific, endogenously generated factors with exogenous pressures for change generated by the environment within which firms are operating. Their work, combined with the perspectives on the theory of the firm put forward by resource-based theorists, provide a much richer view of the firm. The firm no longer remains simply a coordinating, profit maximising device. The firm has the ability to evolve and change by building on its prior competencies and resources; it is a repository of competence or productive expertise, and an institutional device for learning and accumulating such (Winter, 1991); it is the principal source of innovation and growth (Cantwell and Fai, 1999).

The technological environment is changing rapidly and becoming increasingly complex; different technological areas are fusing (Kodama, 1986, 1992) and others are becoming more inter-related (Patel and Pavitt, 1997). As a result, firms have found it necessary to increase the range of technologies with which they are familiar in order to access new product markets; they have become 'multi-tech' (Granstrand et al., 1997). However, at the same time, the firm is constrained by the path dependent, incremental and cumulative nature of technological change and the limits of the firm's ability to learn and manage its growth. These conflicting forces have implications for the phenomenon of technological diversification within firms and this, in turn, will impact upon the evolution of the firm's technological competencies and organisational structure.

Nelson and Winter's development of evolutionary economics (1982) helps us to understand the nature of technological change. When combined with resource/competence based perspectives (Foss, 1993, 1996, Eliasson, 1994;

Montgomery, 1995; Pavitt, 1995) they also help to illuminate how firms might choose to engage in technological diversification and why they follow certain technological paths over others. Similarly, by viewing technology as a firm specific resource, the combination of these two approaches assists our understanding of why some firms are more successful in their pursuit of technological diversity than others.

The paper will take the following format. I first review evolutionary economic theory (Nelson and Winter, 1982) and resource-based theory (Penrose, 1959) paying particular attention to how they help us understand the nature of technological diversification. I then discuss diversification in terms of how the nature of the issue has moved from looking at products to businesses and to technologies**.** Following this, I consider how technological diversification may or may not bring about product diversification. Then, prior to the conclusion I consider the implications technological diversity might have for the organisational issues of the firm.

Theoretical Influences

The theory of the firm has long been debated. In the neoclassical school, in so far as the firm existed, it did so through its production function. The market for the basic resources of land, labour and capital determined input prices. Output levels were determined by price equilibrium in the marketplace. There was no sense of differentiation between qualities or skills inherent within each these categories. Nevertheless, the appropriate combination of inputs, representing the 'technology' involved (as either labour- or capital-intensive) would be used to meet the demand for output at the market-determined price. The firm would aim to maximise profits. The theory of the firm idiosyncratically considered prices and markets – not firms. There was no consideration of the roles of management and organization. Subsequent works have tried to address these issues by actually looking inside firms. The two which are most influential in this discussion of technological diversification are evolutionary and resource-based theories.

<u>Evolutionary Influences</u>

Nelson & Winter (1982) made the major unifying theoretical contribution to evolutionary economic theory through their establishment of three basic concepts:

routines, search and the selection environment[1]. Despite having been written for much broader application than just the firm level, this has not detracted from its explanatory value when applied to the micro level. Interestingly, despite the pivotal importance of the evolutionary concept to their theory, the subject of diversity (ergo variety) does not appear to be discussed explicitly within their seminal work. However, the three fundamental concepts are particularly relevant to diversification; I expand on each below.

Organisational routines

> "At any time, organizations have built into them a set of ways of doing things and ways of determining what to do…. [this] is not to say it is unchanging or that it is ineffective…it is to recognize that the flexibility of routinized behavior is of limited scope and that a changing environment can force firms to risk their very survival on attempts to modify their routines" (op. cit., pp. 400).

Firms' have a set of rules/heuristics which are standardised within the organisation and which enable the firm to go about its daily business. They are partially codified and partially tacit channels of communication within firms. Nelson and Winter's comment suggests that routines are at the very essence of the firm's strength, even its existence and that they tend to persist, although there is scope for incremental change. Because routines are developed from the firm's own experiences they will tend to be firm specific and idiosyncratic in nature. With specific application to technology, the notion of routine may be applied at different conceptual levels.

It may suggest that firms embody technologies in processes and products in a routine manner e.g. certain combinations of technologies will be used together, in the same way, time and time again to produce a product as they lie at the technological heart of the firm. Alternatively, routines may suggest that the firm uses the same technologies routinely to produce a range of products, but that the technologies are used in a different balance of combinations and in different ways. However, Nelson and Winter's definition also builds in scope for the existence of meta-routines that might bring about changes in subordinate routines. For example, firms may establish

[1] Of course evolutionary economic theory has its origins in the works of Joseph Schumpeter in the

routines that require them to be on the constant look out for new technologies that will enhance the current technological combinations that then improve products and processes and so lead to incremental innovation where 'innovation' means a change in routine has taken place. The 'new' technologies need not be entirely 'new' in the conventional sense of the word to the firm or industry, just novel in its application to existing routines - as in the Schumpeterian concept of innovation involving the "carrying out of new combinations" (Schumpeter, 1937, pp. 65-66).

Search

The example of the meta-routine described in the above example is in this instance is synonymous with 'search' (Levinthal and March, 1981). Nelson & Winter (1982) describe search as:

> "all those organizational activities which are associated with the evaluation of current routines and which may lead to their modification, to more drastic change or to their replacement" (ibid, pp. 400).

Thus, search itself may be routinised and predictable but may also stochastically generate mutations. Behaviour in all routines associated with success - including ones related to search, will tend to be repeated whilst behaviour which is associated with failure will either not become routinised, or if embedded in existing routines, these routines will be altered or ultimately dropped altogether and replaced by new ones. By keeping successful routines, the firm builds persistence into its profile of competencies.

With respect to technological competencies and search, currently successful technologies and successful search routines for new ones will be maintained by the firm, possibly for long periods of time. On the one hand, currently successful routines might result in shortsighted firms who will, in time, suffer from organisational inertia. On the other hand, if the routinised search for new technologies is successful at identifying technologies of potential use to the firm and it is deemed that it is necessary for the firm to build up some level of competence in that area, or indeed own that technology, successful search routines may result in technological

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1930's and is also highly influenced by the work of Herbert Simon from the 1950's.

diversification. However, diversified behaviour can also potentially arise because of failures; either the technology itself failed within the context of the firm sparking the need for renewed search, or the search and selection routines that led to this technology's adoption by the firm, themselves failed in that these routines led them to choose an 'inappropriate' technology. Thus, routines tend to become modified through a process of incremental and cumulative learning (Stiglitz, 1987; Levinthal and March, 1993; Dodgson, 1991, 1993; Malerba, 1992; Marengo, 1992; Loasby, 1993; Cantwell, 1994).

Routinised search suggests that firms are continuously and actively looking for new solutions to threats and opportunities from both the technological environment and more conventionally, product markets. For the most part firms will engage in the same type of search - for example, looking for technological threats/opportunities within the realm of its competitors' and partners' activities in its own industry or sector, but perhaps occasionally, firms may find opportunities from areas where they would not have expected e.g. from neighbouring industrial sectors, from another distinct industry, perhaps a new country or particular scientific area within the science base. All these areas form part of the firm's 'selection environment'.

The selection environment

This is described as:

> "the ensemble of considerations which affect its [the organisation's] well-being and hence the extent to which it expands and contracts. The selection environment is determined partly by conditions outside the firms in the industry or sector being considered…but also by the characteristics and behavior of the other firms in the sector" (Nelson & Winter, 1982, pp. 401).

This suggests that the firm has to look beyond its own sector for opportunities and solutions to current problems. The most suitable of these solutions are likely to lie 'close into' the firm's current competencies, activities and interests. In other words, they are likely to come with more frequency from the firm's own technological locality or industry. Patel and Pavitt (1994) and Fai and von Tunzelmann (2001a) have demonstrated that profiles of industrial technological competencies are largely distinct and persistently so overtime, with the exception of general-purpose technologies that pervade across industrial divides. However, the firm should still routinely search (and monitor) not only its immediate technological environment (up-stream suppliers, down-stream users and direct competitors) but also more broadly in other industrial areas and the science base. The extent to which effort is devoted in any of these areas may be industry dependent as suggested by Pavitt's taxonomy (1984).

Nelson and Winter's selection environment potentially has two meanings. First, it can be the environment from which the firms selects potential opportunities to follow (Baum and Singh, 1994) and secondly, it can be the environment in which the firm itself is selected as survivor or a victim because of its technological or other strengths or inadequacies. The two are linked in that consistent failure to do first successfully[2] ultimately means that the firm will become weaker and be selected out of the environment as in the second interpretation. My focus is on the first of these interpretations although I am aware that the firm's environment is constantly changing and it is possible for successful routines developed from the firm's experiences in a particular environment to be misleading when the environment changes. Thus, here the selection environment represents the technological 'space' from which firms can select new technologies to use in the production process or embody in new/existing products and thereby diversify either or both their portfolios of technological competence and/or products.

Resource-based theory

Resource-based theory has its foundation in the work of Edith Penrose, (1959). Penrose perceived the firm as "more than an administrative unit; it is also a collection of productive of resources" (pp. 24). Interest in this perception of the firm more or less lay dormant until the early 1980's (with the notable exception of George Richardson's contribution in 1972) but since then much interest in the approach has be stimulated by scholars such as (Wernerfelt, 1984; Dierickx and Cool, 1989; Montgomery and Hariharan, 1991 and Foss, 1996, 1997). It considers a resource to be

[2] This is not the same as saying that they have to be consistently successful - firms do fail in their selection of perceived opportunities and solutions from time to time but they may also improve themselves through a process of learning-by-failing.

an asset of a given firm which at any given time, is tied semi-permanently to the firm (Wernerfelt, 1984). It addresses the assessment of firm resources, their accumulation (Dierickx and Cool, 1989) and how to focus these in such a way so as to convert distinctive competence into competitive advantages that match market opportunities. In particular, the approach concentrates on firm-specific resources that are long-lived and difficult to imitate "history matters, profits are persistent, and change most often occurs slowly and incrementally" (Peteraf, 1991, pp. 14 from Foss *et al.*, 1995, pp. 8).

Complementary aspects

Because of the obvious attraction of the notions of firm-specific resources and the acknowledgement that historical events and past decisions are important, evolutionary theorists and business management scholars have become particularly interested in the view of competencies as resources and their implications for company performance and long-term economic growth (Prahalad and Hamel, 1990; Eliasson, 1994; Duysters and Hagedoorn, 1996). A competence-based theory of the firm has emerged from the more general resource based approach (Richardson, 1972; Winter, 1987, 1991; Nelson, 1992; Loasby, 1991; Foss, 1993, 1997). However, within this body of literature, much of the discussion about competencies remains broad and addresses managerial, organisational and technological competencies together even though they have been recognised as being distinct from one another (Dosi and Teece, 1993). Technological competencies (Cantwell, 1991b) are a subset of the firm's entire profile of competencies and the competence-based theory is particularly appropriate for a study of technological change from an evolutionary perspective because in the former, "the resources with which a particular firm is accustomed to working will shape the productive services its management is capable of rendering…" Penrose (1959, pg. 5). Hence, past resources affect what managers can do today and current resources will affect what mangers can do tomorrow. This accords with the evolutionary perspective in which technological change is perceived as an incremental, cumulative and path-dependent process in which history plays a key part (Nelson and Winter, 1982; Arthur *et al.*, 1987; Arthur, 1989; Cantwell, 1991a; Kelm, 1995).

The evolutionary and resource-based approaches are also complementary in other ways such as their recognition of diversity among and within firms etc., and in their mutual support lent to strengthen each other's weaker points. For example, the evolutionary approach essentially views firms from the industry level whilst the resource-based approach looks within firms themselves, although many of the fundaments of evolutionary theory are as useful to the analysis of firm evolution as they are to the evolution of industries (or indeed nations, Nelson, 1988, 1992, 1993). Similarly, complementarity exists between the evolutionary approach's examination of the process of change whilst resource-based theory originally took a static equilibrium approach (Foss *et al.*, 1995). Of particular interest are those works that have recognised the evolutionary characteristics of cumulative, incrementally changing but path-dependent knowledge embedded in organisational routines, and fused this with the idea that resources may also encompass accumulated knowledge bases[3]. For example, Winter (1987) has identified knowledge, competence, skills, know-how or capability as strategic assets, of which one specific form of particular interest here is technological competence (Cantwell, 1991b).

Competencies and technologies as resources have been recognised to be partially codified, partially tacit, but definitely context specific, and tied to local skills and routines. As a result, a firm's portfolio of technological competencies is highly firm specific. Each firms' history and experiences differ and because there are initial differences between firms in terms of competencies and their context-specific development (in addition to their different input endowments in the more traditional economic sense), we would expect to observe highly idiosyncratic firm behaviour with respect to the direction and rates at which firms' develop their technological skills.

However, one of the dangers of relying heavily on the resource-based perspective is the potential to ignore the external environment that will select among firms. In order not to be 'selected out' by the external environment firms need to have the competence to deal with change in both its own internal operations and broader environment. Teece, *et al*., (1990, 1997) and Teece & Pisano (1994) have identified such skills as 'dynamic capabilities'. Dynamic capability is the ability to:

[3] For a collection of works on this synthesis, see Montgomery, C. A. Ed. (1995), *Resource-based and Evolutionary Theories of the Firm. Towards a Synthesis*. Kluwer Academic Publishers: London..

> "demonstrate timely responsiveness and rapid and flexible product innovation, coupled with the management capability to effectively co-ordinate and redeploy internal and external competences" Teece & Pisano (1994, pp. 1)

The possession of dynamic capability is a complement to the possession of a broad range of resources and competencies and might also be seen as a strategic asset (Markides and Williamson, 1994, 1996). It is insufficient for a firm's long-term survival to possess solely a broad range of complementary resources if it is unable to manage them in such a way that they afford the firm a source of competitive advantage in the longer term. Because the environment around them changes, firms must alter how they use internal prior accumulated competencies and in the process, create or acquire new ones (Nonaka *et al.*, 2000). They must engage in the process of diversification.

Diversification

What is diversification? The New Shorter Oxford Dictionary defines it as:

> "the action of diversifying; the process of becoming diversified… *diversify*…**a** exhibit or produce diversity; vary. **b** of a company etc.; enlarge or vary its range of products, field of operations etc. to reduce its dependence on a particular market etc."

The idea of diversification in the traditional perspective was based very much on the need for firms to offset the economic risk and uncertainty of being dependent on a particular market. This diversification took place in two directions: vertical and horizontal. Diversifying vertically upstream would offset the risk of upstream factors of production coming to a sudden halt through problems in the contractual principal-agent relationship with suppliers of inputs. Similarly, diversifying downstream offset risks associated with barriers to entry to markets by rival firms e.g. the closure of distribution channels. Diversifying horizontally across markets offset the risk of profits being eliminated by the reliance on either a single product market or geographic region and moreover, yielded the benefits of economies of scope and/or scale in the use of factor inputs. Advocates of the transactions cost based approach (Coase, 1937; Williamson, 1985) would require the internalisation of many activities in order to reduce the costs and risks of non-ownership and control. As a result firms became larger, more bureaucratic and slower in their decision-making and reaction to changes in their environment. Only when the costs of internalisation exceeded the costs of conducting the activity via the market, did the boundaries of the firm end.

Interestingly, whilst the desire to offset risks and reach new markets for many firms remains due to the pressures of globalisation, a number of authors (Gambardella and Torrisi, 1996; Piscitello, 1998; Andersen and Walsh, 2000) have made empirical observations, particularly in hi-tech industries, that the product bases of firms have shrunk whilst their technological bases have broadened. This suggests the levels at which we should be considering diversification needs to be refined and defined.

Indeed, the recent past and current era sees diversification in a different light (Penrose, 1959; Montgomery and Hariharan, 1991; Granstrand and Oskarsson, 1994; Markides and Williamson, 1994, Markides, 1995; Argyres, 1996). Diversification is still a strategy for offsetting risk, however diversification has been recognised to exist not only at the levels of products and markets, but also at the level of technology itself. Diversity particularly across technologies is no longer a choice, but a necessity. The pace of development and change in many industries requires firms to be technologically agile. The sophistication of the production processes if not the products themselves involves high degrees of technological complexity. Firms need to develop competencies with a wide range of technologies, even if they do not directly engage in the design and production of the product or process that embodies that technology. They need to do this so that they can usefully engage in relationships with suppliers and partner firms who might be providing component inputs. In other words, firms must 'know more than they do' (Brusoni et al, 2000). Firms should no longer perceive diversification solely as a defensive strategy against risk and uncertainty, but a necessity for survival in a changing world. The possession of a wide range of technological competences and the combinative ability to use them creatively is a way to offset the risks associated with the current product market becoming unprofitable in the future. It forms a basis which firms can leverage quickly to move into new areas in the future if they need/want to without necessitating participation currently. Thus, efforts and resources are able to fully focus on exploiting the currently profitable markets without making the firm totally dependent upon it for its future. Moreover, technological diversification might also be seen an offensive strategy since firms have been recognised as a source of innovation and growth (Cantwell and Fai, 1999). Firms can shape the technological trajectory of their own industries as well as be shaped by the technological environment of the industry in which they operate.

Technological Diversification

There is much work extolling the virtues of diversification across product markets, across strategic business units (SBU's), industries and geographically (Rumelt, 1974; Porter, 1985; Pearce, 1983; Chandler, 1990b; Markides and Williamson, 1994, 1996) and across financial assets (as in portfolio theory). Even within the areas of resource-based and evolutionary approaches, diversification has largely focused upon the reasons for, and nature of product diversification (Rumelt, 1974; Teece, 1982; Pavitt *et al.*, 1989). In the course of such studies the consideration of the notions of relatedness and coherence (Dosi *et al.*, 1992; Teece *et al.*, 1994; Foss *et al.*, 1995; Langlois and Robertson, 1995) have arisen. These concepts led to the perception that by diversifying into related product markets or other areas which lie 'close in' to the firms existing profile of competencies and lines of business, firms could grow (Penrose, 1959) and also attain economies of scale and scope (Chandler, 1990b) in their (technological and other) competencies. In this way, with relatedness between products lying in the use of existing competencies in various complementary combinations, the firm is able to diversify and expand its product base whilst corporate coherence is maintained.

More recently, within the strategic management literature, Markides & Williamson (1994, 1996) expanded upon these rather simple concepts of relatedness to identify three types of "dynamic relatedness". Essentially, the competencies used to develop strategic assets in one strategic business unit (SBU) may be applied in any of the following manners:

- from an existing SBU to improve another existing SBU
- from an existing SBU to aid a new SBU
- From a new SBU to improve an existing SBU.

Markides & Williamson however, still consider diversification through the application of a rather non-specific notion of competencies across business units rather than diversification of technologies *per se*. The specific subject of corporate *technological* diversification itself is less mature, even in the evolutionary perspective.

Granstrand (1999) has identified that technological diversification can simultaneously lead to growth in the firm's R&D expenditures and growth in the technology based firm in the form of increased sales in five different and partly complementary ways (pg 126):

i) static economies of scale (using same technology in several products);
ii) dynamic economies of scale (multiple uses of a technology lead to learning and consequently should lead to improvements in the technology);
iii) economies of scope (cross-fertilisation of technologies can yield new innovations and improve performance of exisiting ones);
iv) economies of speed (intrafirm technological transfer is faster and more effective than interfirm transfers); and
v) economies of space (a technologically diversified company can benefit from operating in multiple locations which have a high concentration and diversity of technologies that yield spillovers).

Furthermore, academic interest in technological diversification has been stimulated by i) the observation that artefacts and processes are becoming more technologically complex over time (Pavitt *et al.*, 1989; Granstrand and Sjölander, 1990, 1992; Cantwell, 1993) but that ii) amongst the largest firms, diversity in technological competencies has become broader than across product ranges with some firms even deliberately refocusing and narrowing their product ranges in the late 1980's and early 1990's (Markides, 1995; Granstrand *et al.*, 1997; Pavitt, 1998) and iii) technologies that were once quite distinct are being combined together in new ways, and 'fusing' to form new technological areas of their own (Kodama, 1986, 1992).

Indeed, few products are made with simple processes these days and recent studies suggest that technological diversity is essential to produce even once simple products. (Rycroft and Kash, 1999). Firms are becoming more "multi-tech" (Granstrand and Sjölander, 1990; Oskarsson, 1990; Granstrand *et al.*, 1997). Moreover, the technological complexity involved in producing even some simple, let alone complex, products is more than one firm alone can handle (Patel and Pavitt, 1997; Rycroft and

Kash, 1999). Thus, whilst managerial capability remains a constraint to the growth rate of the firm, just as Penrose pointed out, it is not the only constraint. Sometimes firms require highly specialised, depth of technological knowledge; sometimes they merely require access to a breadth of shallow technological knowledge. However, the firm cannot adequately address both needs simultaneously (von Tunzelmann, 1995; Wang and von Tunzelmann, 2000) due both to a lack of resources to do so and the inability to manage such complexity in a single organisation. Over-diversification, or diversification into inappropriate technological directions may cause the firm to lose control over their competence leveraging and combinative capabilities, in other words, their organisational coherence (Dosi *et al.*, 1992; Teece *et al.*, 1994; Langlois, 1995; Pavitt, 1998). After all, Pavitt (2001) has highlighted that entrepreneurship in practice is inseparable from the knowledge on which it is based and in the face of the high levels of complexity today, new knowledge requires the assimilation of specialised professionals. Moreover, major technological breakthroughs are increasingly based on publicly funded research in universities and so corporate entrepreneurship will depend increasingly on academic entrepreneurship. Firms, in other words, will have to rely more on their external network organisation (Loasby, 1991).

One of the ways in which firms might simplify the complexity of issues they are facing is to consider whether technological diversification also requires them to engage in further product diversification. It certainly might enable them to do so but is there the desire to do so when the issues at the technological level are so complicated? The necessity cope with technological diversity has meant in some technologically dependent industries such as electronics and chemicals, increased technological diversity within firms, has been accompanied by a reduction in the diversity of product types produced by these firms (Gambardella and Torrisi, 1996; Piscitello, 1998; Andersen and Walsh, 2000). This makes some sense when the products in these markets appear to be exposed to radical market change more often than technological competencies are subject to radical technological change. Whilst distinctive products are competitive assets they may be short lived. Technologies on the other hand may be regarded as strategic assets in that they are firm-specific resources in which, through learning processes, capabilities and competencies can be developed (Wernerfelt, 1984; Peteraf, 1993; Montgomery, 1995; Markides and Williamson, 1996; Foss, 1997). Hence, investment in the largely cumulative, incremental and path-dependent nature of technology provides a better strategy for long-term survival and competitive advantage than investment in a particular product market. The shifts in this type of thinking have meant that technology has risen to the top of the strategic agenda instead of being confined to the research and development departments of firms.

Technological diversification – implications for the firm

The issue of technological diversification is not addressed by traditional neo-classical economic approaches. By treating technology as a 'black box' (Rosenberg, 1982, 1994) - an exogenous factor that can be drawn upon at anytime from a population of technologies - technological diversification becomes an ad hoc and random activity. When the firm realises that market forces are telling it that demand is falling for its current products, the firm merely selects a different combination of factor inputs to produce a new product that suits the market's demands. Similarly, when the price mechanism tells it that its goods are priced uncompetitively the firm is assumed to be able to adjust the mix of its capital-labour ratio, thus employ a new technology and produce the same goods more efficiently and at lower cost than before. The causality in both cases runs from changes in relative prices in either factor or product markets towards technological change as a mere response to such market processes. This is a major fundamental weakness of traditional economic approaches as it allows for the oft-cited scenario of a manufacturer of high fashion shoes to become a producer of personal computers, to become a possibility (Patel and Pavitt, 1994). The firm is assumed to be able to just 'pluck' these electronic technologies from the exogenous technological space and apply them with relative ease, which is clearly not the case. We can (mis)apply the three basic concepts generated by Nelson and Winter, but they appear nonsensical. The notions of routines exist only in a very simple form in this scenario – the firm will switch from one routine to another in accordance with the market signals. There is no scope for learning, unlearning or the organisational memory that is embedded in routines. Search is easy and takes place within a selection environment that assumes full knowledge of all possible outcomes, and identifies the optimal outcome or technological combination of capital and labour that will enable the firm to achieve maximum profits.

Business strategists (Argyres, 1996; Markides, 1995; Markides and Williamson, 1994) as mentioned earlier, have more directly addressed the subject of diversification at the firm level. However, here technological diversification has been subject to a high degree of managerial discretion. Managers (as opposed to the dictates of the markets) decide which technologies they need to use and in which combinations. Here again, there is little, if any, consideration of the endogeneity of technological change and its path-dependent, incremental and cumulative nature. Hence, there is no consideration of how the processes of search and selection are affected by these characteristics. Nor has technology in this arena, been regarded much as a firm specific resource despite the competence that is generated from its use within production. Yet this build up of competence through routines and learning will both enable and limit managers in their choices with respect to the selection environment they are able to search within for new technologies and this is where the strength of a technological trajectory based argument holds promise.

The fact that firms are at least partially responsible for generating innovation and enhancing technological progress means that technologies cannot be 'plucked' from a general technological space under the pressures of market forces. Both the evolutionary and resource-based perspectives propose that by developing technologies and innovation themselves, firms accumulate large amounts of tacit knowledge that are complementary to the more codified aspects which might be more generally available. The accumulation of tacit knowledge both enables firms to generate new innovations and absorb technologies that are related to their prior capabilities and to draw upon those technological areas that are close to these capabilities. In this way firms will incrementally and cumulatively progress down particular technological trajectories whilst at the same time, their lack of tacit knowledge and underlying competence in other technological areas will prevent them from being able to follow other pathways. In this way, firms are limited to an extent in the directions in which they move and managers do not have sole discretion over the technological orientation of the firm but may in fact, be quite heavily constrained (Tidd *et al.*, 1997).

Whilst there is constraint over the direction of a firm's technological pathway, there is considerable room for managerial discretion over the timing and rate at which firms diversify (Patel and Pavitt, 1997). Ultimately though, it is the limits of managerial competence (Penrose, 1959) and organisational constructs that will constrain the growth of the firm. Contemporary firms face what von Tunzelmann calls 'the entrepreneurial problem of scale and scope in the late 20th century' (von-Tunzelmann, 1995, pp.279) whereby increasingly, many (complementary and related) technologies can, or even must, be used to make one product yet a single technology may also be applied in many ways to produce a range of different products. The manager needs to exercise discretion over how many of these technologies he wants to embody, in how many products, in what combinations and balances at any particular time. This separation of discretion over the extent of product diversity from discretion regarding technological diversity represents a significant development over Penrose's concept of diversification. Similarly, the manager needs to decide which technologies need to be maintained in-house and which can be sourced from market or quasi-market relationships.

Brusoni *et al*, (2000) have argued that the definition of the firm's boundaries in terms of the activities performed in-house fails to distinguish between the decision to outsource production from decisions to outsource technological knowledge. Firms 'know more than they do' and this enables them to engage in a number of organisational constructs dependent upon the state of product interdependencies (predictable/ unpredictable) and its relationship with the rate of change of component technologies (even/ uneven). Essentially, if product interdependencies are predictable and the rate of change of component technologies is even, the firm can use decoupled organisational structures i.e. use arms-length relationships with other firms. If product interdependencies are unpredictable and technological change uneven, then firm should engage with tight organisational coupling i.e. internalise the production and other activities. In the other two circumstances, either unpredictable product interdependencies with even rates of change in component technologies, or predictable product interdependencies and uneven technological rates of change among components, the firm should engage in loose organisational coupling. In other words, outsource production and detail engineering, use contracts and in in-house R&D and co-ordinate the two with systems integration. Moreover, firms will move between these types of coupling over time. I shall return to the Brusoni *et al*. framework for the organisation of technologies and production later. In what follows I will focus upon the relationship between technological diversification and product diversification alone.

<u>Relationships between product diversification and technological diversification</u>

Neo-classical economics sees diversification as just a change or an increase in variety of products to offset the risk of dependency on a single market. There is no consideration of how products are related to one another, no concept of firm specific technological competencies and hence no regard for the relationship between products and resources. However, we now recognise that a firm is composed of a set of businesses and a set of resources forming two separate but interrelated bases. As such, the firm can in enter into business/product diversification and/or resource diversification. It can focus on one or the other. However, the important source of dynamics in the evolution of the firm is formed by their interaction. Diversification in businesses and resources can occur in a sequential manner or concurrently. Since each business has a resource base which, may in turn, be exploited in different businesses, overtime, both the firm's resource and business base may shift with some resources, businesses or resource-business couplings being scrapped, some being kept and others added. Typically, there is more addition than scrapping, so this net addition results in diversification (Granstrand, 1999, pp. 123-4). Using this resource-product base framework, I look at technological diversification and its relationship to product diversification, both in a horizontal and vertical manner, and trace how our understanding of the relationship has evolved over time.

In the neoclassical economic perspective, firms that possessed the technology (call it '1') to produce product A and that wanted to horizontally diversify their product range, just selected a new combinations of inputs, which effectively determined the use of technology 2 to make product B. The relationship between products is nil, the relationship between technologies is nil and the relationship between products and technologies was simple and direct (see Figure 1a below).

Figure 1a: Relationship Type I – neoclassical (horizontal diversification)

Initial situation	*Diversified situation*	
Product A	Product A	Product B
↑	↑	↑
Tech 1	Tech 1	Tech 2

Similarly, if the firm decided that it need to diversify vertically (e.g. downstream) from component A into component B, then there need not be any technological relationship between the two, see Figure 1b. The incentive to own both technologies and products was cost-efficiency driven.

Figure 1b: Relationship Type I – neoclassical (vertical downstream diversification)

Initial situation	*Diversified situation*
Component A ← Tech 1	Component A ← Tech 1
	Component B ← Tech 2

There is no scope for the concepts of routine, search and selection, as explained earlier.

Penrose's (1959) concept of diversification recognises that entry into new product markets may be related through common resources, but does not really encompass the issue of technological diversification. Within her view, firms should exploit its excess capacity in resources, including technological competencies. This would imply that diversification of Type II occurs as illustrated in Figures 2a and 2b. Although simplistic, this was a considerable improvement upon the type of diversification neo-classical doctrine would suggest. A limited role for Nelson and Winter's three major contributions starts to emerge. By learning through the repeated use of routines, firms generate economic 'slack', which can be used for product diversification. Search and selection take place at the level of the product base, and moreover these are limited to areas in which the firm already possesses technological competency.

Figure 2a: Relationship Type II – Penrosian mark I (horizontal diversification)

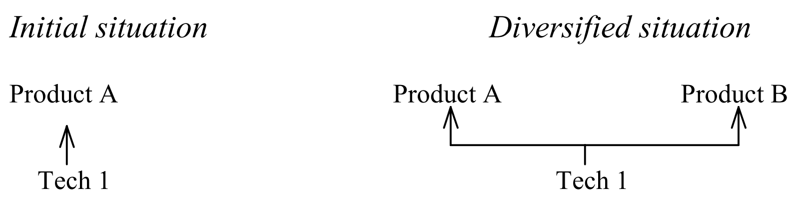
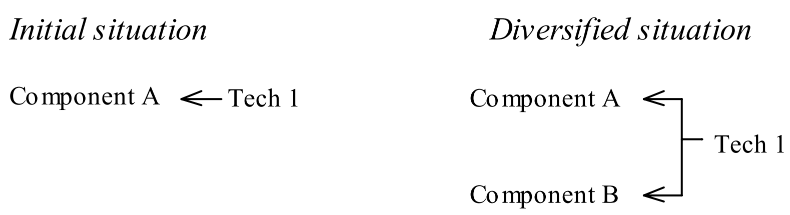


Figure 2b: Relationship Type II – Penrosian mark I (vertical downstream diversification)



Type II is pure product diversification with no technological diversification involved. Technology 1 is used efficiently for the production of product/component A. Excess capacity in technology 1 exists so this becomes a source of innovation and facilitates the innovation and production of product/component B. In Granstrand's (1999) terms, we have static economies of scale arising in the use of technology 1. In extending the application of technology 1 to a second product/component B, it is likely that the firm engages in a incremental learning process so dynamic economies of scale arise in its efficient use to produce both A and B. A relationship is formed between A and B via their mutual dependence on technology 1.

However, Penrose herself noted that:

> "Where diversification involves not only entry into *new markets* but also the establishment of a *new production base*, the competitive advantage in the new field can often be traced to the fact that the firm has developed productive services in its existing productive activities which are especially valuable in the new activity. These services may arise from the high development of a particular type of engineering skill, or a particular kind of chemical process, or from an extensive knowledge of some material or waste product that the firm has discovered can be profitably used. Of hundreds of examples of diversification examined in the course of this study only a handful could be found where there appeared to be no technological link whatsoever between the new production base and the old, and this held true

even though a large proportion of diversification was effected through the acquisition of other firms." (1959, pp. 130)[4].

Although not so explicit within her work, this implies that there is scope within Penrose's theory to consider diversification Type III (see Figures 3a and 3b).

Figure 3a: Relationship Type III – Penrosian mark II (horizontal diversification)

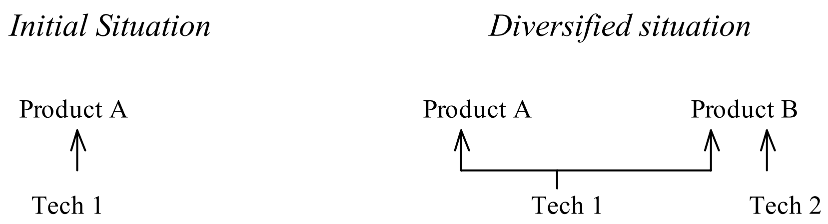
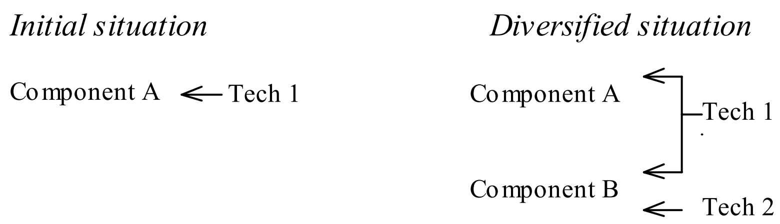


Figure 3b: Relationship Type III – Penrosian mark II (vertical downstream diversification)



Here the starting point is the firm's diversification from product A into product B (or component A into component B in the vertical case) using excess capacity in technology 1 just as in Penrose mark I. However, in the process of innovating B, the firm finds that it needs to develop competence in technology 2. The firm engages in economies of scope and cross fertilisation (Granstrand, 1999). By diversifying into further products or downstream components, the firm has also become technologically diversified. Relationships have been created between the two products/components via their common dependency on technology 1 but a relationship arises between the two technologies through their complementary contributions in use, to product/component B. This fits with Chandler's discussions of diversification of firms in the early twentieth century and their pursuit of new markets and in the process diversifying their technological bases (Chandler, 1990; Cantwell and Fai,

[4] Italics inserted by the author of the current paper

1999a; Fai and Cantwell, 1999; Fai and von Tunzelmann, 2001b). Furthermore, it demonstrates that routines facilitate learning in technology 1, which enables the firm to spot the opportunity for horizontal or vertical product diversification. However, the search and selection process are no longer limited to the product base, but also required at the technological level. Here, search and selection of new technologies (tech 2) is constrained by their need to be appropriate to the new product/component. The relationship between technologies 1 and 2 exists entirely through their complementary use in production, rather than any direct relation to existing technological competencies.

The contributions of research into technological trajectories in the evolutionary perspective however, have led to the recognition that technological diversification can occur independently of product diversification - a notion that is not picked up by Penrose. So, we now have a fourth type of relationship between product and technological diversification (see Figures 4a and 4b).

Figure 4a: Relationship Type IV – 'Pure' technological diversification (horizontal)

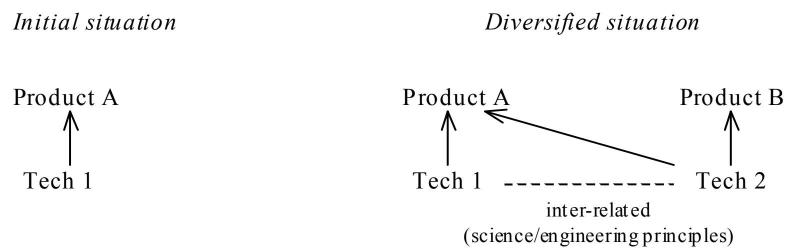
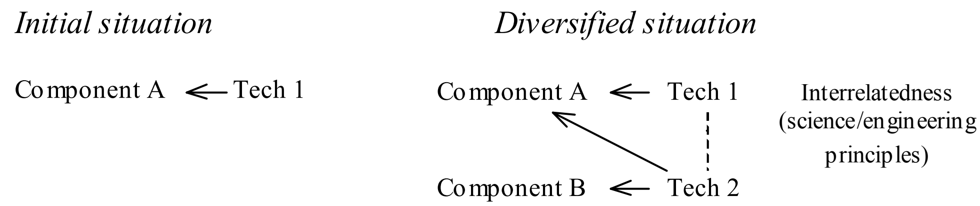


Figure 4b: Relationship Type IV – 'Pure' technological diversification (vertical downstream)



Here *technological relatedness* is the driving force of diversification in that the two technological areas are related by some underlying scientific/engineering principle, skill or knowledge (Breschi *et al*., 1998). At least two scenarios are possible. Firstly, through an extension of its understanding of and experiences with technology 1, the firm is able to build up competencies in a related technology, 2. Technology 2 may initially be required to improve product A. Here we have the case of technological diversification in the absence of product diversification. Over time, experience with technology 2 may enable the firm to pursue horizontal product diversification into product B (or vertical diversification downstream into component B), which it would not have been able to do without the prior underlying expertise it had accumulated with technology 1. A sequential, stepwise process of technological diversification followed by product diversification has taken place. In a second scenario, technological diversification into technology 2 may have been deliberately undertaken for the express purpose of enabling the firm to produce B, in which case, the diversification of the technological and product base is concurrent. This exposition that technological diversification can occur in the absence of product diversification, or that it may indeed spur product diversification, is a further and important development in our understanding about the relationship between product and technological diversification.

Application of the concepts of routine, search and selection suggests that experience in routines associated with technology 1 enables the firm to develop their expertise and knowledge in the underlying scientific or engineering principles behind technology 1. It is this underlying knowledge, which enables the firm to search and select for further technological opportunities. These new technologies may allow the firm to produce A more efficiently, to improve the technical aspects embodied within A or facilitate searches at the product level so that diversification into product B may occur either as a deliberate strategy, or as a positive spillover effect.

Thus, the above serves to illustrate that the resource-based approach challenges the neoclassical approach to diversification by introducing relatedness between the products based upon the utilisation of excess capacity in existing resources. The evolutionary perspective allows for the evolution of products and the resources (in this case, technology) based on the relatedness between technologies based on underlying principles and concepts. As a result of these developments, the emergence of the multi-technology firm (Granstrand and Sjölander, 1990) has been recognised as a distinct entity to the better-recognised multi-product firm, although most large firms today are likely to be a combination of both. This is a significant distinction given that the importance of product diversification (Penrose, 1959; Rumelt, 1974) relative to technological diversification appears to have diminished in recent times. Piscitello (1998) has observed, that whilst coherence in product diversification concerned firms in the late 1970's and mid-'80's, coherence in technological diversification has become a stronger feature among firms from the mid-'80's onwards.

Implications for coherence and structure

Given the increasing complexity of the world and that today's firms, particularly large ones, are typically multi-product and multi-technology (Granstrand and Sjölander, 1990, 1992); Granstrand *et al.*, 1997), when firms attempt to expand beyond single lines of business or technology there are necessarily implications for the issue of coherence within existing organisational structures. Evidence to this effect has been documented by Chandler (1966, 1990b, 1990a, 1992) and Rumelt (1974) in their discussion of firms moving from the functionally divisionalised U-form to the product divisionalised M-form when economies of scale in production were important for firm growth and market penetration. As such, much of the discussion on coherence was in relation to the level of products and the possibilities of expanding product ranges whilst maintaining organisational coherence (Dosi *et al.*, 1992; Teece *et al.*, 1994) and the discussion of the M-form appears to have been appropriate to achieve those aims. However, markets today are characterised for the most part by rapid change, a greater reliance upon science and high technology for innovation and a greater customisation towards user-needs. Firms need to respond to these pressures rapidly and with flexibility. As part of the move towards greater flexibility, empirical observation suggests that large firms in hi-tech industries are decreasing the size of their product base (Markides, 1995) whilst simultaneously expanding their technological base (Granstrand *et al.*, 1997; Piscitello, 1998; Fai and Cantwell, 1999; Fai and von Tunzelmann, 2001a). It seems that the M-form as we know it is no longer a suitable organisational structure for the current climate. If not, what will replace it? If technologies continue to become more complex and inter-related, should we expect to see firms continue taking on increasing numbers of technological areas and will they start to adopt different organisational forms? After all, the point is that firms should not just have a large number of technological competencies. Firms should also possess the dynamic capability (Teece *et al.*, 1990, 1997; Teece and Pisano, 1994) to make the most of their potential complementarity over the longer term to produce products and services, but without destroying levels of coherence within the organisation. Sustainable competitive advantage is the capability to exploit, and create new knowledge out of, existing knowledge (Nonaka *et al.*, 2000). In order to do this effectively, it seems natural to assume that the firm should be structured in such a manner that encourages rather than hinders this dynamic capability.

Penrose (1959) perceived there to be ultimately no limit to the extent of a firm's diversification, merely that the extent of diversification will be tempered by the rate at which it may diversify. However, large established firms have had a rougher ride in the past 20 years than Penrose might have predicted (Pavitt, 2001). One of the major outcomes of research in the recent past has been the recognition of technologies as separate from products. It may be that the organisational considerations need to be adjusted in the light of the recognition that products and technologies are two separate, but interlinked and even interdependent, elements.

At the level of technologies, limits or restraints to the extent of a firm's technological diversity are perceived to exist in the evolutionary perspective because of their relation to the firm's own past experiences and competencies:

> "…the search process of industrial firms to improve their technology is *not* likely to be one where they survey the whole stock of technological knowledge before making their technical choices. Given its highly differentiated nature, firms will instead seek to improve and diversify their technology by searching in zones that enable them to use and build upon their existing technological base." Dosi, (1988, pp. 225).

As a result, Penrose's conjecture has been re-assessed and incrementally altered by the perception that firms are limited in their technological directions to the bounds of their broad industrial class (Patel and Pavitt, 1997). This holds true even in the face of increasing complexity, because firms have accumulated a wealth of underlying knowledge and competencies in similar technological areas previously. This tendency serves to help firms maintain their organisational coherence at least a technological level (Richardson, 1972; Chandler, 1990b, 1992; Mowery *et al.*, 1995; Foss and Christensen, 1996). A firm's organisational coherence is likely to be more severely disturbed when technological solutions/ opportunities arise from industries outside of their own and other external institutions as the gap to be bridged by learning processes is greater.

With organisational coherence, firm-specific capabilities including technological and organisational ones, are more likely to be enhanced and the firm more likely to grow. However, organisational coherence (or the lack of it), will influence and in turn be influenced by organisational capability and organisational structure (Chandler, 1990b, 1992); Henderson and Cockburn, 1994; Hill, 1994; Marengo, 1995). If the firm lacks organisational capability, say because it is inappropriately structured, then its coherence will be weakened and the firm will suffer. For example, Rumelt (1974) examined the structure of product diversified firms over the period 1949-69. He found that firms that held their functional structure in an era of mass production faced administrative strains and so a large majority of them moved to product division structures to overcome this problem.

A parallel for re-structuring the organisational form in more contemporary times can be drawn here. Large firms have, in recent years been delayering, flattening, and increasing their reliance upon network alliances in an attempt to adopt more flexible forms of organisation which enable them to lever their accumulated competencies and knowledge (Nonaka *et al.*, 2000) more effectively.

Management and economic scholars have proposed a number of organisational alternatives for the leveraging of knowledge and competencies within large complex firms. Hill (1988) and Hill & Hoskisson (1987) – (from Markides and Williamson, 1996, pp.342) have proposed the centralized multi-divisional (CM) organizational form where

> "… the corporate center of a diversified firm exercises centralized strategic and financial control over the divisions and also intervenes in their operating divisions. In contrast, under the M-form structure, the head office does *not* get involved in the operating decisions of the divisions" (Markides & Williamson, 1996, pp.347).

This would not seem to me to be sustainable as it would ultimately strain managerial capabilities and cause information overload at the centre.

Bartlett & Ghoshal, (1991) have suggested that global corporations are moving towards organisational forms with looser network structures where knowledge and expertise are key strategic resources. These are distributed across the organisation in various nodes (subunits) and outputs, knowledge and personnel flow across the organisation to transfer and leverage knowledge and competencies. However, this remains essentially an internal organisational form, pertaining to the use of subsidiaries and SBU's in internationally dispersed multinational corporations although it does encompass Granstrand's fifth notion of economies of space that are gained via technological diversification (Granstrand, 1999).

Wang *et al.*, (1997) have suggested that "the M-form [and] its attendant weakness of separating functions in one product-related division from the same functions in other divisions has become much more evident" and so firms are moving from a functional to a process orientation (p.2)[5].

Increasing technological complexity within products and processes places pressures upon firms to take on more and more technologies. It also encourages them to know each one in considerable depth. Similarly, firms may desire, or be required to diversify their product bases to establish new markets or fill an existing niche. However, organisational coherence and capability place limitations upon the extent to which a firm may diversify at any moment in time (Kay, 1982; Teece *et al.*, 1990; Pavitt, 1998). A balance in the trade off between technological breadth and depth must be struck (von Tunzelmann and Wang, 1997) and the range of products the firms produces will necessarily have to be limited, but how will these be determined?

Von Tunzelmann and Wang (2001) have suggested that managing complexity in breadth, particularly in times of more radical technological change, requires new technologies and processes to be bedded down in the structure of the firm i.e. internalised, although whether they are combined with existing technologies is

[5] As a complementary comment to this discussion on organisational structure, it should be said that if capability and coherence are strong within the firm, they may be able to see the firm through any changes in organisational structure it may need to undertake in order to cope with it's growth or changing circumstances (see the account of Du Pont's experiences in Loasby, B. J. (1996),

dependent upon managerial capabilities. Management may be able change the structure of the organisation to facilitate spillover effects between technologies. On the other hand, the structure may become more fragmented through internal subdivision of departments using different technologies. Complexity in depth in the last 25 years appears to be characterised by industrial fragmentation. Firms managed complexity in depth by the increased use of external activity at least in the, machinery, food manufacturing, biotechnology and advanced instrumentation industries, although this need not always be the case. The development of new technologies and new generations of older technologies are being provided by specialist suppliers.

Richardson (1972) makes the general distinction that similar and complementary activities should be maintained in the firm's internal organisation as control and access, are both necessary to exploit such capabilities fully. For activities that are complementary but dissimilar, access alone in sufficient and thus can be retained at some distance in the firm's external organisation. This distinction applies equally well to similar and complementary products that are reliant upon common technologies, as it does to similar and complementary technologies that rely on similar underlying scientific and engineering principles.

Loasby (1991) makes the distinction between a firm's internal and external organisation in a different way: 'knowledge-how' (knowing how to do things for oneself) is distinct from 'knowledge that' (knowing how to get things done for you). The firm can thus maintain its direct capabilities internally and place its indirect capabilities in its external environment (Loasby, 1998, p.9) using market or quasi-market based alternatives (e.g. supplier partnerships).

Both these definitions complement the framework defined by Brusoni *et al*, (2000) which deals with the evolution of component technologies, product interdependencies and organisational coupling as outlined earlier. All three frameworks are highlighted in the following section as I attempt to bring together, technological diversification, product diversification and organisation.

'Organisational capability at Du Pont, 1890-1980,' in *Management, Marketing and the Competitive*

There are a number of ways the firm might choose to deal with the need for the absorption of a new technology and its impact on production and over all organisational coherence. If the new technology is related to existing technological competencies through the underlying science or engineering, but the firm is uncertain as to how it might be used to develop new products or improve existing ones, know-how will exist in the absence of know-that. Consequently, the firm will attempt to both develop competence in this new technology and maintain control over product development internally. The firm is likely to have determined that it needs not just access to the technology, but the ability to influence its development within the firm specific context. The technology and product are likely to form part of the firm's inner core (Prencipe, 1997). There will be tight coupling in the Brusoni *et al*, terminology. Thus, in relationship type IV above, the encompassing of technology 2 into the firm's existing portfolio is somewhat easier because of its scientific or engineering linkages to existing competencies associated with technology 1 (the Richardson reason for internalising). The absorption of technology 2 will thus, be relatively quicker generating economies of speed (Granstrand, 1999) and probably be less disturbing to the organisation's coherence.

The second manner in which firms may get access to a greater diversity of technologies is to use the market. Demsetz (1997) puts forward that in a world of complexity, transactions costs actually mean that the market becomes more important because complexity encourages specialisation and the proliferation of specialised firms in the market. This gives the user firm the ability to acquire/purchase a component or product that uses a depth of competence in a narrow technological area provided by the specialised supplier. The technology and the component in this case, remain in the user firm's outer core (Prencipe, 1997). It is feasible to use the market if, in the Loasby sense, it is not necessary to control the development of the technology by the firm requiring access to it. Indeed, many automotive firms sub-contract the production of components to lower tier suppliers, which are often smaller, specialised firms. Here, the products are complementary, but may rely on dissimilar technologies in each set of components and so support the Richardson argument for

Process, P. E. Earl, Ed. Edward Elgar: Cheltenham.).

the use of the external organisation. Furthermore, if the technology is discrete and standardised to a large extent, and the products and processes in which it is embodied are also standardised, then market transactions for are feasible because the levels of tacit knowledge accompanying the use of the technology are low. Hence, in the type III relationship above, technology 2 is merely acquired in the form of either component input for embodiment in the new/improved product, or in the form of new capital equipment in for inclusion in the production process. There is organisational decoupling between the producer firm and the user firm but the user firm must maintain a system integration capability (Prencipe, 1997).

The third option for managing technological and product diversity within an organisational context is for the firms to enter into quasi-market organisational forms such as collaborative ventures and long-term partnerships. In these situations the partners are recognised each to possess competencies that are potentially complementary but perhaps dissimilar (Richardson). Furthermore each party may be uncertain about how the technologies may be applied or have different ideas with respect to how they might embody such technologies in artefacts. When used together, the learning processes involved in drawing out the complementarities benefit both parties, and synergy and innovation result. Hence, the technology involved is not discrete or standardised and tacit capability requirements are high, but there is little necessity by either party to own the technology fully. Such relationships may form the firm's 'external organisation' (Loasby) and may consist of interactions with local institutions, down- and upstream markets and the local science base (Nelson, 1996). So this time, in the type III relationship, one firm may contribute technology 1 and another firm technology 2 and together the two partners engage in learning during the development and production of product B through the use of loose organisational coupling.

As the above reveals, organisational capability and coherence impacts upon the rate at which a firm may diversify. However, our understanding of the firm as an 'organisation' needs to be adapted to include not only the traditional internal departments, functions and activities of firms, but also its external organisation and relationship with other firms, suppliers, distributors and institutions in the science base. If a product or component requires new technology that involves radically different knowledge to that gleaned from the firm's previous and current technological experiences, organisational coherence may be severely disturbed. Therefore, we should expect technological diversification attempts by firms to be more successful when the firm diversifies in an incremental manner, building relatedly upon the areas in which it has a reservoir of expertise already. We should also expect them to continue becoming increasingly reliant on networks of relationships with other organisations and developing systems integration capabilities. In this way, organisational coherence both internal and external is maintained in the face of technological complexity and its complex interplay with product diversity.

Conclusion

This paper has sought to look at the issue of technological diversification and its implications for the firm. The nature of technological diversification is a process and is best explained with a combination of the evolutionary and resource-based perspectives. It is important because of the technologically complex environment firms are operating in and because of the need to manage technologies in order to produce technologically complex products (either complex in their production process e.g. pharmaceuticals, or complex in the product itself e.g. medical diagnostic equipment). As a result of the arising complexity, it is important to understand the nature of the relationship between technological diversity and product diversity. Four possible relationships were outlined. These relationships will influence technological coherence and the organisational structure required to maintain organisational coherence in the face of technological complexity. Hence, technological diversification has multiple implications for the study of the firm.

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