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Formalising intellectual property protection as a key indicator of the evolution of a developing country MNC

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A research project submitted to the Gordon Institute of Business Science, University of Pretoria, in partial fulfilment of the requirements for the degree of Master of Business Administration.

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ABSTRACT

Prior research on capability upgrading in developing country firms has emphasised the importance of gaining legitimacy in the public domain. For technology-based firms this implies disclosure of knowledge assets through patents and scientific publications. In the absence of a managed approach to intellectual property (IP) protection, this disclosure often takes place in a desultory manner with disappointing results. Therefore, this research focuses on the formalisation of IP as a key indicator of the evolution of a developing country technology-based MNC using Sasol as a case study. The paucity of research into South African firms compared to the abundance of literature on the evolution of firms from other developing countries provides further justification for this study.

Patent and publication data associated with Sasol (1955-2005) was analysed using multidimensional scaling and multiple regression techniques in order to examine the nature of disclosure. Patent value was estimated using forward citations and an adaptation of Putnam's Value Index, while journal impact factors served as a proxy for the value of scientific publications. The role of international connections was investigated by examining co-authorships.

The evidence suggests that formalisation of IP promotes an awareness of the purpose of disclosure, enhancing indigenous capability to appropriate returns from R&D and gain legitimacy within the global research community. This evolutionary trajectory may be accelerated by leveraging international research connections.

DECLARATION

I declare that this research project is my own work. It is submitted in partial fulfilment of the requirements for the degree of Master of Business Administration at the Gordon Institute of Business Science, University of Pretoria. It has not been submitted before for any degree or examination in any other University.

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CONTENTS

There are no secrets to success. It is the result of preparation, hard work and learning from failure.

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1. INTRODUCTION TO RESEARCH PROBLEM

During the process of capability upgrading, technology firms accumulate knowledge stocks that can either be appropriated (i.e. used by the firm for its own new processes, products or services) or used as currency for external scientific exchange with other parties. The codification of these knowledge assets in the form of patents and scientific publications enables their use as information transfer mechanisms (Long, 2002). However, many developing country firms do not have the capacity to extract full value from this form of disclosure. This results in failure to appropriate returns from R&D investment, and a lack of credibility amongst peer technology firms in developed countries.

This study aims to explore the extent to which formalisation of intellectual property is an indicator of the evolution of a developing country technology-based firm. The role of effective international R&D linkages in providing impetus to the capturing of value from disclosure also forms a key theme in this research.

1.1 Problem definition

The role of multinational companies (MNC's) in the upgrading of developing countries through foreign R&D activities was the focus of a recent World Investment Report dedicated to *transnational corporations and the internationalisation of R&D* (UNCTAD, 2005). The report found R&D activity in developing countries to be taking on a more innovative rather than adaptive guise. There was also evidence of increasing investment by developing countries MNC's as a means to gain access to advanced technological capability within developed economies. Since this is a fairly recent phenomenon, the contribution of these firms to global R&D spend is relatively small, yet there is a clutch of Asian companies that are attracting considerable attention through their rapid expansion of R&D activities; for instance, three South Korean firms feature on the list of the top 700 R&D spenders worldwide (Samsung Electronics – 33rd, Hyundai Motor – 95th and LG Electronics - 110th) (UNCTAD, 2005). These companies are indigenous to the so-called Asian Newly Industrialised Economies (NIE's) which are characterised by their late-industrialisation and technological catch-up through the success of their multinationals (Wong, 1999).

In contrast, the BRICS countries (Brazil, Russia, India, China and South Africa) are characterised by their adoption of generally isolationist policies in the second half of the twentieth century, and have only fairly recently started to re-enter the global economic arena. Indeed, little has been said of the foray of South African multinationals into the developed world. Certainly, the imposition of political and economic sanctions against the country severely hampered efforts of firms to globalise. However, the transition to democracy in 1994 ushered in an era of ever-increasing outflow of foreign direct investment (FDI) as South African companies expand globally. In terms of R&D expenditure however, only one company from South Africa makes the list of the top 700 R&D spenders in the world: Sasol, listed 516th with an R&D spend of $91m in 2003 (UNCTAD, 2005).

This research focuses on the formalisation of intellectual property as a key indicator of capability upgrading of an emerging multinational technology-based firm from South Africa, using Sasol as a case study.

Sasol is an indigenous South African petrochemical company that has commercialised the technology to produce fuel from coal using the Fischer-Tropsch technology (Collings, 2002). Initially intended by the government of the day as a strategic alternative to spiralling oil prices and embargoes of the 1970's, the company has recently emerged as a leading supplier of the technology for the monetisation of stranded gas deposits in the Gulf region. This is the culmination of a strategic decision that 50% of the company's revenue would come from offshore business by 2005. This decision was based on the company having experienced considerable organic growth over the past fifty years, as well as significant expansion through targeted acquisition of firms with complementary technologies (Collings, 2002).

Evidence of organisational learning can be found in the accumulation of indigenous capability (Madanmohan, 2000) and in the technological milestones that punctuate Sasol's history. However, assessing the degree to which capability upgrading is reflected in learning to manage intellectual property requires a more nuanced study of the formalising and protection of technological advancement.

Prior research has highlighted the use of patents as indicators of technical change (Griliches, 1990), and of scientific publications as the currency needed for technical knowledge exchange (Hicks, 1995). However, for many developing country firms, these channels of disclosure do not yield the expected returns on investment. It has further been suggested that the success of firm-level innovation systems is dependent on the state of the prevailing national system of innovation (Hobday, 2005). At another level, the role of effective international research connections in overcoming institutional failures in developing countries has been highlighted (Katz and Martin, 1997). Recently, a study by Barnard (2006) revealed that FDI outflows from developing country firms to developed countries can offer opportunities for capability upgrading through access to knowledge networks. These studies highlight the plethora of research that exists on organisational evolution from the perspective of capability upgrading. Nevertheless, there remains a clear need to explore how the transition to formalised intellectual property management has enhanced value capture from disclosure of knowledge assets, and how this serves as an indicator of organisational evolution.

Therefore, the objective of the present study is to use patent and publication data from Sasol to develop a theoretical framework that explains the relationship between the management of intellectual property and capability upgrading in a technology-based developing country firm.

2. LITERATURE REVIEW

In order to position the study within the domain of academic research, it is necessary to critically review the relevant literature. The role of capability upgrading as a key component in the evolution of developing country organisations sets the broad context within which a number of themes are developed. These include a review of the primary indicators of capability upgrading, particularly in the context of technology-based firms, where the protection of intellectual property is of critical importance. The use of patents and scientific publications is discussed in order to evaluate the propensity for formal disclosure of technological advancement. Finally, a consideration of the role of external linkages as enablers to capability upgrading in the context of developing country firms provides further texture to this review.

2.1 Key aspects of the organisational evolution of the MNC

Well established MNC's typically exhibit complex internally differentiated structures (Bartlett and Ghoshal, 1989) as a result of the array of sub-environments and strategic objectives that constitute the operations of the MNC. Indeed, a longitudinal study of two pharmaceutical companies by Malnight (2001) revealed that MNC's increase their structural complexity in response to increasingly complex global environments. The formation of integrated technological networks by MNC's, particularly in Europe, is believed to be correlated with national technological competitiveness (Cantwell and Janne, 2000). The research highlights the formation of networks for deriving strategic advantage due to the 'combinative capacity' which reflects both the individual strengths of operating units as well as the degree of integration between them. These findings further suggest that the organisational debate has moved beyond the traditional dichotomy of centralisation versus decentralisation. Much, if not all, of this research has been conducted on firms from the developed world that have expanded operations to other countries. Research on firms emanating from developing economies and attempting to achieve the status of integrated MNC is less prolific. One of the most relevant texts is a study by Barnard (2006) which investigates the development of capability bases of developing country firms through investment in advanced economies. Using multi-level analysis, the study reveals a complex relationship between the struggle to compete and the creation of knowledge that occurs primarily through more informal mechanisms. In order to deal effectively with the complexity of deriving competitive advantage through knowledge creation, Murmann (2003) has attempted to link industrial, technological and institutional dynamics using co-evolutionary theory. His model, articulated through case studies of the synthetic dye industry, describes the historical development of national institutions concomitantly with technological advancement and the protection of intellectual property via patent systems.

Two diametrically opposed views on organisational evolution exist; one assumes path-dependency (Patel and Pavitt, 1997) and the other purports periods of discontinuous change interspersed between periods of relative stability (Romanelli and Tushman, 1994; Sabherwal, Hirscheim and Goles, 2001). In the latter model, referred to as punctuated equilibrium, exogenous shocks (technological, political or economic) or radical internal events can act as sources of discontinuity.

The gradualistic path-dependent model considers the competencies of firms to be cumulative and developed through local search (Patel and Pavitt, 1998; Stuart and Podolny, 1996). This stance is based on evolutionary economics which posits that innovative capability follows prior investment in infrastructure and competency development (Teece, Pisano and Shuen, 1997). These competencies are stable over time and determine the portfolio of innovations that are patented by firms, producing what is referred to by Patel and Pavitt (1998, p. 206) as "Revealed Technological Advantage".

Proponents of the punctuated equilibrium theoretical framework have criticised the path-dependent model for implying that the fate of technology is determined at the outset of capability development (Loch and Huberman, 1999). Instead, it is argued that even radical technological innovation is sufficient to disturb the state of equilibrium that exists as a result of endogenous routines and inertia (Haveman, Russo and Meyer, 2001; Romanelli and Tushman, 1994). With specific reference to technology diffusion, Loch and Huberman (1999) assert that punctuated equilibria exist because the new technology may destroy existing competencies or disrupt the current business network. Furthermore, the presence of positive externalities related to the technology could assist in achieving a state of disequilibrium.

2.2 National Innovation Systems and implications for developing countries

The multifarious literature on the topic of National Innovation Systems (NIS) ranges from the mere existence of national institutions of innovation (such as universities and research institutes) alongside R&D departments housed in technology-based firms (Freeman, 1992), to the need for a mutually reinforcing relationship between each constituent (Nelson and Rosenberg, 1993). Much has been written on the influence of innovation systems on the success of firms. From an integrated perspective on the resource-based view of the firm, the network interaction process of technological learning in the context of late-industrialisation, Wong (1999) has developed a conceptual framework to explain the divergent evolutionary patterns that emerge from the innovation systems of Korea, Taiwan and Singapore. This is further extended by the work of Hobday (2005) who has critically evaluated firm-level innovation systems of developed and developing countries. A very recent study on capability upgrading of foreign subsidiaries in Thailand highlighted the importance of national policy mechanisms in encouraging skills development and the receptiveness of developing country firms towards upgrading (Hobday and Rush, 2007).

2.3 Development of capability

Many researchers have expounded on the initial work on absorptive capacity by Cohen and Levinthal (1990), which relates to the ability of firms to recognise and assimilate foreign information for commercial gain. With specific reference to technology, García-Morales, Ruiz-Moreno and Llorens-Montes (2007) have recently developed a model that analyses the extent to which organisational learning and innovation is influenced by technology absorptive capacity and technology proactivity. The former is simply the ability to exploit external technology, while the latter refers to the degree to which firms provide leadership in the industry and shape direction as a result of their absorptive capacity (García-Morales *et al*, 2007). In periods of rapid technological change, this requires dynamic capabilities (Teece *et al*, 1997). In developing countries developing absorptive capacity is an essential component of upgrading, since most technology is imported (Bernardes and Albuquerque, 2003). However, it is likely that the foreign technology will not function optimally in the developing country firm, possibly as a result of incomplete understanding, or the need for adaptation for local conditions.

Therefore, developing country firms are likely to engage in learning-by-doing and learning-by-learning routines in order to develop indigenous technology capability (Lall, 1993; Madanmohan, 2000). During this period, the firm would be expected to endure numerous setbacks or failures which may have substantial financial or technological implications. As a coping strategy, Madanmohan (2000) offers a project management approach to attaining indigenous technology capability, by institutionalising routines and systems that reinforce the underlying capability base.

From a synthesis of the literature, Hobday and Rush (2007) list nine dimensions of capability required by technology-based firms:

- an awareness of the need for internal capability
- the ability to select the appropriate technology
- the ability to acquire and absorb foreign technology
- the ability to conduct local search and cope with exogenous threats
- the creation of a unique competitive advantage
- a strategy for technology management
- effective implementation of technological solutions
- organisational learning routines that support technological change
- ability to form and exploit external linkages

However, as noted by Ernst (2002), this upgrading is not automatic and requires significant investments in technology and human capital.

2.3.1 Codification of technological advancement

R&D-intensive firms place a heavy reliance on their stocks of knowledge assets (Daizadeh, 2006). Indeed, according to Teece (1998), the exploitation for commercial gain of technological know-how, intellectual property and branding are amongst the most important determinants of wealth creation at the firm-level. This recommendation by Teece followed his seminal paper titled *Profiting from Innovation* (Teece, 1986)[1], in which he advocated a shift in focus in the management of knowledge assets from cost minimisation to value capturing. Central to this theoretical framework was the argument that the inherent ease of

[1] In 1999, voted the most cited paper in the journal *Research Policy*

replication as well as the strength of legal impediments to competitors determined the imitability of innovation (Teece, 2006). Together these constituted the "appropriability regime" (Teece, 1986, p. 285), in which business strategy decisions required an understanding of the value of intellectual property. A study using patent and publication data, undertaken by Mina, Ramlogan, Tampubolon and Metcalfe (2007) is a relevant example of the codification of knowledge for the accumulation and dispersion of intellectual property.

2.4 Intellectual property protection in a developing country

Notwithstanding the existence of a highly structured, efficient patent system in the developed world, the enforcement of intellectual property protection in the developing world has long been a topic of heated debate (Oddi, 1987; Sell, 1995; Chen and Puttitanum, 2002). Conventional wisdom is that weak IPRs (Intellectual Property Rights) in developing countries have encouraged imitation of (foreign) technology to the benefit of domestic consumers, while reducing the market power of foreign innovating firms. A corollary is that stronger IPRs serve the interest of foreign innovating (typically Northern, or developed country) firms at the expense of locals, and hence most innovations in developing countries fall outside the patent system (Oddi, 1987).

However, Chen and Puttitanum (2002) argue that strengthening IPRs in developing countries is beneficial to promoting domestic innovation activity. From a dataset of 64 developing countries (including South Africa) for the period 1975-1995, an empirical analysis revealed a U-shaped relationship between GDP per capita (used as a proxy for level of technological capability) and IPRs (Chen and Puttitanum, 2002). This supports the notion that imitation dominates when IPRs are weak and innovation dominates when IPRs are enforced. The authors conclude that domestic innovation in a developing country will increase concomitantly with intellectual property right protection, and that the optimal level of IPR will depend on the level of technological ability (or economic development). Central to this conclusion is the pervading assumption that innovative ability is directly correlated with economic development.

The positive impact of IPRs in aiding domestic development is expounded upon by Oddi (1987). In a comprehensive assessment of the impact of the International Patent System on the developing world, Oddi examines whether the granting of patents may facilitate the transfer of technology in support of industrial development. The main finding is that, while the purchase of technology is an efficient approach to capability upgrading, many developing countries lack the level of industrial sophistication to practice inventions that have been patented by innovative firms from the developed world (Oddi, 1987).

2.5 The value of patenting

According to Levin (1986, p.199), "in theory, a patent confers perfect appropriability by granting legal monopoly of an invention for a limited period of time in return for a public disclosure". In reality however, many patents provide little protection to the inventor because they are impossible to enforce or because alternative approaches to the same solution exist. Based on a survey of 130 R&D-intensive industries, it was found that patents were only viewed by R&D executives of chemical industries as being effective in maintaining competitive advantage (Levin, Klevorick, Nelson and Winter, 1984).

In addition, *product* patents were deemed more useful in conferring appropriability than *process* patents, and patents substantially increased the cost of imitation in chemical-related industries (Levin *et al*, 1987). In a subsequent publication, Levin purports that patents may be useful for purposes other than conferring appropriability, including, amongst others, gaining access to foreign markets through licensing (Levin, 1986). The use of patents as ‘bargaining chips’ for cross-licensing has also been reported (Reitzig, 2003). A further benefit may come in the form of economic returns (as royalties) or recognition earned by inventors (Griliches, 1990; Harter, 1994).

The salient features of novelty and inventive activity have also been used to define the value of patents (Reitzig, 2003). Novelty is described by Reitzig (2003, p. 14) as “the technological distance between the patented invention and the prior art”. This definition has been further expounded upon by Greene and Scotchmer (1995) for whom the value to the patent-holder is the degree of novelty embodied in the patent. This is distinguished from the ‘obviousness’ factor which is the degree to which the invention might have been an obvious approach based on existing knowledge (Reitzig, 2003).

2.5.1 Patents as indicators of technical change

Since the early work by Comanor and Scherer (1969), numerous efforts have been made to connect patents to technical output and subsequent improvements in profitability (Cantwell, 1993; Almeida, 1996). In their analysis of new products and chemical entities in the pharmaceutical industry, Comanor and Scherer (1969) observed a weakly positive correlation between patent applications (rather than granted patents) and new products.

Patent data was used by Almeida (1996) to track knowledge sourcing by multinational firms in the US semi-conductor industry. From this study it emerged that patents played a key role in evaluating inter-firm technical expertise and in regional technological development.

2.5.2 Propensity to patent

Despite the economic justification for patenting, not all inventions are patented (Mansfield, 1986; Lieberman, 1987; Harter, 1994). This may be for reasons of imperfect appropriability (Levin, 1986), lack of enforceability (Levin, 1984) or rapid obsolescence of inventions (Mansfield, 1986). A decline in the number of patents granted to US inventors during the 1970's was even hypothesised to be a result of disillusionment with the patent system (Milnamow, 1982), although data presented by Mansfield (1986) on the percentage of inventions patented invalidated this theory. Instead, Mansfield's work lent support for the notion of inter-industry differences in the propensity to patent.

Low research-intensive industries derived little value from the patent system in commercialising new products, while firms engaged in chemicals-related activities sought patent protection for 80 percent of their patentable inventions (Mansfield, 1986). Trade secret protection was generally considered more effective for processes rather than products (Levin, Klevorick, Nelson, Winter, Gilbert and Griliches, 1987).

The propensity to patent appears to be closely related to the behaviour of non-innovator firms in the same industry (Lieberman, 1987; Harter, 1994). Innovator firms tend to patent when there is little indication that non-innovators will utilise the disclosed information directly to imitate the invention. The propensity to patent was found to be lower in situations when imitation risk was high (as in the case of weak IPRs). Harter concluded that patenting by innovating firms was done primarily to prevent close substitutes (Harter, 1994).

2.5.3 The role of patents in capability upgrading

From an empirical study of the chemical industry, Lieberman (1987) asserted that learning-by-doing stimulated an increase in process patenting. It was further argued that significant subsequent incremental innovation followed as a result of spillovers from these initial patents. In response to a model developed by Spence (1984) (based on Arrow's 1962 concept of imperfect appropriability) which suggested that an increase in R&D spillovers would reduce the incentive to invest in R&D, Levin undertook a survey on the effectiveness of alternative methods of learning using a sample of 650 R&D executives at 130 industries (Levin, 1988).

Respondents rated licensing, reverse engineering and independent R&D as being the most effective methods of acquiring technical knowledge, yet also the most costly.

Other spillover channels, such as patent disclosures, scientific publications or informal conversations, were seen as significantly less expensive but highly effective approaches to acquiring valuable rival firm technical information (Levin, 1988). Furthermore, this study revealed that where technical advance is cumulative, rather than discrete, spillovers from rival firm innovations may increase the value of in-house R&D. This led Levin to argue that, contrary to the findings of Spence, spillover effects may actually encourage R&D investment.

2.5.4 Patent citations as indicators of spillovers

According to Griliches (1990), the identification and measurement of R&D spillovers remains a major issue in the field of economics of technology. The use of patent data to identify sources of knowledge and the future users of this knowledge has become commonplace. International Patent Codes (IPC) provide insight into the areas of technological activity that firms are active in based on the classification of their patent applications (Griliches, 1990). However, inconsistencies in classification and the application of IPC codes as well as the fact that the US Patent and Trademark Office (USPTO) has its own unique system of classification often limits their use as indicators of knowledge spillovers.

Regional data of inventors or country of assignee has been used by Jaffe (1989) to investigate spillovers emerging out of academic research. More recently however, patent citations have been used as indicators of knowledge spillover (Trajtenberg, 1990; Jaffe *et al*, 1993; Jaffe *et al*, 1996; Harhoff *et al*, 1999; Jaffe *et al*, 2000). A citation of one patent in another is an acknowledgement of the existence of the first patent as an antecedent to the current invention. The already-existing body of knowledge on a topic is referred to as ‘prior art’ and there exists a legal requirement for inventors to disclose all known forms of prior art in their patent application. According to Reitzig (2003), backward citations of patents have been used to operationalise the novelty of new patent applications.

In order to demonstrate the path-dependence of innovation capability in the Japanese semi-conductor industry, Stuart and Podolny (1996) used patent citation data to position firms according to similarities in their technological niches.

Patent citation data has been used to track the geographic localisation of R&D spillovers (Jaffe *et al*, 1993). Jaffe and Trajtenberg (1996) found that the probability of citation of a patent over time varied with a mixture of diffusion and obsolescence functions. Given that the study was largely confined to patents filed by US corporations and institutions in the United States, an observation that intra-country citations were more numerous than foreign ones is perhaps not surprising.

As noted by Long (2002), the codification of knowledge in the form of patents serves both to privatise as well as publicise information in a credible manner. Hence, patents “exchange information for protection” (Long, 2002, p. 626), and therefore the amount of information disclosed should be dictated by the requirements for protection (Horstmann, MacDonald and Slivinski, 1985). Given that disclosure through patents enables appropriation of knowledge assets for commercial gain, the publication of research in scientific journals presents an interesting tension (Rappert, Webster and Charles, 1999). As with patents, scientific publications signal the existence of knowledge assets, but, instead of conferring appropriability, journal articles serve as the currency needed for exchange of technical knowledge within the scientific community (Hicks, 1995).

2.6 The purpose of scientific publications

Of all the traditions created by people throughout history, participation in science is atypical in that it involves global participation, rather than parochial cultivation (Schott, 1993). Science is therefore referred to as the “body of public knowledge” (Kurata *et al*, 2007, p. 1403), and scholarly journals are the primary means by which researchers communicate their findings. In addition to forming a repository of scientific endeavour for future reference, journals also serve the purpose of giving recognition to researchers. The critical assessment of manuscripts submitted for publication by independent experts, via a process of peer-review, ensures a certain level of quality in scholarly journals (Pickar, 2007).

Thus, according to Kurata *et al* (2007), scholarly journals exist for the sole purpose of formal communication, enabling both a public critique of the scientific information contained therein, as well as a public acknowledgement of the contributions to science made by the researchers themselves. Furthermore, according to Sorenson and Fleming (2004), publications are an important mechanism for accelerating the rate of technological innovation as a result of their rapid diffusion of knowledge. Indeed, citations to scientific publications have been used to measure the diffusion of science around the world (Fok and Franses, 2007). As a result, researchers seek to have their work accepted for publication in high impact factor journals (Garfield, 1972) since this carries prestige and greater exposure, with the increased possibility of being cited.

Since they contribute to the prior art, publications are often used as a defensive strategy by laggard companies seeking to affect the patentability of related inventions by swifter competitors (Bar, 2006). However, this strategy requires both firms to invest more heavily in research than they would have done in the absence of such publications. Therefore, the study by Bar (2006) revealed that follower firms should utilise defensive publications when lagging significantly behind a firm that is deemed to be close to filing a potentially vital patent.

2.7 Management of Intellectual Property

According to Sherry and Teece (2004), management often confuse the value of technological innovation with the value of the intellectual property rights (IPR) associated with it. Indeed, the legal process of drafting, filing and prosecuting a patent application has no direct bearing on the technology, but can add significant economic value. Therefore, in circumstances where appropriability is possible and knowledge assets exist, Pikethly (2001) purported a formalised approach to IP management in order to ensure that the maximum benefit is derived from IPR. According to the author, a clearly articulated IP strategy is required to ensure alignment of IP practise with business objectives, and clarify the firm's approach to litigation in the event of infringement (whether offensive or defensive).

Furthermore, an internally-managed IP department would oversee the creation and protection of intellectual property with the assistance of patent attorneys (Pikethly, 2001). In its capacity as custodian of intellectual property, the IP department would be expected to advise on the most appropriate vehicle for IP protection (patent, defensive publication or trade secret).

A pragmatic approach to managing IP within the business paradigm developed by Daizadeh *et al* (2002) has proven useful in formulating an approach to the protection of patentable ideas.

This framework (Figure 1) reveals the close relationship between patents and publications in IP management, and emphasises the trade-off between the protection and dissemination of research information. Indeed, as noted by Tijssen (2004), the spillover of technical knowledge, whether by formal means of disclosure, or accidental leakage, does increase the risk of appropriation by competitors.

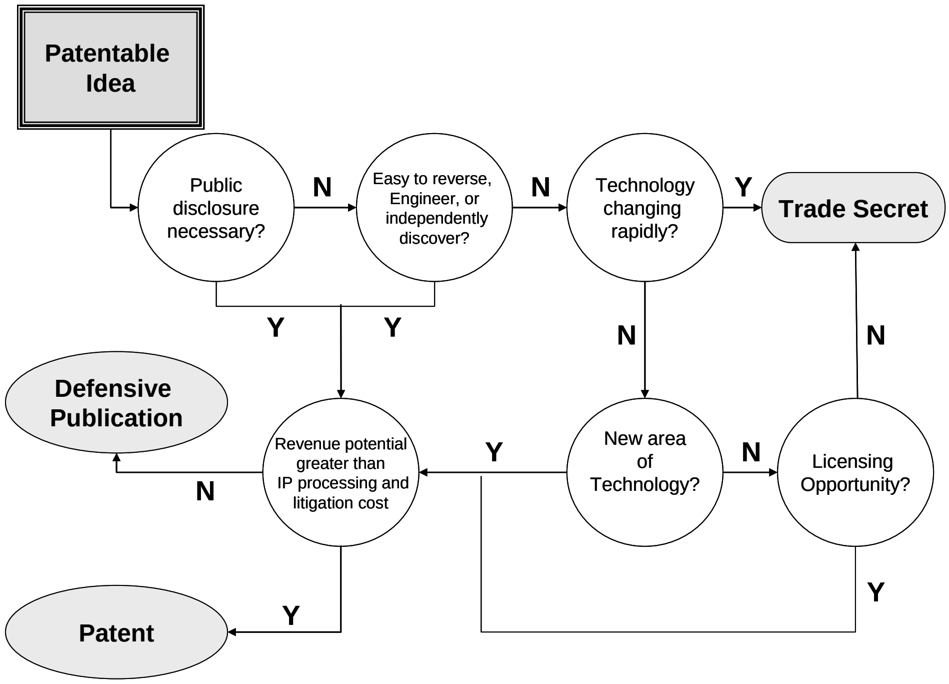


Figure 1: Decision tree approach to evaluating the most appropriate vehicle for IP protection (From Daizadeh *et al*, 2002)

While this methodology provides a logical framework for assessing the implications of pursuing different forms of disclosure, it does not address the inherent patentability (novelty) of the invention. Thus, firm-wide IP awareness, encompassing researcher through IP lawyer is required to ensure effective IP management (Daizedeh, 2007).

2.8 Management of innovation in MNC's

The R&D function is typically responsible for the development and maintenance of proprietary technology within firms. With the unique challenge this presents, effectively managing innovation in MNC's has also been the topic of much research. Nobel and Birkinshaw (1998) examined patterns of communication and control in international R&D operations and identified three typologies namely; local adaptor, international adaptor and international creator. The authors concluded that each type needs to be managed through a different mode of control and this has implications for the management of global innovation. Furthermore, their findings suggested that international R&D units are often intentionally given discrete areas of responsibility that *minimise* the level of technological interdependency between research groups. From this they conclude that global R&D is an ideal that is hard to achieve in practice.

One of the ways that multinationals can leverage innovation capabilities within their global network is through the formation of centres of excellence (Frost, Birkinshaw and Ensign, 2002). These centres of excellence have been defined by Frost *et al* (2002, p. 997) as "an organisational unit that embodies a set of capabilities that has been explicitly recognised by the firm as an important source of value creation, with the intention that these capabilities be leveraged by and/or disseminated to other parts of the firm." The formation of these centres of excellence is governed to some extent by the local environment as well as various aspects of the subsidiary's relationship with other parts of the multinational firm. Research on the evolution of cross-border corporate networking has also focussed on the 'stickiness of knowledge' and knowledge networks as relevant constructs in the emerging global network economy (Ernst and Kim, 2002). This is further extended to the knowledge context of the firm, which is defined by Fey and Birkinshaw (2005) as the openness to new ideas and the codifiability of knowledge assets, and is seen as an important indicator of R&D performance, along with the choice of governance mode for external R&D. This finding suggests that the strategy that a firm employs to access external knowledge determines its ability to achieve superior performance.

2.8.1 International Connections

A recent study of innovation data gathered from the UK Community Innovation Survey revealed that multinational firms have a higher propensity to innovate, and can sustain longer periods of continuous innovation (Frenz and Ietto-Gillies, 2007). According to von Zedtwitz and Gassmann (2002), the internationalisation of R&D is seen as a mechanism to exploit location specific innovation advantages. The authors assert that international R&D is not synonymous with a globally integrated approach to research, and that access to scientific and engineering skills is more of a determinant of the archetype than geographic origin or industry. Therefore, in the wake of disruptive changes imposed on national innovation systems by globalisation, developing country firms can benefit from international linkages (Ernst, 2002).

2.8.2 Research Collaborations

Faced with the challenges of rising costs of innovation, and shorter development cycles, firms are increasingly seeking to collaborate (Tijssen, 2004). Although research collaborations represent a unique category of 'connection' at the firm-level, the general concept of collaboration in research is somewhat nebulous and there is a lack of consensus on the precise definition (Katz and Martin, 1997). It has even been suggested that science is a global collaborative effort (Subramanyam, 1983), and that it is therefore senseless to try to isolate specific interactions. Collaborations can occur at multiple levels, between any number of individuals and across boundaries (Wagner and Leydesdorff, 2005). In an attempt to understand the nature of collaborative effort, Katz and Martin (1997) developed a classification system. According to their taxonomy, *homogeneous* collaborations occur between individuals and institutions that all share some common feature and *heterogeneous* collaborations are between individuals or institutions from different sectors, locations or disciplines.

In evaluating the propensity for firm-level collaboration, Stuart (1998) proposed a positional explanation based on the relative differences between capabilities. Thus emerging firms would seek alliances as a means to gain legitimacy amongst established players in the industry (Stuart, 2000). Therefore, the author argued that these alliances serve as "pathways for the exchange of resources and signals that convey social status and recognition" (Stuart, 2000, p. 791).

In a different vein, Chen (1997) suggested collaboration in the form of decentralised R&D as an operational tactic to gain access to funding and skills.

The themes of ‘access relationships’ (Stuart, 2000) and ‘connectedness’ of technology firms (Cockburn and Henderson, 1998) have recently become more pervasive in the literature (Lee, Lee and Pennings, 2001). Reasons offered for this include the role of information technology in bridging geographical distance between researchers (Wagner and Leydesdorff, 2005), and improving political factors (Katz and Martin, 1997). The latter relates to the upgrading of capacity in countries where infrastructure does not exist or has been ravaged by conflict. As an example, Katz and Martin (1997) cite the role of Western Europe in supporting research in parts of Eastern Europe following the political changes that have occurred there.

Amid the lack of agreement on what constitutes a definition of collaboration, there is broader consensus on the bibliometric use of co-authorships as a measure of collaborative activity (Subramanyam, 1983; Wagner and Leydesdorff, 2005). However, since the very definition of collaboration is vague and open to interpretation, bibliometric analysis of co-authorships can only suffice as a partial indicator of the extent of joint research activity. As mentioned by Katz and Martin (1997), bibliometric analysis only considers the names and affiliations of co-authors, and therefore any other form of collaboration that does not result in authorship, will be excluded.

By tracking co-authorships, Wagner and Leydesdorff (2005) mapped the network of global science over the period 1990 to 2000, and observed the emergence of regional hubs, together with a general rise in internationalisation of research. Parts of the network appear to be developing independently of the national systems of innovation, and the authors suggest that these national systems are likely to be positively influenced by the increased exchange of knowledge between multinational firms.

2.8.3 Technological acquisitions

The acquisition of foreign firms is another common strategy adopted by MNC's for establishing international connections. From a resource-based view of the firm, Ahuja and Katila (2001) investigated the impact of acquisitions as a means to expand the technology base of firms in the chemical industry. It was found that post-acquisition innovation performance was positively correlated with the absolute size of the acquired knowledge base. Moreover, a certain degree of relatedness in technology bases increased the likelihood of higher post-acquisition performance (Ahuja and Katila, 2001).

2.9 Conclusion to literature review

In summary, from an evolutionary perspective, organisational development is characterised by varying stocks of knowledge assets. These may be accumulated over time, or arise from a discontinuity in the technological or business paradigm of the firm. For technology-based firms, the successful exploitation of these assets is a nuanced interplay between technology absorptive capacity, appropriability regime and the prevailing national system of innovation. In the case of multinational firms, international connections contribute on various levels towards capability upgrading. Finally, the codification of tacit knowledge through patents and scientific publications emphasises the tension between dissemination and protection of knowledge assets, and highlights the imperative for an integrated approach to intellectual property management.

Although the literature does extract evidence from developing country firms, the paucity of studies on South African technology-based firms presents an opportunity for research. Moreover, while patents and publications may signal firm-level capabilities, the reviewed literature does not present conclusive evidence for the formalisation of intellectual property protection as a clear indicator of organisational evolution. There exists the need therefore to evaluate the extent to which deriving value from formalised intellectual property protection is an indicator of capability upgrading.

3. RESEARCH QUESTION

From a review of the literature, it is apparent that the challenges facing emerging multinationals from developing countries are somewhat different to those encountered by firms in the developed world. Moreover, the process of capability upgrading is evolutionary and occurs along with technical and business development. However, the literature does not adequately address the issue of precisely how capability upgrading of a developing country technology-based firm is reflected through external disclosure while deriving value from the process of intellectual property protection.

Therefore, the focus of this research will be:

How is capability upgrading reflected in learning to manage the IP process?

Two propositions have been formulated with respect to this research question by operationalising the construct *learning to manage IP* in terms of capturing *value* in the IP process.

Proposition I

Developing a deep understanding of the ***purpose*** of formal ***disclosure*** is an essential component in capturing the ***value*** inherent in ***intellectual property protection***.

Proposition II

Effective international connections are enabling factors in deriving value from intellectual property.

4. RESEARCH METHODOLOGY

The relevant literature positions this study within the context of developing country multinationals on an evolutionary trajectory towards an integrated network organisation, operating in both the developed and developing world economies. The role of IP and the positive contribution made by international connections in engendering a deepening awareness of learning-based spillovers form the central themes in this study.

4.1 Research Design

The research has taken the form of a historical study of patents, scientific publications and annual reports from 1955 to 2005 to track how the science, technology and managerial competency base of Sasol became increasingly capable of dealing with the complex issue of intellectual property protection. Given the fact that 2007 marks the 50th anniversary of Sasol's R&D division, this study was well-timed to reflect on the role of disclosure and international linkages in capability upgrading during this period.

According to Yin (2003), case studies are the preferred strategy when interested in developing a textured understanding of contemporary organisational phenomena such as the maturation of industries. In contrast, archival or historical analyses are better suited to dealing with tracing operational behaviours and trends over time (Yin, 2003). Furthermore, historical studies are the only alternative when no relevant persons are available to corroborate evidence, even retrospectively. When historical studies deal with events that become contemporary, they begin to take on the guise of case studies and can be treated similarly when archival evidence is replaced with interviews and observations (Yin, 2003).

Case studies, and historical studies of a single case, are generalizable only to the propositions that are put forward regarding the subjects under study, and not to wider populations (Yin, 2003). They empirically deal with contextual conditions, and attempt to elucidate the decision pattern that resulted in, or emanated from a specific context. The use of both quantitative and qualitative evidence in historical studies is not uncommon (Yin, 2003).

In a 1962 publication in *The Business History Review*, Clarence Walton reflected on some of the major challenges experienced by students of business history (Walton, 1962). One of the fundamental issues concerned the debate surrounding the appropriateness of history as a methodology in the study of corporations. In attempting to clarify the main issues, Walton argued that historians provide a “commodious edifice, structured in reality” (Walton, 1962, p. 27), which must contain sufficient economic context so as to be relevant. Cleometric (historical economics) analyses, and corporate archival studies are among the most common in business history (Forman, 1981). In many instances, the subjects of study of business historians are no longer in existence and hence the outcomes of this research is often only of academic value. In addition, Forman argues that company histories constructed by outsiders often neglect current information and contemporary views, and frequently misrepresent reality or lack perspective (Forman, 1981). As a result, current trends in historical research are towards aggregate studies of industries rather than characterising the influence of well-known political events or the activities of leading individuals. In turn, aggregate studies require access to large, representative samples and the use of statistical methods in order to make inferences. Although historical, the present study benefited from considerable personal insights and perspectives from current Sasol employees.

In the present study, narratives have been used to supplement statistical analysis in order to investigate the validity of each of the research propositions formulated in response to the research question. The specific methodology adopted is described in detail hereunder.

4.2 Population and sample size

Patents

The entire portfolio of patent applications filed or acquired by the Sasol Group of Companies during the 50 year period from inception in 1955 until 2005 constituted the population of patent data used in this study. This amounted to 835 patent applications filed in any of 95 countries worldwide. An array of sampling frames was applied in order to analyse the impact of acquisitions on the patent portfolio, as well as any shift in emphasis from a country-filing or technology perspective over time.

Patent data have been used as a measure of innovative output since the pioneering work by Schmookler and Scherer in the 1960's (Comanor and Scherer, 1969). Yet, despite the prolific literature on their use, patent counts alone are regarded by some as imperfect measures of innovation activity in organisations (Lanjouw, Pakes and Putnam, 1998). Therefore, in the present study, patent counts are used in conjunction with other measures (such as quality and intensity of scientific publication) in order to examine the process of capability upgrading in a more substantive fashion.

Scientific Publications

All publications in scientific journals or proceedings from conferences, authored or co-authored by Sasol employees during the period 1955-2005, were included in the population of scientific publications. The journal impact factor (Garfield, 1972) was used as a proxy for publication value, according to the database of the Institute for Scientific Information (ISI).

Proposition I: Developing a deep understanding of the ***purpose*** of formal ***disclosure*** is an essential component in capturing the ***value*** inherent in ***intellectual property protection***.

Patents and scientific publications constitute two of the most common forms of formal disclosure of scientific endeavour. Therefore, in addressing the first proposition, the *process* of formal disclosure was defined in terms of the constructs *learning to patent* and *learning to publish in scientific journals.* These constructs were then operationalised using a combination of qualitative and quantitative methodologies to assess changes in patterns of formal disclosure of technological advancement as a function of time. Estimation of the *value* inherent in patents and scientific publication was done by adapting published methods developed for this purpose.

4.3 Proposition I: Methodology

A narrative on the development of Intellectual Property at Sasol was constructed using personal insights of employees and archived material. In combination with annual reports, patent and publication data this contextualised the case study.

The process of learning to patent and publish was followed by dividing the patent and publication data into two eras:

1. Pre formal IP function (pre 1997)
2. Post introduction of IP function (post 1997)

These eras represent two (of three) distinct periods in the evolution of intellectual property at Sasol. The third era relates to the role of Advisory Boards and will be dealt with in Proposition II.

Prior to the introduction of a formal IP function in 1996, patenting was done on an ad hoc basis. The formalisation of the IP group brought company-wide realisation of the value in assessing the most appropriate vehicle for protecting intellectual property.

4.3.1 Multiple Regression Analysis

Multiple regression analysis was done using the NCSS Statistical software package (Hintze, 2004) in order to identify the determinants of trends in patenting and publishing in journals over time. Technological trends were followed by classifying these documents according to three broad themes: Gas Production, Gas Conversion (represented as Fischer-Tropsch Technology) and Chemicals Synthesis. The latter included non-FT routes to chemicals production. Turnover and workforce data were added as control variables.

4.3.2 Multidimensional Scaling

The evolutionary trajectory of intellectual property protection at Sasol was also modelled by applying multidimensional scaling (MDS) to patent and publication data. Changes in in-house patent filing strategies, and the focus of acquisitive strategies were modeled by including technology area and country filing data in the MDS study. NCSS Software (Hintze, 2004) was used to perform the MDS analysis.

Multidimensional scaling was selected because it affords a graphic portrayal of the evolution of patenting strategy at Sasol, and highlights the often subtle relationships between in-house and acquired patents in terms of technology focus. Using similarity (or dissimilarity) as an input, this application of multivariate analysis generates a spatial representation of objects without the *a priori* knowledge of the relevant dimensions of the objects to be scaled (Schiffman, Reynolds and Young, 1981).

By extension of the Pythagorean Theorem, the actual distance between two points *i* and *j* can be computed using the Euclidean distance formula:

$$d_{ij} = \sqrt{\sum_{k=1}^{p} \left(x_{ik} - x_{jk}\right)^2}$$

Where *p* is the number of dimensions, d_{ij} is the distance, and x_{ik} is the value of the i^{th} row and k^{th} column of data (Hintze, 2004).

The proximity of objects is used to operationalise the constructs of similarity and dissimilarity; the latter representing the distances between objects and the former being the conformity to the rule: $similarity_{ij} \leq (similarity_{ii}$ *and* $similarity_{jj})$ for all points *i* and *j*. Both similarity and dissimilarity matrices are symmetrical. In this study, a correlation matrix was first computed in order to determine the similarities (s_{ij}) between variables, and these were converted to dissimilarities (d_{ij}) using the formula:

$$d_{ij} = \sqrt{s_{ii} + s_{jj} - 2s_{ij}}$$

Dissimilarities were entered as an upper-triangular matrix.

In classical (metric) multidimensional scaling, the actual distances between points are computed, while in non-metric MDS, the ranks of the distances are reproduced in spatial format. It has been found that non-metric scaling provides a better fit in low dimensionality than metric solutions (Schiffman *et al*, 1981). Hence, non-metric multidimensional scaling has been applied in the current study.

The goodness-of-fit statistic for an MDS model is the *stress*, which is a measure of the variance between the actual distances (d_{ij}) separating points and their predicted values ($\hat{d}_{ij}$), according to the formula:

$$stress = \sqrt{\frac{\sum\left(d_{ij} - \hat{d}_{ij}\right)^2}{\sum d_{ij}^{\ 2}}}$$

It is highly dependent on the number of dimensions used and the type of algorithm selected. The parsimonious solution that yields an acceptably small stress value determines the number of dimensions that are required to represent the dissimilarity matrix accurately. Typically, stress values below 0.05 are considered acceptable.

The number of dimensions that should be retained in the solution is also indicated by the relative sizes of the positive eigenvalues, and the cumulative total of the percentage of the eigenvalues accounted for by the number of dimensions selected. In the MDS plot, the data is scaled so that the sum of squares for each column is equal to the eigenvalue for that dimension (Hintze, 2004).

The evolution of the IP landscape of Sasol over five eras from 1955 to 2005, each punctuated by a technological milestone, was mapped using non-metric MDS. The justification for the number of dimensions retained in each solution was based on achieving a minimum cumulative percent of total eigenvalue variation greater than 95 percent and a stress value of less than 0.05 within a maximum of 50 iterations.

The results have been represented graphically in pairwise dimensions, with the axes labelled according to the dominant opposing eigenvalues. Relationships between the variables were inferred from their spatial orientation.

4.3.3 Analysis of Variance

In order to evaluate the degree to which the attitude towards patenting and publication changed over time, a two tailed test using the one way analysis of variance (ANOVA) of means at a significance level of α=0.05 was performed with 'Era' as the grouping variable. The statistical significance of the ANOVA test was determined using the F-ratio (α=0.05). The null hypothesis (H_0) specifying that all means are equal was rejected in favour of the alternative hypothesis (H_a) where $p < 0.05$. However, rejection of the null hypothesis merely indicated a significant difference between means, but yielded no insight into which pairs of means were different.

Therefore, having rejected the null hypothesis for the ANOVA, the Bonferroni All Pairs Multiple Comparison Procedure was used to ascertain *which* pairs of means were significantly different (Hintze, 2004). It is a two-tailed t-test that assumes independence between eras and controls the probability of making a Type I error for the entire family of eras, denoted, α_f, by choosing the appropriate pairwise error rate, denoted α. The probability of making a Type I error, α_f, increases exponentially with the number of eras (*c*), according to the relationship $\alpha_f = 1-(1-\alpha)^c$ and therefore, to achieve a α_f of 0.05 with five eras, the comparison pairwise error rate was set to α=0.01.

4.3.4 Valuation of patents and publications

The second integer in the first proposition related to the capturing of ***value*** inherent in the IP process. This required an assessment of the value of patents and publications.

As proxy for the value of scientific publications, the impact factor of the journal in which the paper appears was modelled as a function of time using regression analysis. Journal impact factors are a measure of the frequency of citation of articles published in a specific journal over a three year period (Garfield, 1972). They are often used as a proxy for the relative importance of a journal to a particular field, and have proven to be reliable indicators of long-term journal influence in finance and economics (Borokhovich, Bricker and Simkins, 2000), as well as in science (Fok and Franses, 2007). Many authors advocate exercising caution when applying impact factors, since there are many other variables that influence citation rates in publications (Seglen, 1997; Borokhovich *et al*, 2000). Despite the debate as to whether citations are indicative of the quality of a publication, or the popularity of that field of research, they remain useful indicators of scientific output.

Similarly, the use of forward citations of patents is commonplace in the literature as an indicator of the usefulness of patents as sources of innovation. In the present work this has been supplemented by a value index, of the form developed by Putnam (in Lanjouw *et al*, 1998), which is based on number of country filings.

Forward citations of Sasol filed patents were tracked using regression analysis following a methodology similar to that applied by Mowery, Sampat and Zeidonis (2002). In this study, the authors utilised the number of citations, referred to as 'prior art' in subsequent patents (by outside assignees) as a proxy for the importance of university patents. According to this methodology, patents that were more heavily cited were interpreted as being more relevant sources of ensuing inventive activity. The study undertaken by Mowery *et al* (2002) was limited to US patents, while the data set in the present study includes all Sasol filed patents.

Self-citation (in which the assignee cites its own previous patents) is listed as a potential source of error by Mowery *et al (2002)*, and all occurrences of this were therefore excluded from their study. However, all instances of self-citation have been included in the present study since the purpose was to assess the degree to which organisational learning has taken place. It is argued therefore, that self-citation of previous patent applications is an indication of learning by doing. The use of citation trees was used to track the progeny of certain patents in order to illustrate their value.

In a legitimate attempt to improve the quality of patent data, Lanjouw *et al* (1998) advocated the inclusion of additional data on patent renewals or country filings with simple weighting schemes. The rationale behind the latter is that patents that are perceived to be of higher value are filed in more countries. This methodology has been evaluated in the present study, and a Value Index (VI) following the method of Putnam (in Lanjouw *et al*, 1998), has been constructed.

Patents were grouped according to the number of countries they were filed in. Then the Value Index (VI) of each year was computed using the formula:

$$VI = \sum_{j=1}^{J} \omega_j N_j$$

Where *J* is the number of groups of patents containing N_j patents in groups 'j' and ω_j is the weight associated with each group. Although it is possible to determine the weights using regression analysis, a selection of relative mean values for patent families of different sizes has been adapted from Lanjouw *et al* (1998). The basis for the weights chosen is the assumption that a patent filed in four countries is worth one and a half times a patent filed in three countries. This log-linear scale is used to develop weights for patents filed in as many as 17 countries, which is the maximum number of country-filings in the sample studied by Putnam in his doctoral thesis. In the paper co-authored by Putnam, the sample included patents filed in 18 countries and the mean value weight applied in this case was twice the value for a patent filed in 17 countries.

This was justified on the basis that an 18-country patent held twice the value of a 17-country patent (Lanjouw *et al*, 1998). It is not clear how this conclusion was reached, but following the approach of doubling the mean value weight each time another country is added, yields unrealistically large numbers when the list exceeds 26 countries. Therefore, the method of doubling patent values for every country above 17 was not adopted in the present study.

Mathematically, Putnam's Value Index is confounded by the fact that it is of the form, $y = me^{-cx}$, with *m* = 0.0009 and *c* = 0,3123 for the best fit line. In this exponential function, the rate at which *y* changes with *x* at large values of *x* is greatly dependent on the value of *c*. For instance, VI = 0.46 for a patent filed in 20 countries and VI = 1560 for another patent filed in 46 countries. Not only is this unlikely to reflect reality, it also implies that the VI increases indefinitely with increasing country filings. Again, it is argued that the marginal increase in the value if a patent by the addition of a single country is likely to become negligible at limiting values of x. Therefore, Putnam's VI would be more appropriate if it took the shape of an S-curve. This approach has been adopted in the present study by defining the limiting VI as 25 or more countries (Table 1).

Table 1: Putnam's Value Index as applied in the present study (adapted from Lanjouw *et al*, 1998).

No. of countries	Value Index	No. of countries	Value Index	No. of countries	Value Index
1	0.000	9	0.016	17	0.207
2	0.000	10	0.020	18	0.311
3	0.002	11	0.026	19	0.460
4	0.003	12	0.039	20	0.700
5	0.004	13	0.051	21	1.05
6	0.006	14	0.066	22	1.57
7	0.009	15	0.092	23	2.36
8	0.012	16	0.138	24	3.54
				25+	5.31

4.3.5 Assumptions of methodology

It is assumed that citations and country filings are a reliable, if not entirely accurate measure of patent value. Similarly, in estimating the value of scientific publications, it is assumed that journal impact factors are a reliable proxy. According to Seglen (1997), impact factors should only be applied to the journal as a whole, and should not be used to evaluate the quality of an individual publication, since this is an aggregate parameter.

4.3.6 Shortcomings in methodology and possible sources of error

Possible sources of error in the use of patent citations have been highlighted by Mowery *et al* (2002). The first is defined as a *truncation* bias which would arise in recently-filed patents which would have had less time to be cited than earlier filings. Hence, the entire lifetime of potential citations of every patent would not be captured. Mowery *et al* (2002) eliminated this by restricting their analysis to patent applications in a specific timeframe, and considered forward citations up to five years beyond the year of issue. This approach has been followed in the present study, and citations beyond 2000 have been excluded from the analysis.

One of the main shortcomings with Putnam's Value Index of patents is the fact that it does not consider the reasons for filing in certain countries, or the potential revenue associated with specific countries. Hence, in the present study, the value ascribed to a patent filed in 7 countries would be the same regardless of whether those countries were located in Sub-Saharan Africa or in Western Europe. Clearly, these locations offer significantly different market potential. Therefore, a metric that includes a weighting of each country based on its relative importance would provide a useful comparison. An appropriate measure such as the GDP of each country could serve as a suitable weighting. This has not been done in the present study, hence this represents a potential source of error.

Proposition II: Effective international connections are enabling factors in deriving value from intellectual property

The literature on capability upgrading alludes to the importance of international connections in generating learning-based spillovers. In the R&D context, these could take multiple forms, including advisory panels, research consortia, or centres of excellence. The aim of this proposition is therefore to assess the degree to which these international research connections contributed towards enhancing the value of scientific output.

4.4 Proposition II: Methodology

In order to evaluate the impact of the constitution of Advisory Boards in 2000 on the propensity and quality of disclosure, time-series patent and publication data was organised into three eras (extending proposition I):

1. Pre formal IP function (pre 1997)
2. Interregnum (1997 – 2000)
3. Post Advisory Boards (post 2000)

In addition to total counts of patents and publications, international co-inventorships on patents and co-authorships on publications were analysed using regression analysis. Co-authorships and co-inventorships were used to operationalise the construct of effective international linkage and were intended to reveal the extent to which collaborative research contributed to scientific output of higher quality.

As with Proposition I, average journal impact factors were used as proxy for the quality of scientific publications. Changes in the average impact factor of journal publications were evaluated using the one way ANOVA with Bonferroni all pairs comparison test, as described above.

4.4.1 Shortcomings in methodology and possible sources of error

The use of journal impact factors is widespread in the literature. However, Seglen (1997) cautions against their use as indicators of the quality of research reported in discrete articles, since they are aggregate measures of the relative importance of a journal to a particular field. Furthermore, the propensity to cite journal articles varies between scientific disciplines. In the present study, this potential source of error is controlled to some extent by the fact that most papers were submitted to journals in the fields of chemistry and chemical engineering, which have similar citation patterns.

Finally, the fact that this study relies on data from a single case represents perhaps the single greatest limitation in attempting to understand the evolution of developing country firms.

As noted by Yin (2003), case studies are not generalisable, and the paucity of research on South African firms exacerbates this problem since comparative studies are scarce.

4.5 Conclusion to research methodology

The combined use of different methodologies in operational research has been documented; of particular relevance is Jackson's work on the orchestration of coherent pluralism in management science (Jackson, 1999). Building on Linstone's multi-perspective research methodology in which a technical (data-based) perspective was augmented by an organisational and personal perspective, Jackson referred to each perspective as a filter through which complex problem situations could be visualised (Jackson, 1999). Therefore, in this study, the use of multiple methods allows for a nuanced investigation into the process of formalising intellectual property in the evolutionary trajectory of a developing country MNC.

5. RESULTS

The evolutionary development of a formalised approach to intellectual property at Sasol forms the central theme of this study. Patent and scientific publication data associated with Sasol for the period 1955 to 2005 have been analysed, using a variety of quantitative and qualitative methods, and supplemented with narratives in order to determine the key indicators of capability upgrading via external disclosure.

Proposition I: Developing a deep understanding of the ***purpose*** of formal ***disclosure*** is an essential component in capturing the ***value*** inherent in ***intellectual property protection***.

5.1 Understanding the purpose of formal disclosure

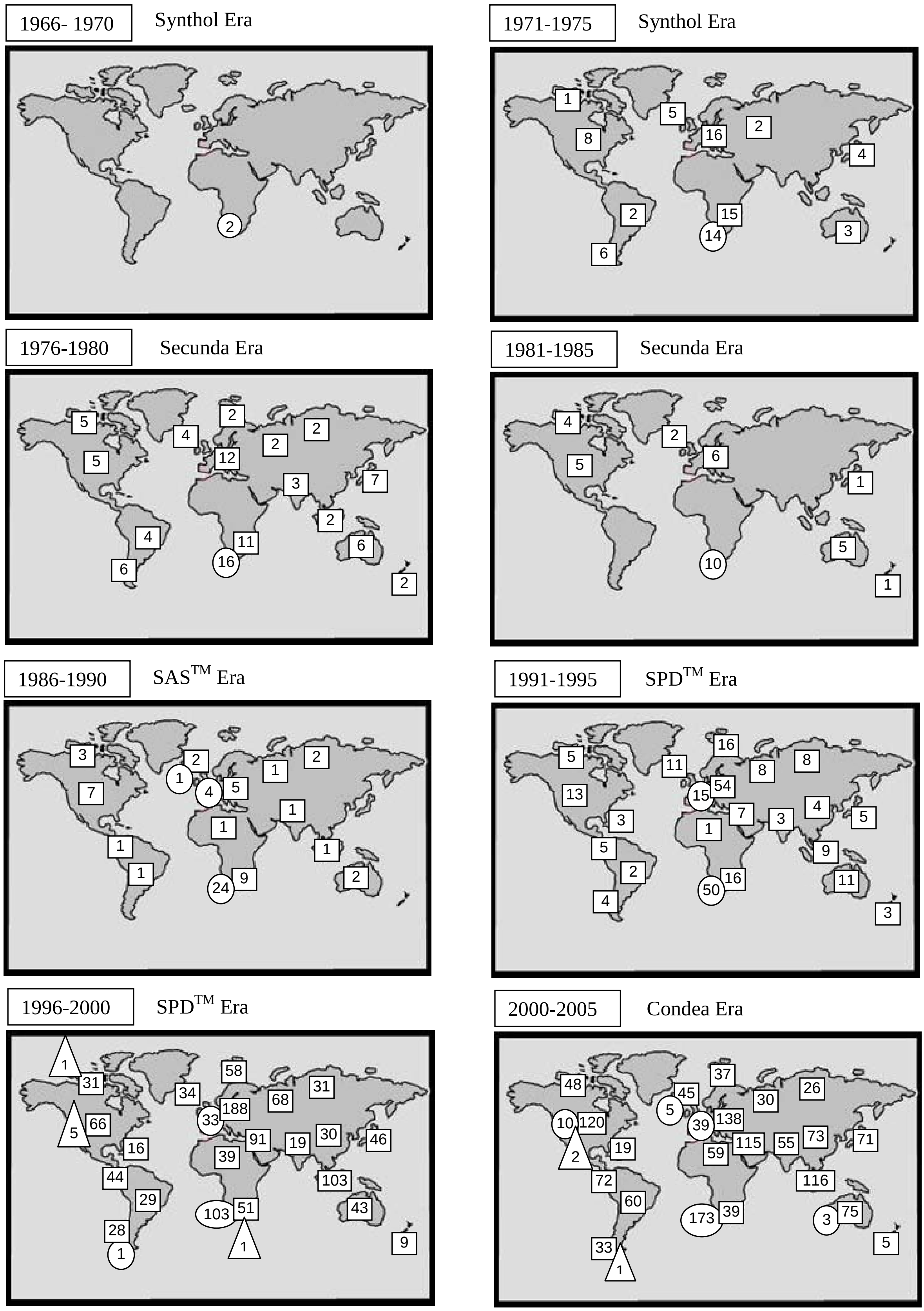
A sufficiently nuanced study of the evolution of the IP process at Sasol had to be contextualised within the framework of capability development. In the results that follow, an archival perspective of technological discovery has been provided in the form of a sequential narrative in order to contextualise the evolution of learning to patent and publish scientific innovation. Further texture has been added through statistical analysis of patent and publication data.

5.1.1 A historical overview of IP development at Sasol

Sasol's history is punctuated by a number of significant events, ranging from the commercialisation of key technologies to large-scale business ventures. The next section briefly reviews the history of patenting and technology development at Sasol.

The development of Sasol's patent portfolio over time is shown in Figure 2, capturing original patent applications (in the country of invention), and re-filings of the same patent in other parts of the world over eight 4-year periods from 1966 to 2005. Patents denoted in triangles are those that were not filed originally in their country of invention. This would most likely have been due to the need to secure certain markets.

As shown in Figure 2, in the early years, Sasol clearly resembled most young firms across the world in terms of codified knowledge, displaying a limited awareness of the potential value of patents. Many of the first research reports were written in Afrikaans, except those that were penned by foreigners or intended for use by them. There was however, extensive investment in local capacity development, enabled by the establishment of a research department in 1957 with an operating budget of R100 000 (Annual Report, 1957); until then, ad hoc research had been conducted at process laboratories in the plant. Initially, the research unit focussed on improving the performance of the FT process but later expanded to include the recovery and synthesis of valuable products.



Legend: ○ Original filing □ Re-filing △ Original not filed in country of invention

Figure 2: Global distribution of Sasol-filed patent specifications

The first patent on the Sasol Fischer-Tropsch (FT) process was filed only in South Africa in 1968, in an era when investment in the codification of knowledge was limited, but what was done reflected an internal orientation. For instance, in the period 1971-1975, 15 patents were filed in neighbouring countries (Botswana, Lesotho and Swaziland) and the so-called “independent homelands” (Figure 3).

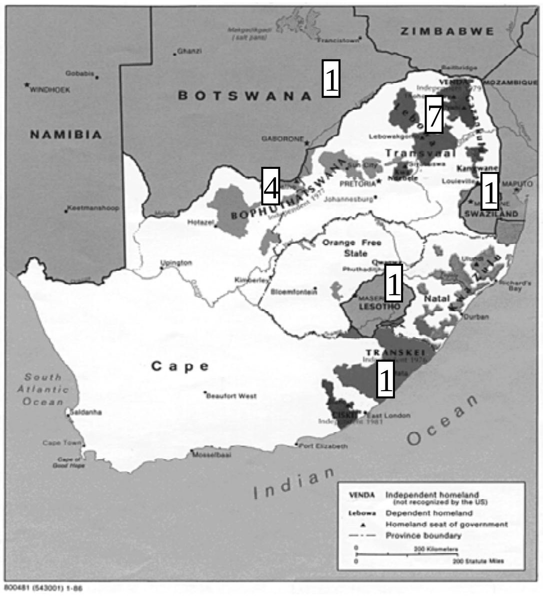


Figure 3: Patent applications filed by Sasol in the Independent Homeland states in the period 1971-1975

No attempt was made to publish peer-reviewed research in scientific journals in the early years. However, when a greater awareness developed about the value of participating in global knowledge networks, research results from this period still proved to be publishable. For example, a number of peer-reviewed papers on the development of Sasol’s FT technology (drawing on findings from the early years) were published from 1982 onwards and a seminal text on the Fischer-Tropsch process published by Elsevier discusses the development of the proprietary SAS™ and SPD™ processes (Steynberg and Dry, 2004). The chronology of scientific publications is shown in Table 2.

Table 2: Sasol publications in peer-reviewed journals

	1966-1970	1971-1975	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001-2005
	Synthol era		Secunda era		SAS™ era	SPD™ era		Globalisation era
Total peer-reviewed papers published	0	2	16	37	25	31	65	172
Total papers published in ISI database journals	0	0	10	19	17	14	30	124
Average impact factor of journals*	0	0	0.43	0.44	0.78	0.30	0.49	1.30

*Non-ISI journals are coded as having an impact factor of 0

Around the mid-1970s Sasol started to formally publicize its newly developed knowledge. One of Sasol's first journal publications was written in 1976 by German researchers Dressler and Uhde and appeared (in German) in *Fette, Seifen, Anstrichm*. A total of 29 papers were published in ISI journals with an average impact factor of 0.44 (see Table 2) and 26 patents were filed over a 10-year period between 1975 and 1985 (Figure 2). About half of the patents were also filed abroad (mainly Europe, although in certain cases also North America and Australia) and research was published equally in local and international outlets. Collaborations with foreign partners, mainly firms from the USA and Germany, generated 10 papers.

The 1979 listing on the Johannesburg Stock Exchange was the largest listing in South Africa until then, and the combination of private capital with the assurance of a continued (and in fact, increased) tariff protection provided Sasol with the funds it needed to expand its capacity. Technology development projects tend to have long timeframes, and a number of initiatives were ongoing. But the expansion did force Sasol to shift its main focus from creating new knowledge to expanding the application of existing knowledge. The cost of this set of choices only became clear when the anti-Apartheid struggle was at its most violent, and the world responded by limiting international contact. The impact of political isolation on the publication of research findings and the need for protection of intellectual property can be clearly seen from Figure 2 in terms of the substantial decline in the number of patents filed in the period 1981-1985.

Sasol's desired technological advances, and the difficulty of procuring technology for recovery and upgrading of products, increasingly required in-house technology development. The achievements of the small coterie of Sasol researchers are impressive. Following extensive research Sasol commissioned a demonstration reactor in 1983, followed by the first commercial scale operation of the SAS^{TM} (Sasol Advanced Synthol) reactor in 1989 (Steynberg and Dry, 2004). These new generation reactors afforded lower capital cost, increased flexibility and lower operating costs. However, these developments continued to require greater research capacity than Sasol had, even with ongoing local capacity development programs like bursary schemes. Sasol began to rely more heavily on foreign collaborations to help achieve its ambitious technology development goals. For example, Sasol leveraged its relationship with Badger/Raytheon in US for the development of the SAS™ reactors (Collings, 2002). This highly successful collaboration also resulted in a number of co-authored papers in peer-reviewed journals.

Sasol was maturing into a company that was technologically capable of both contributing to and benefiting from the processes of global scientific knowledge creation. Amid anti-Apartheid sentiment, and faced with potential exclusion from knowledge creation networks because of a lack of political legitimacy, Sasol sought to increase its perceived *technological* legitimacy. The joint filing of patents in the field of gasification technology by teams of German and South African experts from the Sasol Lurgi joint venture bears witness to this (see Western Europe original filings in Figure 2, 1986-1990).

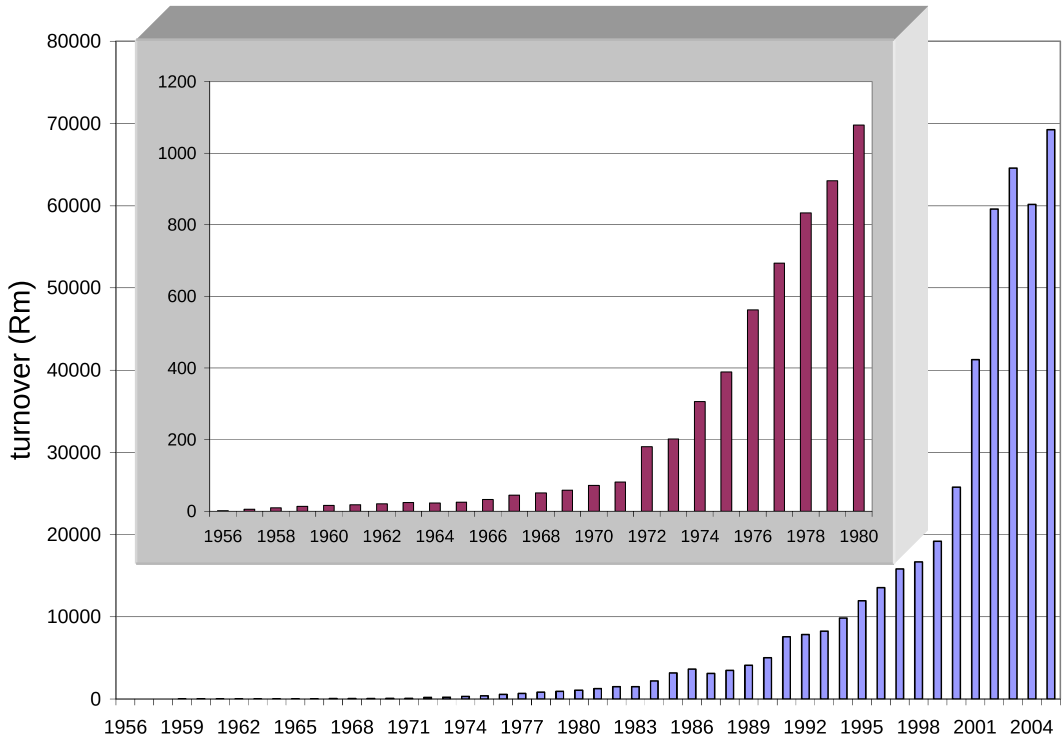
In the early 1990's, Sasol's FT technology was licensed to Mossgas for the conversion of natural gas into liquid fuels, providing a local market for Sasol's know-how. In response, Sasol accelerated patenting to more effectively support knowledge exchange in the emerging South African petrochemical industry. Therefore, Sasol increased the number of local patent filings and extended its list of country filings abroad (Figure 2, 1986-1990), and published in journals with noticeably higher impact factors than before (Table 2). Still, the number of official collaborations sharply reduced during the height of political isolation. The political context made it virtually impossible to enter into official academic international collaborations, although Sasol was able to maintain informal relationships by increasing its visibility in the formal networks of knowledge creation.

In 1995, Dr Arie Geertsema, then MD of Sasol Technology R&D, identified the need for a more formalised approach to the protection of intellectual property at Sasol. Prior to this, patent applications were handled on an ad hoc basis by the Company Secretary, and an external patent attorney.

The establishment of an in-house IP function in 1996, ushered in a formal approach to intellectual property management that was hitherto unheard of in South Africa. Moreover, against the grain of its foreign counterparts, Sasol adopted a strategy of encouraging Sasol employees (scientists and engineers) to pursue careers as qualified patent attorneys. In this way, all patent attorneys would be very familiar with the technology as well as having the required legal qualifications. As a result, most of the IP legal advisors at Sasol have a scientific background and a thorough knowledge of the Sasol process.

In spite of the re-entry of South Africa to the global economy in the 1990's, the lingering effects of the isolation are evident from the low impact factor of journals in which Sasol published during this time (Table 2), and the difficulties in (re)-establishing collaborative research relationships. The negative effects of the lack of international relationships would in time have spilled over to the local capacity base, but Sasol moved swiftly to restore international connections. Recognising the urgency of re-establishing international contact, and the need for institutional rather than individual linkages, Sasol put a high priority on international joint ventures.

In 2001, Sasol announced a new corporate vision statement, starting out with the desire "to be a respected global enterprise." As part of this strategy, in 2001 Sasol concluded a €1.3bn asset and share purchase agreement with the German firm RWE-DEA for that company's entire chemical business, Condea (renamed Sasol Chemie). The Condea acquisition had an immediate effect on Sasol's turnover (Figure 4), and Sasol also gained access to Condea's R&D laboratories and patent portfolio.



Note: The inset is an enlargement of the period from 1956-1980

Figure 4: Annual turnover (Rm) for the period 1956 – 2005

In 1999, Sasol and Chevron agreed to form a joint venture (JV) for the identification, development and implementation of gas-to-liquids ventures worldwide based on Sasol's FT technology. This joint venture brought much learning regarding intellectual property protection. In fact, IP risk mitigation was a key component of the formation of the JV. One of the best practices adopted by Sasol in 2000 was the use of IP Review Teams to formally decide, per technology area, on the most appropriate vehicle of IP protection (trade secret, patent or scientific publication) in order to manage the business and technological risk associated with disclosure.

These teams have proven to be very successful in competitor analysis and technology landscaping, enabling agile responses in terms of in-house filing strategies and opposition proceedings. In order to ensure alignment with the corporate strategy, an IP governance committee ratifies decisions taken by the Review team. More recently, so-called “Deep-dive Specialists” and “Value-chain Coordinators” have been appointed to ensure that the patent portfolio has the desired balance between focussed specialisation and technology integration across process units.

5.1.2 Statistical analysis of patent and publication data

The evolution of the IP landscape of Sasol was mapped using non-metric multidimensional scaling in order to identify relationships between focus areas of in-house filings and acquired patents. For the purpose of this study, the fifty year period from Sasol's founding in 1955 until 2005 was divided into five eras (Table 3), the first four defined by technological milestones, and the last corresponding to a business decision to globalise. The latter includes the formation of the Sasol-Chevron Global Joint Venture and the acquisition of Condea.

Table 3: Technological eras in Sasol from founding in 1955 until 2005

Era		Distinguishing marker
1	± 1950 – 1975	Synthol era
2	± 1976 – 1985	Secunda era
3	± 1986 – 1990	SAS™ era
4	± 1991 – 2000	SPD™ era
5	± 2001 – 2005	Globalisation era

For each era, multidimensional scaling (MDS) was applied to a set of patent data that included the major technology areas that define Sasol's business (FT, gasification, chemicals), the origin of the patents (in-house or acquisition), and an indication of whether they were filed locally or internationally. These indicators enabled the focus of Sasol's indigenous efforts at technology development and patenting to be compared to that of foreign firms that had been acquired by Sasol for their technology bases. Dissimilarities (differences in clustering of these indicators in the MDS) between eras signalled the evolution of capability at Sasol as communicated by formal disclosure through patents.

In non-metric MDS, the intention is for the solution to maintain the same rank ordering of the calculated distances as found in the original dissimilarity matrix. Therefore, the predicted dissimilarity *values* might differ from the actual values, but the *ordering* of dissimilarities will reflect reality. This methodology gives a better solution in low dimensionality than the metric solution which attempts to reproduce the actual dissimilarity values, often requiring additional dimensions. In the present study, the number of dimensions retained in each solution was based on achieving a minimum cumulative percent of total eigenvalue variation greater than 95 percent and a stress value of less than 0.05 within a maximum of 50 iterations. For ease of interpretation, the MDS map that captures the greatest portion of the solution for each era is shown. There is no formal orientation to the maps, and values could be rotated around the centre of the plot. In all cases, the main features of the maps are the relative positions of the points and any clusters that are apparent. In some instances, clusters of indicators have been circled for emphasis.

MDS analysis of patent data (Figure 5) for the period from 1950 to 1975 (denoted as the Synthol era) required three dimensions to be retained in the final solution. It must be noted here that all chemicals patents held by Sasol during this time were acquired from other companies, unlike the in-house filed FT and gasification patents. Consequently, there was a perfect correlation between Acquired patents and Chemicals patents; hence only the latter variable was included in the analysis of the data for this era.

In the first dimension of the MDS map shown in Figure 5, there is a clear distinction between technology areas, and a large dissimilarity exists between patents in FT and those in Chemicals and Gasification technology. Moreover, clustering of chemicals (acquired) patents near USA and Germany differentiates them as being 'internationally' filed relative to the Sasol patents which have a more local filing strategy (shown clearly in the second dimension), particularly for patents in gasification. This highlights the inward-looking focus of Sasol that prevailed at this time.

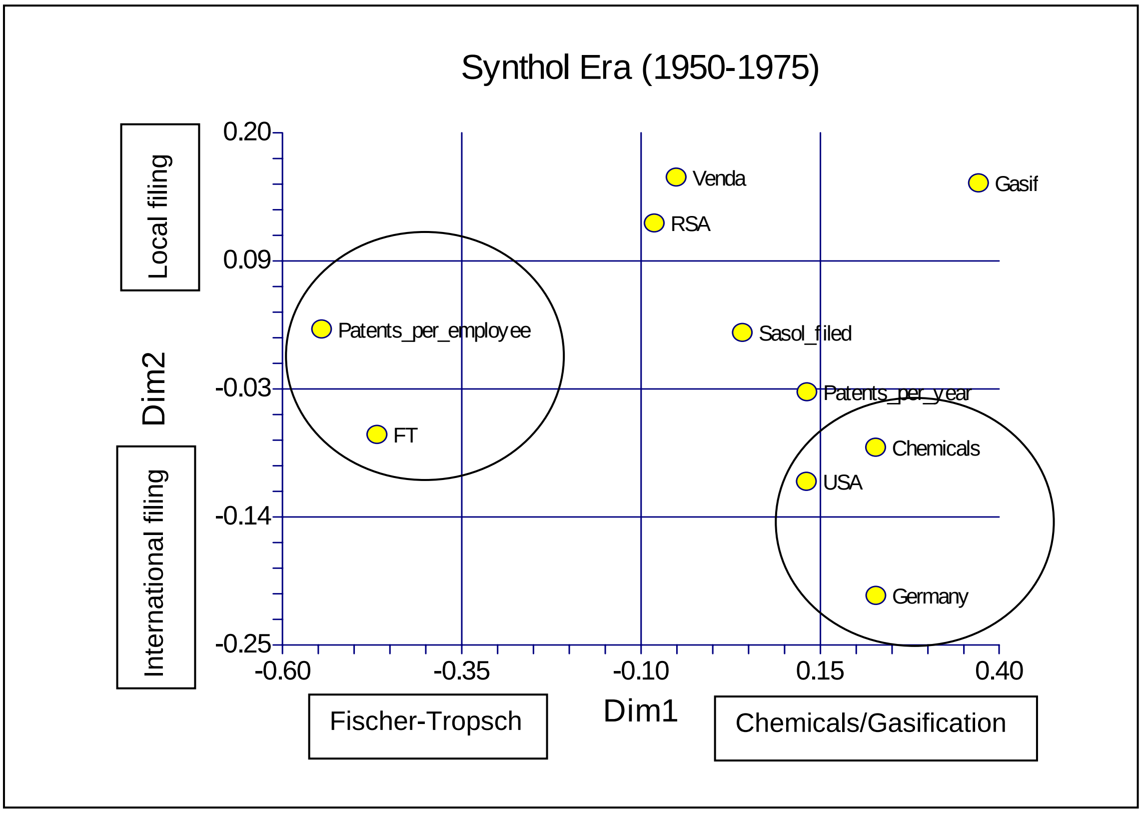


Figure 5: MDS Map of the Synthol Era (1950-1975)

Most patents filed by Sasol employees during this period were in the area of FT, and it could be argued that these patents had a slightly more international orientation than the gasification patents which were based on South African coal deposits. Finally, the location of the "Patents per year" variable equidistant from the Sasol-filed and Chemicals (Acquired) patents suggests that both contributed equally to the clutch of patents held by Sasol at this time.

In the third dimension (not shown), the focus of patenting by Sasol employees can be clearly seen in the clustering of FT and Gasification patents in close proximity to the "Patents per employee" variable.

In the years that followed (1976-1985), defined as the Secunda period because it marked the expansion of Sasol's capacity with the construction of two new plants, the trend of local versus international focus in patenting is maintained (Figures 6a and 6b). Patents in FT, gasification, and chemicals appear to be highly dissimilar during this era.

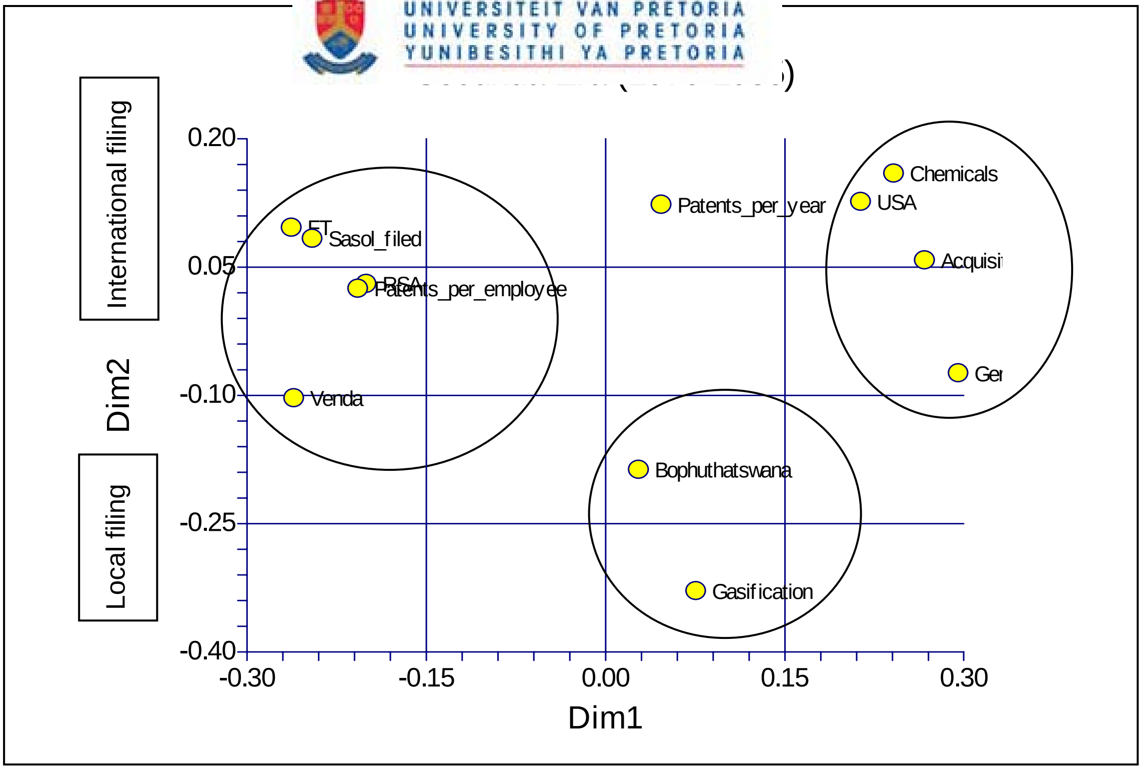


Figure 6a: MDS Map of the Secunda Era (1976-1985) showing local versus international patenting focus in second dimension

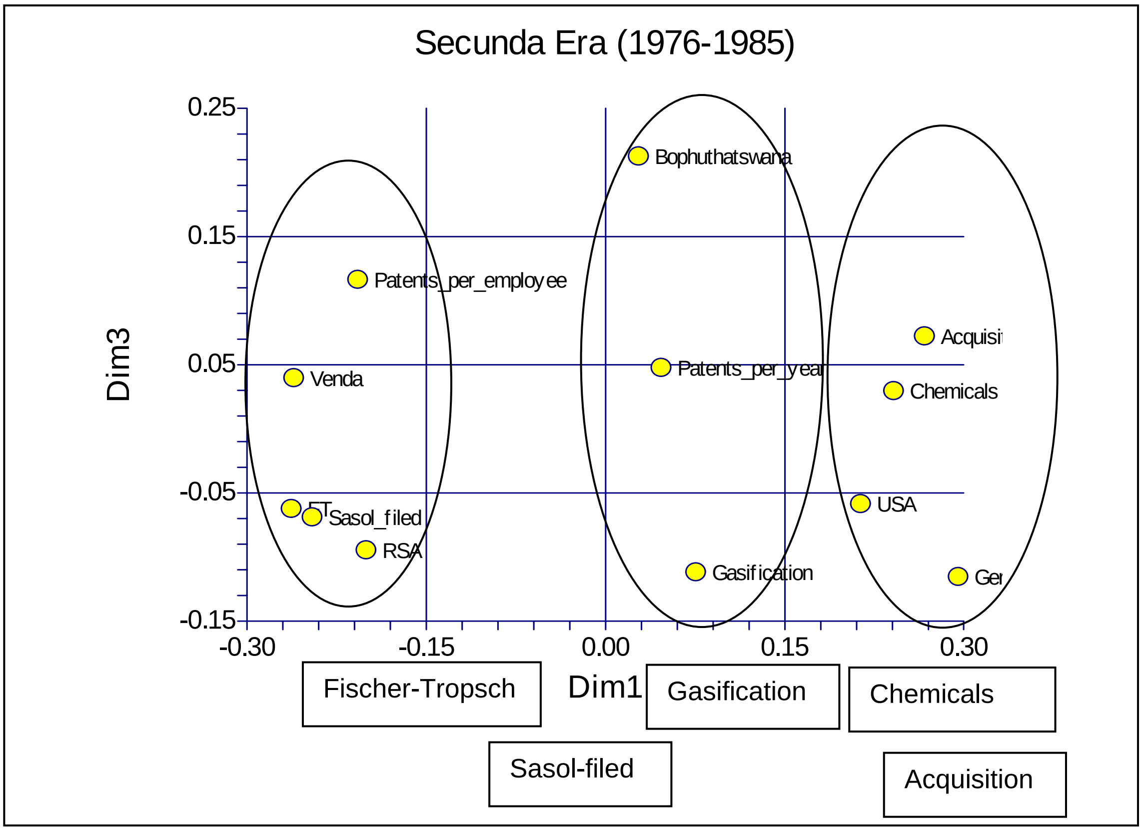


Figure 6b: MDS Map of the Secunda Era (1976-1985) showing dissimilarity of focus between Sasol's indigenous and acquired technology bases

It is evident from Figure 6b that innovation in Sasol was concentrated in the areas of FT and gasification, and that chemical patents were acquired externally.

In Figure 7 there is still evidence of chemical patents being loosely associated with acquisitions, but the closer proximity to Sasol-filed patents signifies increased in-house activity in this area, although FT remains its focus. The clustering of gasification with Germany signals the joint patenting with Sasol-Lurgi, but these patents appear to be dissimilar to other Sasol patents.

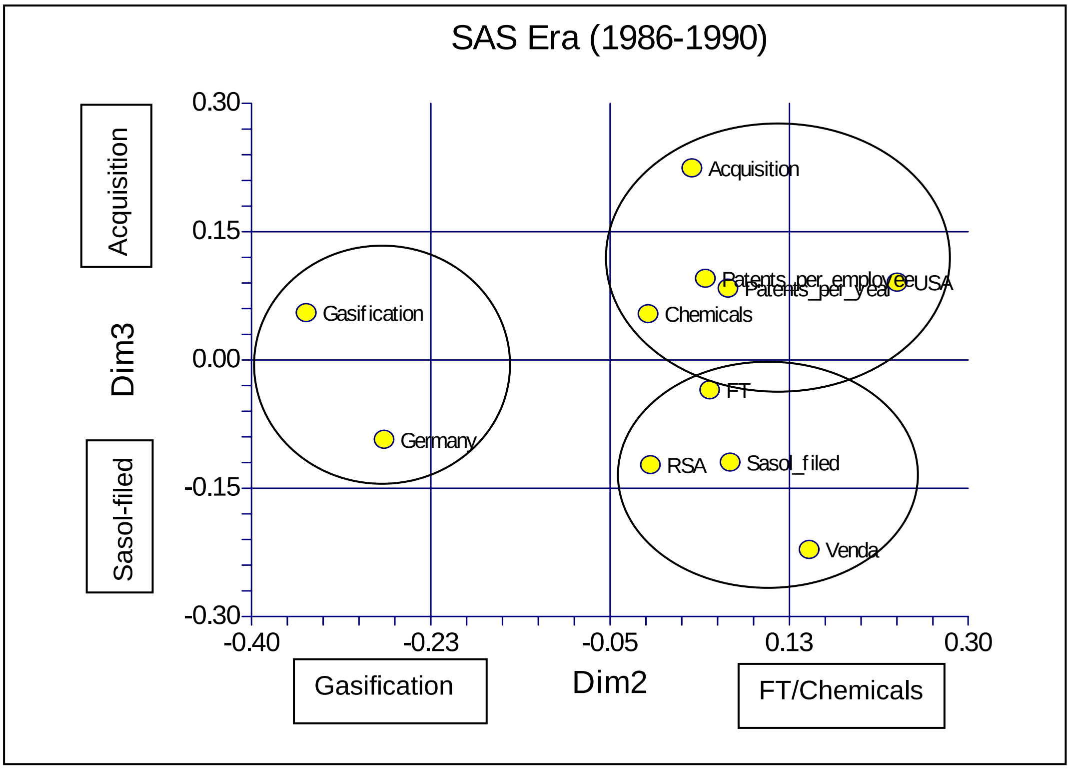


Figure 7: MDS Map of SAS™ Era (1986-1990) showing Sasol's capability base broadening towards chemicals while still maintaining focus in FT.

During this period, Sasol filed 29 patents, which was similar to the 25 of Secunda era and almost double the 16 applications filed in the Synthol era. The Bonferroni Pairwise Test performed as part of the ANOVA (α=0.5) for the variation in Sasol-filed patents per year indicate that the three eras until 1990 are statistically different from the SPD™ and Globalisation eras that followed (Table 4).

Table 4: ANOVA results for Number of Sasol patents per year per era

Response variable	DF	p value	F-ratio	MSE	Bonferroni pairwise test*	
					Group A	Group B
Number of Sasol patents per year	36	0.00000	28.51	69.43	Synthol Secunda SAS™	SPD™ Globalisation

*Eras in Group A were not statistically different to each other, but were found to be significantly different from those in Group B and vice versa.

Indeed, in the SPD™ Era (Figure 8), Sasol's patent activity increased significantly with 219 applications filed during this period. This coincided with the development of the commercial Slurry phase (SPD™) Fischer-Tropsch technology which would later form the basis of Sasol's global FT ventures.

This era also marks the first realisation of the need for a broader international filing strategy for patents. A number of FT patents were filed in the newly independent states previously part of the USSR (including Kazakstan, Turkmenistan, Kyrzygstan etc.).

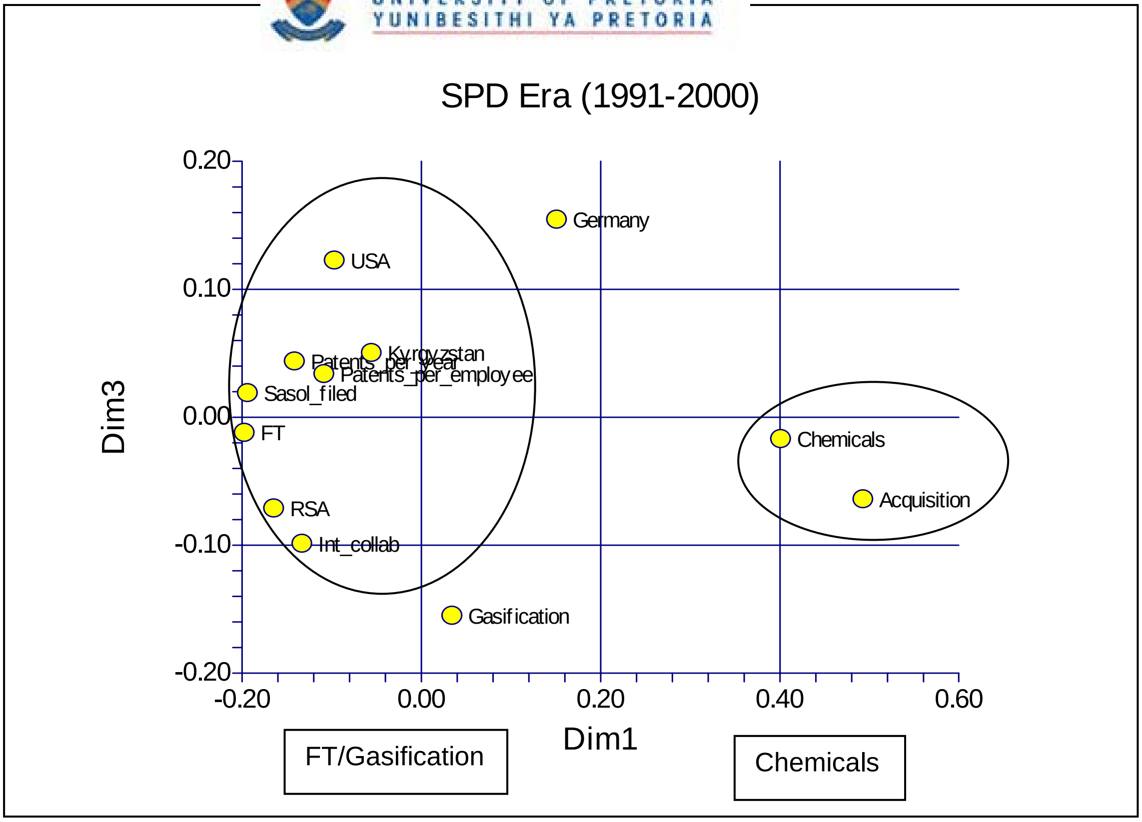


Figure 8: MDS map of the SPD™ era (1991-2000) showing renewed focus in FT technology and the emergence of international collaborations on patents

In support of the development in FT technology, there is also evidence of renewed activity in gasification as shown by the results of the Bonferroni Pairwise Test (Table 5). The SPD™ era is found to differ significantly from the earlier Secunda Era in terms of number of patents in gasification technology, even though both were periods of increased activity in this area.

Furthermore, international collaborations as indicated by co-inventorships on patents began to play a significant role in the development of technology related to the mining and gasification of coal.

Table 5: ANOVA results for number of gasification patents per era

Response	DF	p	F-ratio	MSE	Bonferroni pairwise test*	
					Group A	Group B
Gasification patents	30	0.0280	3.87	1.33	SPD™	Secunda

*Eras in Group A were not statistically different to each other, but were found to be significantly different from those in Group B and vice versa.

The strategy of diversification into high-value chemicals, together with a decision to explore opportunities for licensing FT defined the globalisation era. As a result of the acquisition of Condea, Sasol now boasted in-house competency in chemicals, as indicated by Figure 9. The bulk of patenting during this period was in chemicals in support of the corporate diversification strategy. The close association of gasification and acquisition patents is misleading. These two variables were not related to each other in terms of technology, but both represented the minority of patents in this era, hence their juxtaposition to the other variables.

In the previous SPD™ era (Figure 8), international collaborations was associated with gasification technology, but as shown in Figure 9, most co-invented patents were in the area of Chemicals during the globalisation area. These patents came as a result of collaboration between Sasol scientists based in South Africa and those from the newly acquired Condea laboratories in Europe and the USA.

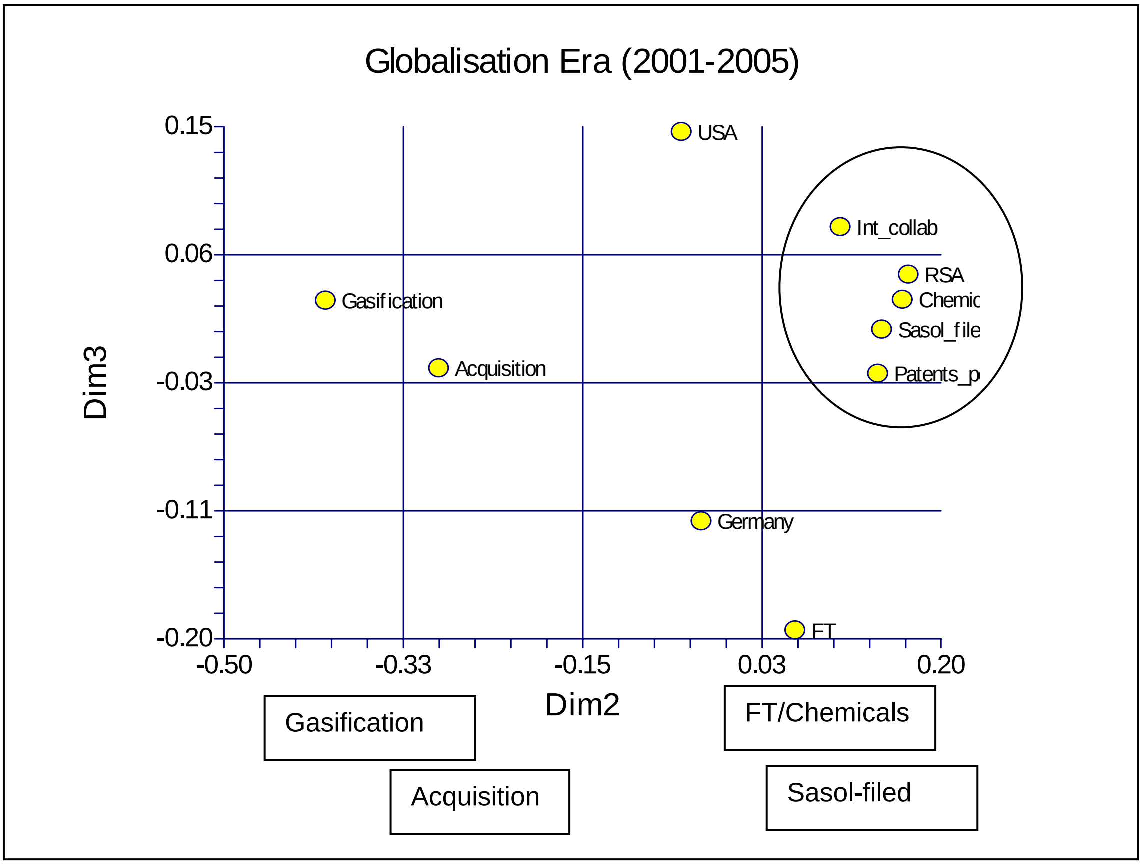


Figure 9: MDS Map for the globalisation era (2000-2005) showing the diversification of Sasol into chemicals as a result of an acquisitive strategy

Therefore, from the changes in clustering of patent data from era to era, the MDS analysis reveals an evolutionary process of learning-by-doing at Sasol together with expansion of the firm's technology base through targeted acquisition of complementary knowledge assets.

5.1.2.1 Propensity to patent as measured by regression analysis

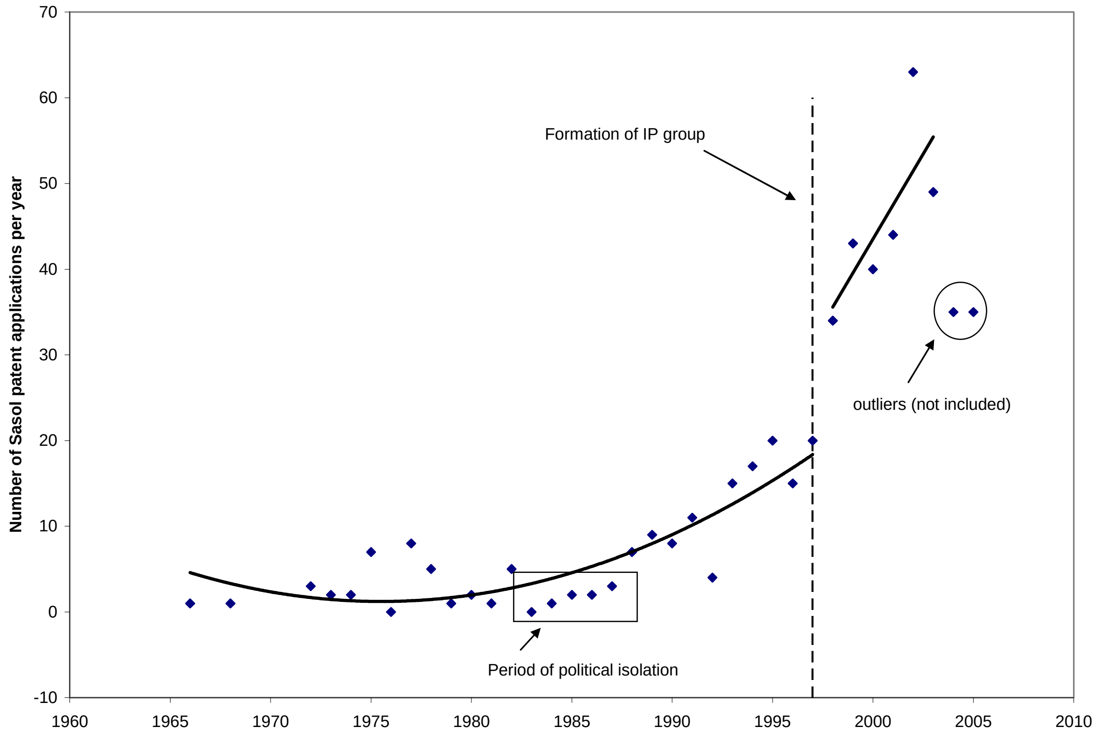


Figure 10: Variation in number of patents filed by Sasol employees during the period 1966-2005

In the preceding section, the analysis of MDS data pointed towards an evolutionary trajectory in the development of intellectual property protection at Sasol. Indeed as shown in Figure 10, there is a gradual upward trend in the number of patents filed by Sasol until 1997, although the negative effect of political isolation on patenting is apparent. A positive step-change in the propensity to patent follows the formation of the IP group in 1997.

From the time-series plot in Figure 10, it is evident that the data points at 2004 and 2005 are outliers, and have been omitted from the multiple regression analysis. These spurious data points arose during the data collection phase because patent applications which were listed as pending during 2004 or 2005 were not included in the data set. This resulted in the count of patents for the years 2004 and 2005 being lower than was actually the case.

Multiple regression analysis was performed on the time series data from Figure 10 in order to evaluate the determinants of the propensity to patent (Table 6). Two regression models were generated, the one covering the period from 1966-1997 (denoted Pre IP Group in Table 6) and the other the period from 1998 onwards (denoted Post IP Group in Table 6). Turnover and workforce size were included as control variables in the period prior to the formation of the IP group, however, there was not sufficient data to include these variables in the Post IP group regression analysis. Nevertheless, as in the case of the Pre IP group model, their influence was likely to be negligible. No attempt was made to control for the exogenous effect of sanctions on the filing of patent applications, although this would have been expected to improve the quality of the regression model.

From the regression coefficients in Table 6, it is evident that the variation in patenting at Sasol is explained mostly by the introduction of the IP group in 1997 and developments in FT technology. However, an increase in chemicals patents after 1997 is in line with the diversification strategy.

Table 6: Determinants of propensity to patent at Sasol

Dependent variable = Number of Sasol patent applications per year

Independent variables	Standardised Beta coefficients	
	Pre IP Group	Post IP Group
Years (1966-1997)	0.305	
Years (1998-2003)		3.16[a]
Turnover	0.0009**	[b]
No. of Employees	-0.0001	[b]
Technology Areas		
FT	1.269**	0.72
Chemicals	-0.194	1.44
Gasification	0.932[#]	1.97
R^2	0.8845	0.9993
Adj R^2	0.8498	0.9966
d.f.	26	5
MSE	5.73	0.332
F	25	367

*p<0.0001

**p<0.05

[#] p=0.6

[a] as a result of the small number of data points, the level of significance was reduced

[b]insufficient data to complete the analysis if these variables were included

5.1.2.2 Propensity to publish scientific discoveries in academic journals

Whereas patents are intended to confer appropriability of research endeavour, publications in scientific journals connect the firm to the global science community. As shown in Figure 11 below, there is a change in the propensity to publish in scientific journals with the formation of the IP function in 1997, most likely as a result of heightened awareness as to their purpose. As with patents, the effect of political isolation during the period 1985 to 1990 on the rate of publications can be clearly seen.

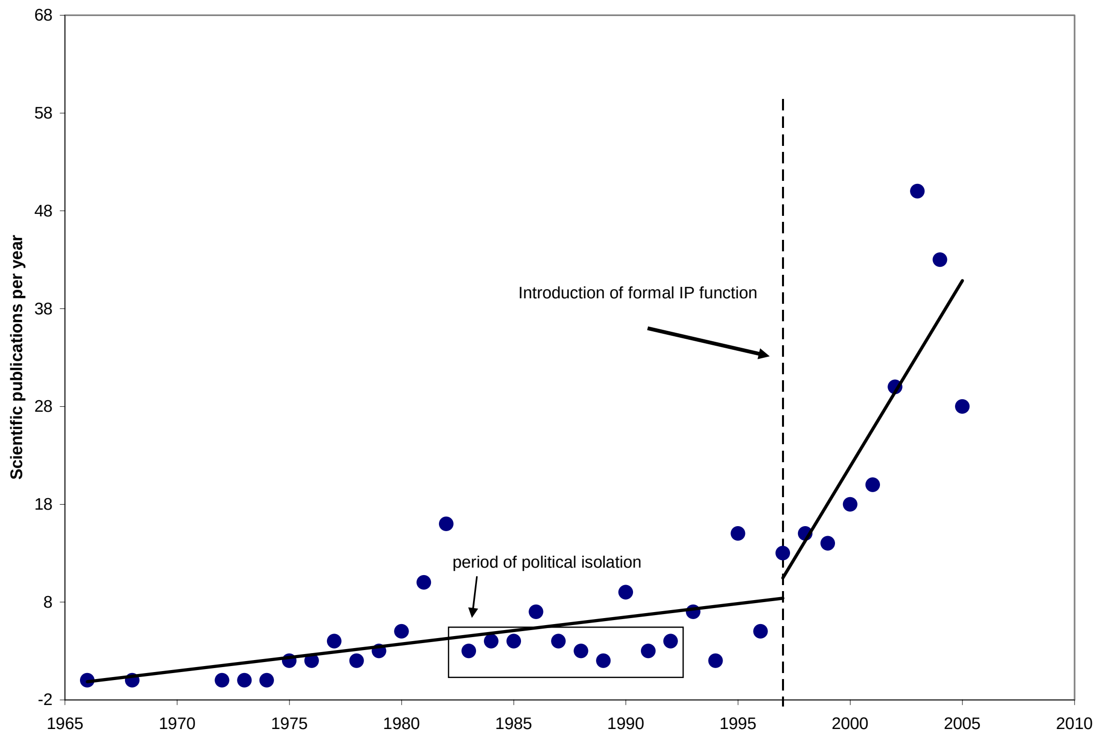


Figure 11: Variation in number of scientific publications from 1966 to 2005

The regression data in Table 7 reveals a similar effect to that observed for the number of patents; the introduction of a formal IP function in 1997 marking a step change in the number of publications.

Prior to the formation of the IP group, the regression coefficients indicate an average publication rate of 0.0023, and this increases dramatically to 4.84 during the Post IP group period (Table 7).

Table 7: Determinants of propensity to publish in scientific journals

Dependent variable = Number of publications per year

Independent variables	Standardised Beta coefficients	
	Pre IP Group (1966 -1997)	Post IP Group (1998 - 2003)
Years	0.0023	4.84
Technology Areas		
FT	1.47*	-0.67
Chemicals	-1.20	0.469
Gas Production	1.32*	1.59
R^2	0.8264	0.9987
Adj R^2	0.7962	0.9937
d.f.	27	5
MSE	3.93	1.19
F	27	198

*$p<0.0001$

**$p<0.05$

In the period leading up to 1997, publications were focused on developments in FT and Gas Production. The effect of the acquisition of Condea in 2001 on the shift towards publications on chemicals research can be seen from the dramatic change in the regression coefficient for this independent variable (from -1.2 to 0.469). The decrease in FT papers is contrasted with an increase in FT patents in the period post 1997 (Table 6). This suggests a shift in emphasis towards appropriation of FT research.

5.1.3 The value of patents and scientific publications

The preceding sections dealt with the *quantity* of disclosure as revealed through the number of patents and publications. However, in assessing the formalising of IP it is also important to examine its effect on the *quality* of disclosure (i.e. the value that is captured by the firm in exchange for dissemination of knowledge).

Forward citations of Sasol filed patents were counted as one measure of their value, following the methodology of Mowery *et al* (2002). Figure 12 shows all the Sasol patent applications that had received at least one forward citation prior to 2005. There is a clear change in the slope of a linear regression line just after 1990, coinciding with the start of the SPD^{TM} Era. It was during this period that Sasol developed and commercialised its slurry phase FT technology.

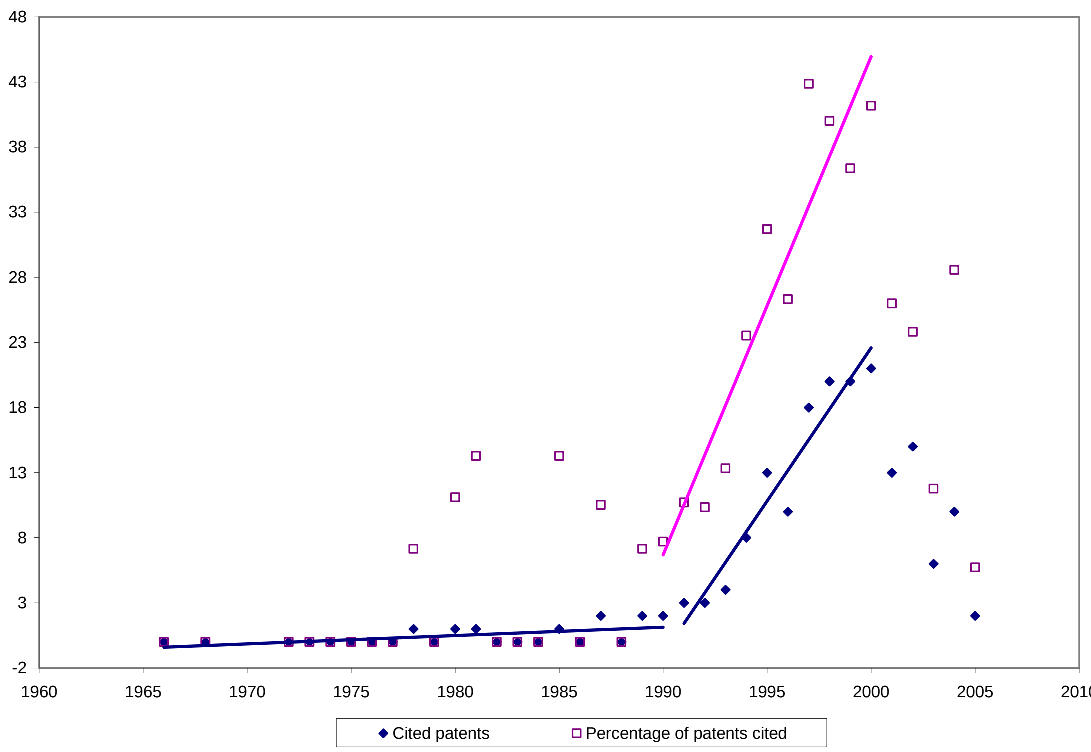


Figure 12: Forward citations of Sasol-filed patents (1966-2005)

The Bonferroni pairwise test (Table 8) confirms that the SPD^{TM} Era and Globalisation events are significantly different to the previous 3 eras in terms of number of forward citations.

Table 8: ANOVA results for the variation in number of forward citations of Sasol patents

Response	DF	p	F-ratio	MSE	Bonferroni pairwise test*	
					Group A	Group B
Number of forward citations	172	0.00286	7.56	5.84	Secunda	SPD^{TM} Globalisation

*Eras in Group A were not statistically different to each other, but were found to be significantly different from those in Group B and vice versa.

It has already been shown that the number of patents also increased dramatically in the latter two eras (Table 4). Therefore it was necessary to demonstrate that the increase in citations was not merely due to an increase in patenting.

As shown in Figure 13, the number of cited patents does increase with a greater propensity to patent; however, Figure 12 also clearly shows an increase in the *percentage* of cited patents post 1990. The decrease in citations post 2000 in Figure 12 is evidence of truncation bias as a result of which, later patents will have fewer citations. To eliminate the effect of truncation bias, regression analysis was performed until 2000 (Table 9).

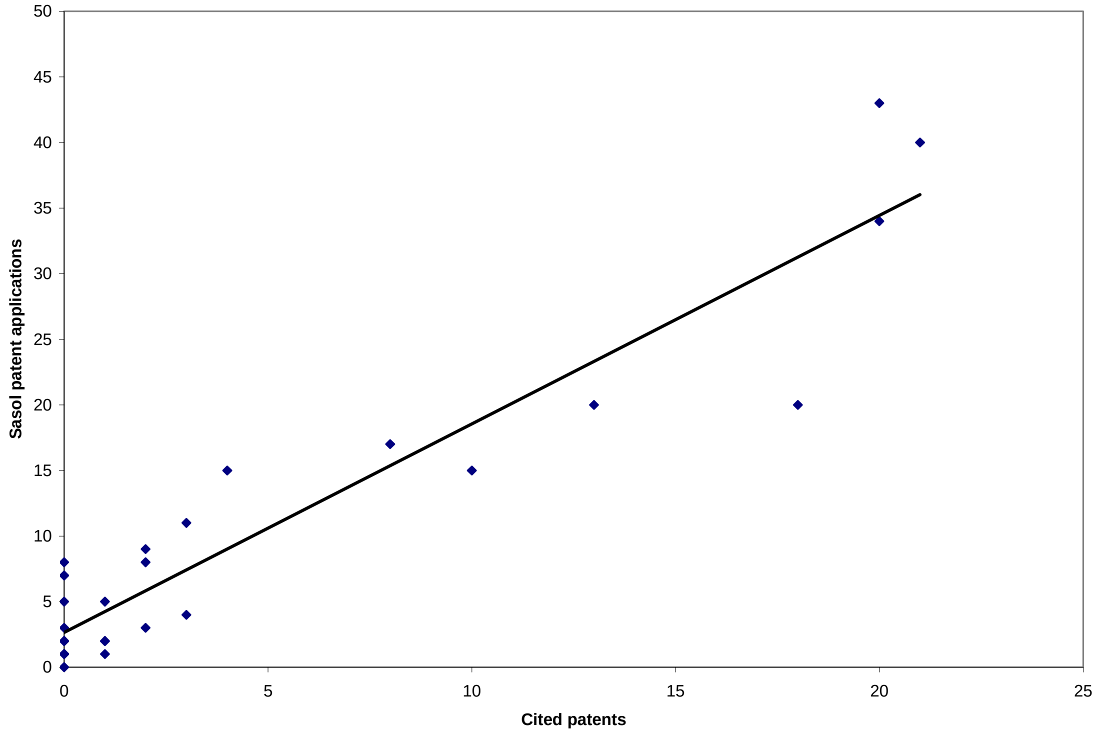


Figure 13: Scatterplot showing correlation between Sasol patent applications and number of cited Sasol patents for the period 1966-2000

The variation in the number of cited patents prior to 2001 was explained using multiple regression analysis (Table 9). Patenting in FT emerged as the only significant independent variable. This supports the observation of the increase in forward citations coinciding with the development and commercialisation of the SPD^{TM} process during the 1990's.

Table 9: Variation in the number of cited patents prior to 2001

Dependent variable = Number of forward cited Sasol patents

Independent variables	Standardised Beta coefficients
Years (1966-2000)	0.1011
Technology Areas	
FT	0.8703**
Chemicals	0.2513
Gasification	0.2263
Country filing:	
USA	0.0489
RSA	0.0382
R^2	0.8661
Adj R^2	0.8312
d.f.	29
MSE	8.06
F	25

**$p<0.05$

These technological advances in FT laid the foundation for much of the worldwide progress in CTL and GTL technology as shown by the citation tree of one Sasol FT patent application (Figure 14).

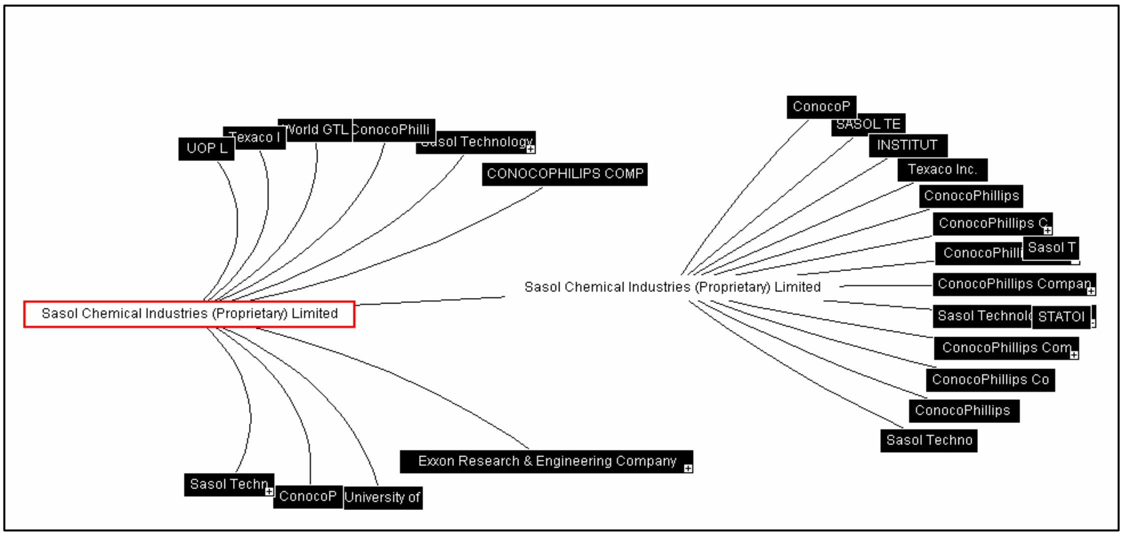


Figure 14: An analysis of the forward citation tree of Sasol patent US 5599849 indicating its role as a node in the development of slurry phase FT technology

Forward citations are an excellent indicator of the usefulness of patents as sources of inventive activity by outside firms. Self-citation data on the other hand can give some insight into the process of learning-by-doing, and of an awareness of the value of citing one’s own patents when referring to prior art.

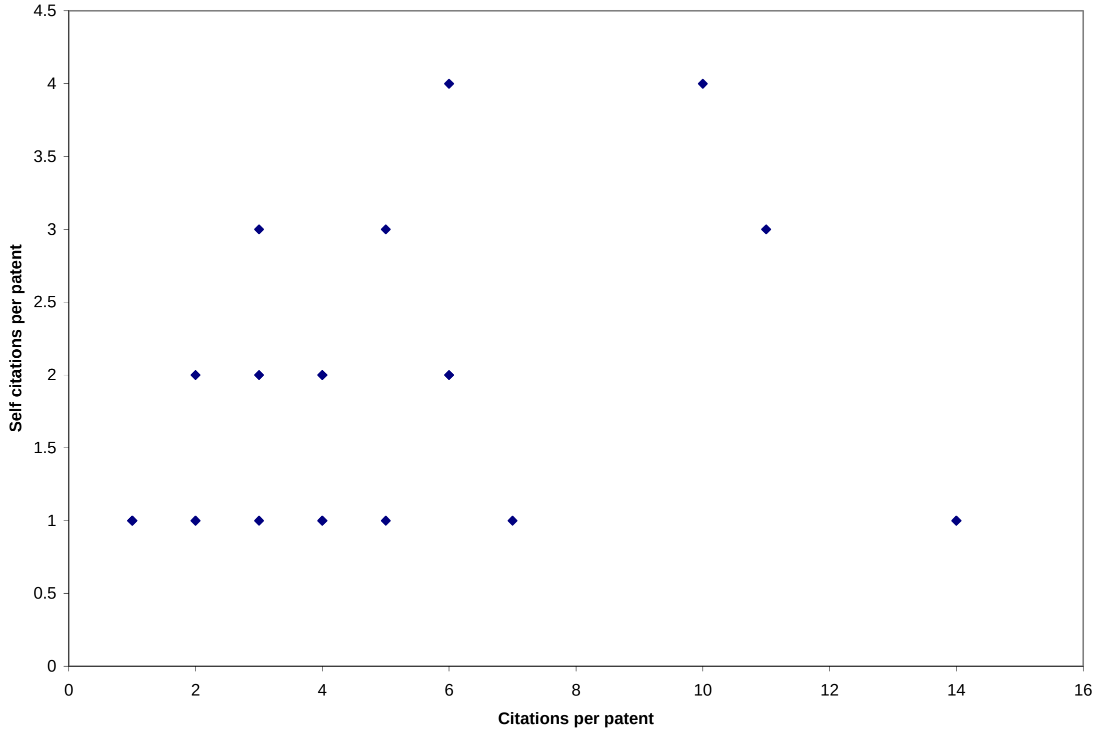


Figure 15: Scatterplot of self-citations per patent against citations per patent

In Figure 15, it would appear that self-citations correlate to some extent with forward citations, but there are notable exceptions. For instance the most cited patent secured 14 forward citations and was only used by Sasol once as the basis for a new patent application.

The second instrument used to measure patent value was Putnam's Value Index which assigns weights to patents based on the number of country filings. The basis for this approach is the notion that higher value inventions are patented more widely. The aggregate annual Putnam's Value Index in Figure 16 reveals a number of distinctly different regions.

Firstly, prior to 1997, the majority of patents had a Putnam's Value Index only fractionally above zero, indicating their filing in fewer than ten countries. It is noteworthy to mention that many of these patents were filed in the Independent Homelands of South Africa (Figure 3) (and since these were counted as separate countries in this analysis, the number of country filings may have even been somewhat exaggerated!). Then, in the period 1985-1995, the annual Putnam Value Index is seen to increase dramatically, exceeding 5 at times. Upon closer investigation, it emerged that a clutch of patents were filed in an inordinate number of countries (four were filed in 30 or more countries) during this period. Finally, in Figure 16, the immediate impact of formalised IP on the Value Index is apparent, followed by a gradual decline in later years.

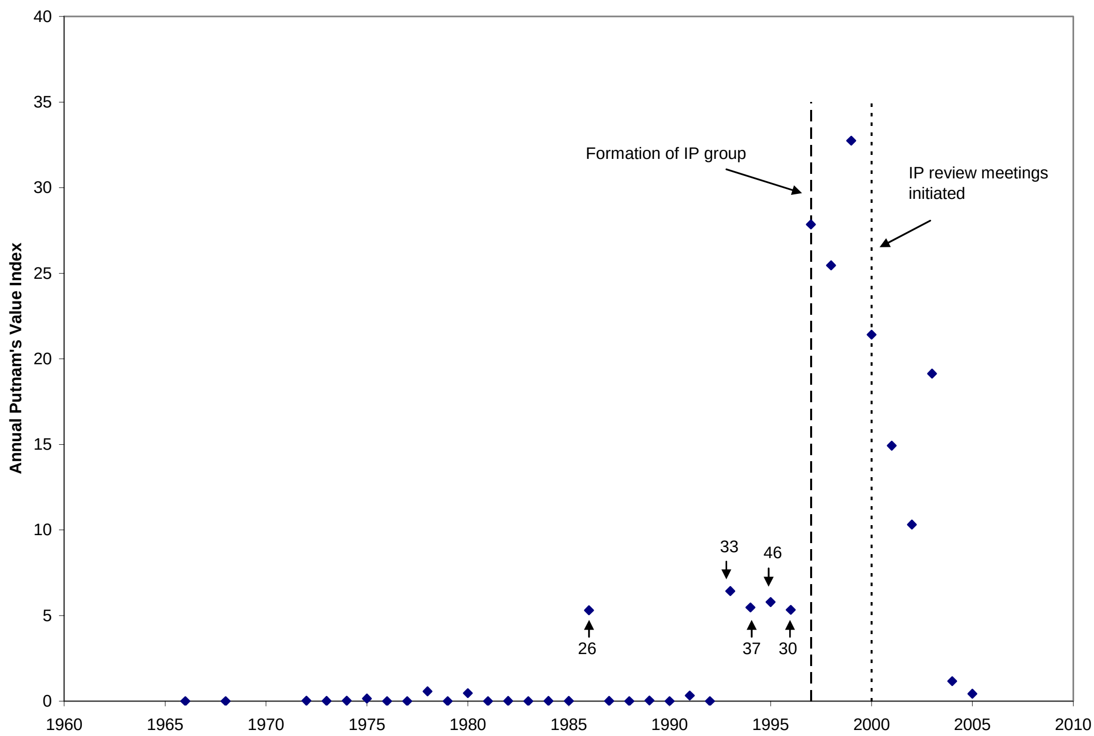


Figure 16: Variation in Putnam's Value Index over the period 1966 to 2005, showing the impact of the formation of the IP group. (The numbers on the data points indicate the number of country filings of selected patents).

Since the increase in patenting following the introduction of the IP group has already been established, the data in Figure 16 requires further interpretation using the average Putnam's Value Index per patent calculated on a per annum basis (Figure17).

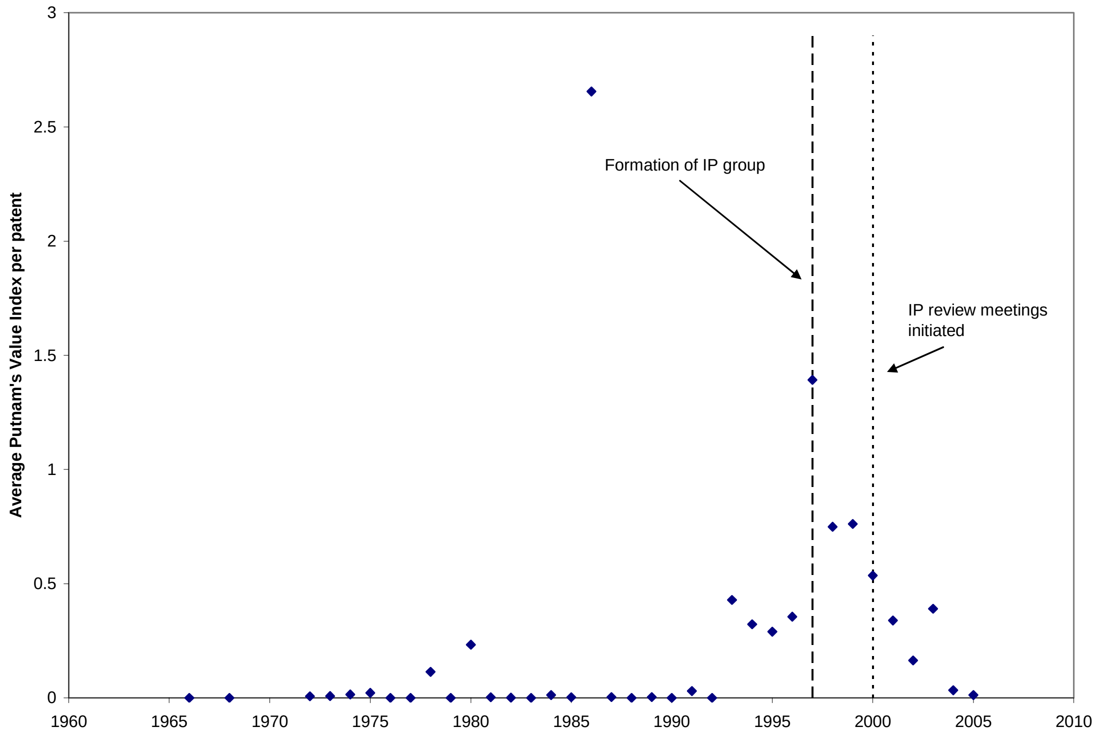


Figure 17: Average Putnam's Value Index per patent on a per annum basis

The data in Figure 17 supports the discussion of Figure 16 in terms of the narrow filing strategy adopted until the 1990's at Sasol, with the notable exception of a patent filed in 1986 in 26 countries (yielding a Putnam's Value Index of 5.31 for this patent alone). Since there were two patents filed in 1986, the average Value Index per patent dropped to 2.5.

With the dawn of the SPD™ era, patenting increased at Sasol. In 1995, the firm filed 20 patents with an average Value Index of 0.289, including one patent filed in 46 countries (on its own contributing a value of ω = 5.31 on the Putnam VI scale). Therefore, most of the other patents had Value Indices of zero (indicating that they were filed in no more than two countries). The patent that was filed in 46 countries has only received 4 citations and 2 self-citations to date. This application was for an invention that is related to the FT process, but was not a core patent. Therefore, it is questionable whether the broad country filing strategy was justified.

In 1997 at the height of the height of the SPD™ era, Sasol also filed 20 patents, but the average Putnam's Value Index per patent increased to 1.39 (Figure 17). There were also fewer zero value patents, suggesting an awareness of the value of patenting in multiple countries.

The advent of the IP Review Teams in 2000 heralded a more rigorous approach to patenting. Specific country filing strategies were developed for different technology areas. As a result, there was a decline in the Value Index (Figure16), as seldom were patents filed in more than ten or 15 countries. However, these countries were carefully chosen from a pre-selected list of markets, sources of feedstock or location of synthetic fuel plants.

Thus, forward citations and number of country filings were used to estimate the changing value of patenting at Sasol. In assessing the change in value of scientific publications following the formalisation of IP at Sasol, average Journal Impact Factor was used (Figure 18). The data appears fairly scattered and there is no clear evidence of the introduction of the IP group, although there is a steady rise per year. This is not surprising since the formalisation of the IP function would have created an awareness of the value of disclosure, but would not have been able to influence the scientific quality of the research.

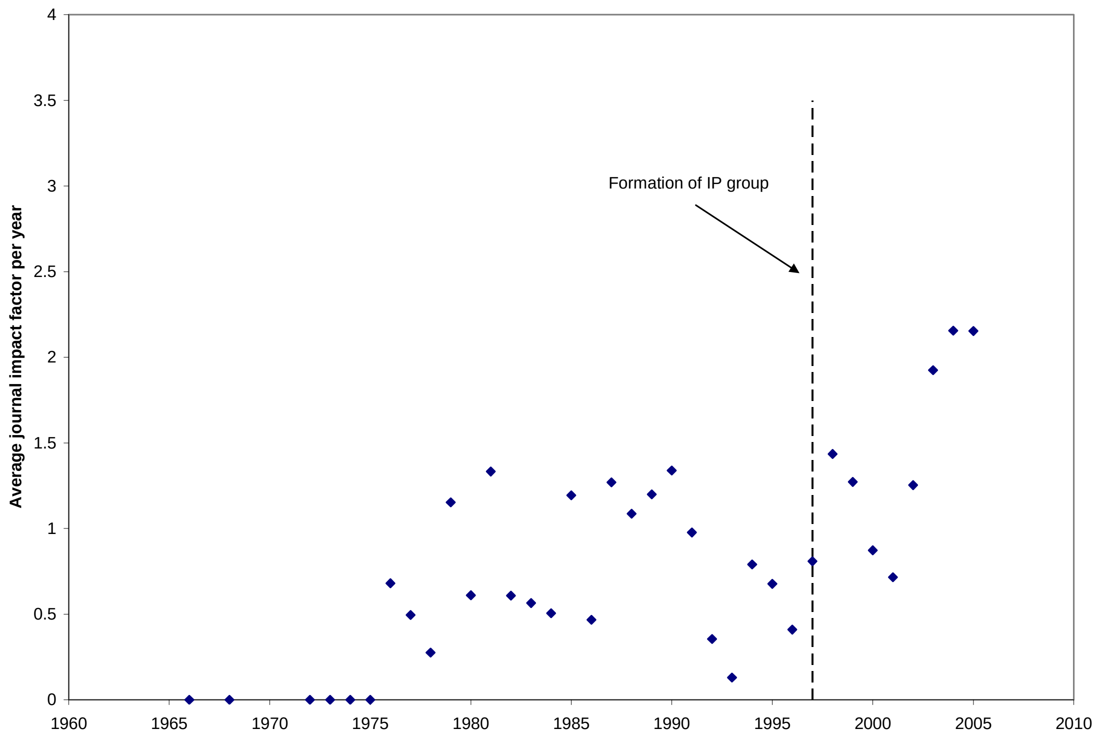


Figure 18: Variation in Average journal impact factor per year

The results presented above clearly show how capability upgrading at Sasol is reflected in learning to manage the IP process through increasing awareness of the value in formal disclosure. The data gathered to evaluate the role of international linkages is presented in the following section.

Proposition II: Effective international connections are enabling factors in deriving value from intellectual property

5.2 International connections at Sasol

A number of interventions in capability upgrading were initiated at Sasol in the years prior to globalisation. Recognising its limited awareness of the global research landscape, Sasol constituted the Homogeneous Catalysis Advisory Board in 2000, following the appointment of a senior scientist from BP, who accessed his network of international experts in order to obtain advice and guidance on setting up a research group focussed on the selective formation of high-value chemicals. No such competency existed in SA at the time, and there was a lack of confidence in local ability to establish a world-class research group in this field.

The Homogeneous Catalysis Advisory Board met four times annually, and assisted in knowledge transfer, competency development, recruitment and training, as well as in the technical auditing of research programmes. The Board was formally dissolved in 2003, having achieved its objective to establish a world-class research group that could support and develop technologies for the production of high-value chemicals that are integrated with the Fischer-Tropsch feedstocks. A number of research groups have been established at local South African universities as a result of the interaction with members of the Homogeneous Advisory Board. Despite the fact that the board no longer exists in its initial form, many of the board members continue to collaborate with Sasol, and a number of joint publications have followed as a result.

A second panel of experts, the Heterogeneous Catalysis Advisory Board was also constituted in 2000. The objective differed from the Homogeneous Catalysis Advisory Board in that the competencies for developing catalysts for the FT process were well established at Sasol. Its purpose was to provide access to international groups with specialised skills or techniques, as well as to technically review research programmes. In addition to this, as a result of their extensive experience and knowledge, each of the board members performs a consultative role on catalyst and process development. The Heterogeneous Catalysis Advisory Board is still active and meets annually at Sasol R&D to interact with local researchers. A number of joint publications with Advisory Board members appear in peer-reviewed journals with high impact factors.

In another attempt to access world-class research skills that were not available in SA, Sasol embarked on the establishment of satellite R&D groups in the Netherlands and St Andrews in 2002. The focus of the group in the Netherlands, based at the University of Twente, is reactor engineering and 4 world-class engineers were recruited from Dutch universities to work in the group. The second satellite laboratory, the Sasol Technology UK research laboratory (STUK) is a joint venture with the School of Chemistry of the University of St Andrew's in Scotland, and was established primarily to support activities in Sasolburg by conducting research into homogeneous catalysis. The Sasol Board approved the employment of 25 PhD level scientists at the facility over a period of 4 years, in agreement with Scottish Enterprise Fife. A number of patents have been co-invented by members of the STUK laboratory, as well as other foreign laboratories with which Sasol has affiliations.

5.2.1 Contribution of International collaborations towards patents and scientific publications

Time series data (Figure 19) of co-invented patents reveal three features. Firstly, the dearth of co-invented patents prior to 1990 (as a result of international condemnation of the Apartheid regime in South Africa) is followed by a period in which development in explosions technology was done in collaboration with a foreign institution. These patents have since been sold to a third party. The surge in co-invented patents since 2000 is directly related to the Sasol-Chevron Global Joint Venture and the acquisition of chemicals firm Condea.

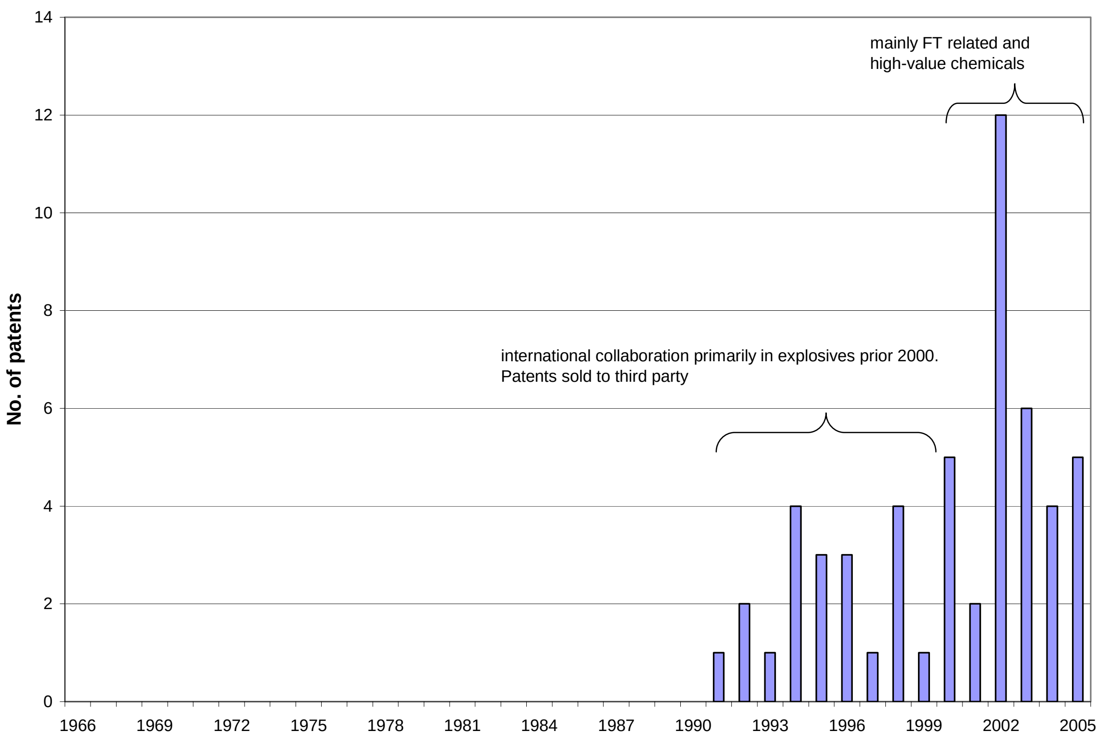


Figure 19: **International collaborations resulting in patent applications**

Figure 20 reveals the effect of the Advisory Boards on the quality of scientific publications. As mentioned earlier, the introduction of the IP group had no noticeable effect on the average journal impact factor. However, it is clear from Figure 20, that the establishment of the Advisory Boards was followed by a significant increase in publications in high-impact journals.

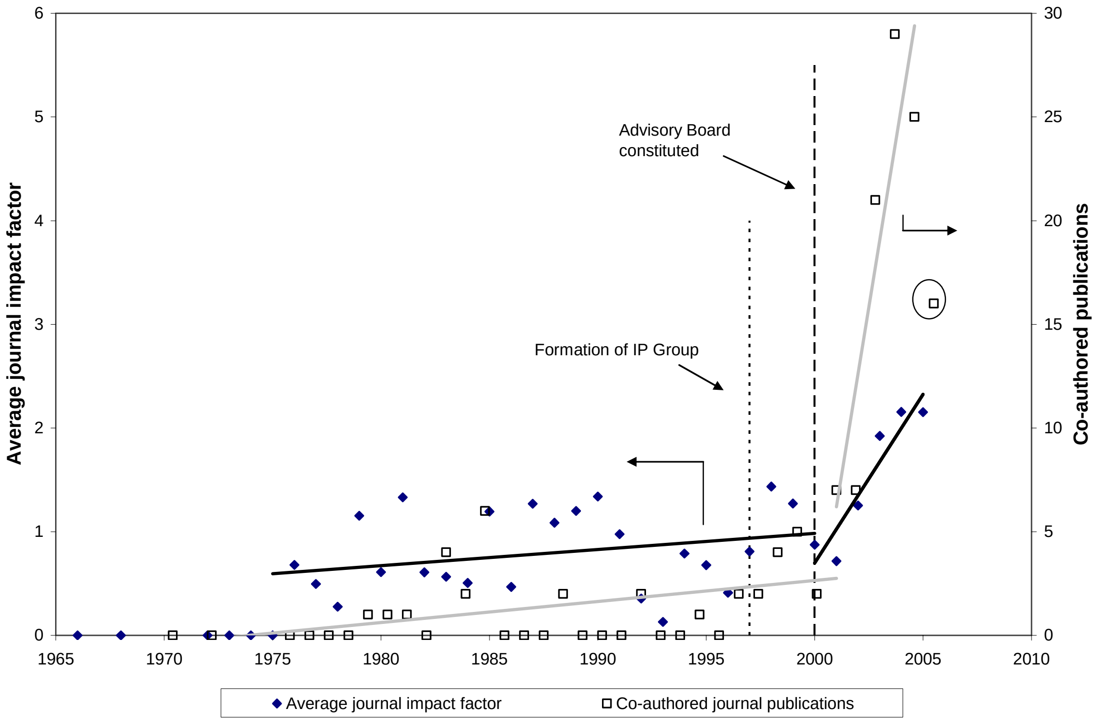


Figure 20: Effect of International linkages on the quality of scientific publications in journals

Moreover, collaboration on publications increased following the establishment of the Advisory Boards. Indeed many of the journal publications of 2003 were co-authored by members of the Advisory Boards or their research teams.

As shown in Table 10, there is a relationship between the quality of research done and the number of co-authored publications. This provides conclusive evidence for the role of international research connections in enhancing the quality of scientific publications.

Table 10: The impact of foreign co-authorships on quality of journal publications

Dependent variable = Number of co-authored publications

Independent variables	Standardised Beta coefficients				
	Equation 1			Equation 2	
	1966-1997	1966-2000	2000-2004#	1966-2000	2000-2004#
Years	0.0252	0.0643	5.800**		
Average impact factor per year				0.5839	14.85**
R^2	0.0213	0.1272	0.7994	0.0190	0.8436
Adj R^2	0.0213	0.1272	0.7326	0.0020	0.7915
d.f.	28	31	5	25	5
MSE	2.36	2.9	28.13	3.07	21.9
F	11.87	4	11.5	0.446	16.2

Beta coefficients with no asterisks are not significant at α=0.05

*p<0.0001

**p<0.05

insufficient data to complete the analysis if 2005 is included

In the following section, these findings will be discussed in the light of the theory base provided by the relevant literature.

6. DISCUSSION OF RESULTS

The central argument in this study relates to how capability upgrading is reflected in learning to manage the IP process, resulting in an increase in value capture from formal disclosure. This may be achieved through improved awareness of the purpose of patents and publications, as well as the leveraging of international research connections. Therefore, in order to track the development of a formalised approach to intellectual property management as an indicator of organisational evolution, patent and scientific publication data from Sasol for the period 1950-2005 have been analysed using a variety of qualitative and quantitative methods. The propositions formulated in response to the research question will be discussed through a critical interpretation of the findings from this study with reference to the theory base.

6.1 Proposition I: Developing a deep understanding of the ***purpose*** of formal ***disclosure*** is an essential component in capturing the ***value*** inherent in ***intellectual property protection***.

The literature abounds with evidence that patent counts are an imperfect measure of innovative activity, owing to varying propensities to patent. However, in the case of developing country firms like Sasol, a study of changing behaviour towards patenting reveals much about the state of technological advancement and the level of awareness of the value in disclosure. Even unwittingly, firms use patents to signal the state of their knowledge stocks, their technological focus areas and other less measurable firm attributes (Long, 2002).

This study advances the theory of the mechanisms through which knowledge emerges in firms and how the disclosure of that knowledge reflects capability upgrading. As with Mina *et al* (2007), the focus of the present study is not the edification of innovative individuals, but the tracking of the evolution of technology development through codification of knowledge. In both cases, patterns of accumulation and dispersion of intellectual property reflect selective forces operating under a variety of motives.

In seeking to use formal disclosure as evidence for capability upgrading, it is necessary to examine the reasons for patenting and publishing from the perspective of the firm.

Sasol's formative years are characterised by a limited outward diffusion of information typical of start-up firms (Daizadeh, 2006), and a defiant nationalist stance that eschewed international participation. Furthermore, Sasol's founding was based on technology imported from Germany and the USA, and much of the first (Synthol) era was occupied with technology transfer and optimisation. For example, it was 18 years before the first Sasol patent in FT was filed. As noted by Albuquerque (2000), innovative modifications of foreign technology do not typically result in patents, particularly when firm capability is low.

Absorptive capacity, the ability to recognise and assimilate foreign information (Cohen and Levinthal, 1990), requires a certain level of internal capabilities (Bernardes and Albuquerque, 2003). More recently, the concept of technology absorptive capacity has been introduced as a measure of the ability of the organisation to seek and exploit foreign technology (García-Morales *et al*, 2007). Sasol's technology absorptive capability was enhanced by the fact that the American technology had not been tested commercially, and suffered from many shortcomings. The sheer resolve of Sasol's scientists and engineers to overcome the problems associated with the American Kellogg technology resulted in the development of the so-called Synthol process. Many developing country firms in this adaptive mode fail to cope sufficiently with borrowed technology that is high in tacit knowledge content and requires systemic efforts to implement (Madanmohan, 2000). Yet, it is argued, that had the imported technology worked as anticipated, the internal capability at Sasol might not have developed to the extent that it did. Nonetheless, the early disclosure of this capability was limited by a fierce belief in secrecy as the best form of protection, and the lack of a local national system of innovation (NSI) to support it.

According to Lall (1993), selective state intervention in focusing technology and institutional efforts in areas of future national comparative advantage is required when resources for capability development are limited. Yet, notwithstanding the stated intention of the South African government to achieve self-sufficiency, particularly with respect to fuel supply in the wake of the oil crises of the 1970's and the political isolation that followed a decade later, there is little evidence of institutional technological support to the fledgling Sasol at a national level.

Indeed, the local capacity to generate either the science or technology required for the conversion of coal to fuels did not exist in South Africa and it took many years to develop research groups at local universities aimed at supporting the technologies of Sasol. As a result, the company became self-reliant in pursuing basic research (Cockburn and Henderson, 1998).

This finding suggests that the national policy in South Africa during this period did not support the co-evolutionary development of firm-level technology together with national institutions as proposed by Murmann (2003). In many respects, this typifies the challenges faced by developing countries. Following an examination of less-developed countries, Bernardes and Albuquerque (2003) purported that the interactions of science and technology are of paramount importance at the beginning of the development process, and that they differ relative to developed countries. In addition, the import of technology has been found to complement indigenous technology development in developing countries (Lall, 1993). From the foregoing, it is clear that the development of capability at Sasol relates to the development of capacity in South Africa at a national level.

Framed in a resource-based view, Tijssen (2004) argues that a lack of investment in tangible or tacit knowledge sources at the firm-level can also hamper technical progress at a later stage.

As shown clearly through the MDS analysis of patent data (Figures 5 and 6), the technological trajectories along which Sasol developed technology absorptive capability were firstly in the core areas of gas production (gasification technology) and gas conversion (Fischer-Tropsch). In later years, evidence of technology proactivity (García-Morales et *al*, 2007) was to be found in the highly successful in-house development of the SAS™ and SPD™ processes (Figures 7 and 8). By leveraging these capabilities, Sasol was able to advance the frontiers of Fischer-Tropsch technology, culminating in the licensing of its proprietary SPD™ process to the Global Joint Venture with Chevron for the development of the first Gas-To-Liquids (GTL) facility in the world.

The increased patent activity in the 1990's (Table 4) is clustered in the areas of FT and gasification technology (Figure 8) and signals the first deliberate attempt to appropriate returns from R&D through licensing (Levin, 1986). Furthermore, the fact that Sasol's patent portfolio featured in the negotiations with US firm Chevron highlights their use as bargaining chips (Reitzig, 2003).

As noted by Pisano (2006), firms can capture value from their innovations when appropriability regimes are strong. However, when imitation is easy or IPR are not enforced, firms need complementary assets (Teece, 2006) in order to appropriate value from innovation. Following Teece's model, Sasol's research into gasification technology generated complementary knowledge assets to its core Fischer-Tropsch technology. This confirms the finding of Helfat (1997) on the complementarity of R&D in the field of synthetic fuels by firms that have access to coal reserves. By generating knowledge assets that are vertically integrated, firms can exploit low-appropriability regimes, such as the use of natural resources.

Together with the concomitant rise in patenting (Figure 10) and self-citations (Figure 15) as a result of iterative stages of learning-by-doing and learning-by-learning, development of the SAS and SPD^{TM} processes offer compelling evidence of indigenous technological capability (Madanmohan, 2000). The complexity and path-dependency of these competencies reflect the accumulation of firm-specific experiences (Patel and Pavitt, 1997).

Indeed, the clustering of patent features in the MDS maps (Figures 5 through 8) suggests the emergence of coherent sets of firm-specific innovative capabilities. Although the present study is focused at the firm-level, it draws an interesting parallel to the industry-wide MDS analysis of the evolution of technological positions by Stuart and Podolny (1996). Within each era, the development of capability in the technology to convert coal to fuels influenced the direction of future innovations, which supports the assertion by Stuart and Podolny (1996) that local search constrains the directions of R&D. Moreover, the clustering of similar technology-areas in the MDS maps of Sasol affirms the notion of technological positioning and portfolio development.

The relative stability of the clustering on the MDS maps point towards a path-dependent co-evolution of scientific and technical knowledge within a certain paradigm. The notion of a paradigm governing the development of technology has been described by Podolny and Stuart (1995), who advance the construct of a technological niche as a focal point of technical change (such as a patent that is used as a node for future innovation). Thus the self-citation of patents by Sasol would indicate the existence of a technological paradigm that focuses development in a specific direction. As shown in the citation tree in Figure 14, the first patent acts as a node for an unfolding network of patents, thereby creating a technological niche for all actors (including Sasol and its competitors). Hence, the forward citation of patents point towards a perpetuation of a technological paradigm.

It is known that few firms exhibit persistent innovative activity (Geroski *et al*, 1997), and in Sasol's case, research programmes tend to have long time frames. Therefore, in analysing the patenting behaviour over time, it is important to understand that even a continuous stream of innovative activity would not produce a regular pattern of patents.

While there is evidence of cumulative capability development and technological niche formation, the formalisation of IP protection in 1997 constitutes an inflection point in the rate of disclosure (Figures 10 and 11), typical of the discontinuity that defines a punctuated equilibrium model (Romanelli and Tushman, 1994). As a result of this intervention, the value of patents (using Putnam's Value Index) increased, and then decreased over time following the introduction of formal IP review sessions (Figures 16 and 17). Putnam's Value Index estimates patent value based on number of country filings, without taking account of the strategy behind a specific country selection (Lanjouw *et al*, 1998).

Prior to 1997, a handful of patents was filed in an inordinate number of countries (Figure 16), while the rest were filed locally (or at best in the US as well). Filing patents in South Africa, particularly during the period of foreign dis-investment, is viewed purely as a cost-effective form of disclosure, since there was no threat of local competition to Sasol. It is common for developing country firms to experiment with patenting by filing domestic patents (Albuquerque 2000); hence, local filings are important signalling devices. Deciding to also file patents at USPTO is in line with the Brazilian approach of signalling increasing capability (Albuquerque, 2000). Notwithstanding this, it is clear that while patenting took place at Sasol prior to 1997, it appeared to be in a fairly desultory fashion.

With respect to publications, it is argued that the absence of local academic partners (who would have had a higher propensity to publish findings) weakened Sasol's own ability to realise the value in scientific papers. The default journal selections were the South African Journal of Chemistry or the South African Journal of Oil and Gas, which often published papers in Afrikaans. As a consequence of the use of an indigenous language and the association with an oppressive political regime, the circulation of these journals was very limited and yielded no advantage to Sasol in terms of global credibility for their research capability. Conversely, however, it afforded the opportunity to practice scientific writing in a virtually risk-free environment. While the absence of peer-review deprived Sasol of valuable feedback on the quality of the research (and of the publications in general), it did enable the company to take small steps in disclosing their findings, and introduce a culture of publishing.

In the case of patents, forward citations are of value to the innovating *firm* (in the case of self-citation) or its competitors (Jaffe *et al*, 2000), whereas, it is typically the *authors* of scientific publications who receive citations in journals. Such citations attest to the research prowess of the authors, and their affiliation is not usually particularly relevant. Therefore, it is argued that the value of scientific publications as a form of disclosure to reflect the evolving organisational capability base of Sasol lies in the publicity that is generated first and foremost for the organisation, not the researchers in their individual capacity. However, since scientific knowledge is embodied in the researcher, it is necessary for the firm to assist the individual in gaining peer recognition through publication in accredited journals in research areas that enhance the profile of the firm. Thus, by association to the respected researcher, the firm may achieve legitimacy in the global arena, irrespective of whether the work receives citations in future. This emphasises the difference in motivation to publish by for-profit organisations compared to traditional not-for-profit academic institutions.

The steady increase in number of papers filed in higher impact factor journals (Figure 18) reflects both an increasing awareness of the purpose of gaining credibility through public disclosure, and an increasing desire to participate in the global research community. Bernardes and Albuquerque (2003) argue that research performed for local needs is most likely to be published in domestic journals (if at all), and therefore would not appear in international (ISI) high impact journals.

Hence, such publications are often not captured in business research that uses the ISI database of scientific papers as a source of secondary data. By considering all examples of scientific publications by Sasol employees, both in local and international journals, the present study advances the current notion of learning to publish. In agreement with Bernardes and Albuquerque (2003), the selection of local journals might well reflect research for local needs; although another interpretation might be the lack of a well-developed national system of innovation (NSI) in South Africa.

The dramatic increase in patenting coinciding with the advent of the IP group is viewed as somewhat of an over-recovery, with the average Putnam's Value Index rising to 1.5 per patent (corresponding to 22 countries) in 1997 (Figure 17). Hence, while there was recognition of the *need* to patent, the ability to decide *where* to patent was still lacking. It is likely that the cost associated with this extensive filing strategy would have been exorbitant, particularly when compared to the meagre cost of patenting in prior years. Therefore, the introduction of the IP Review Team in 2000 is seen as a further step in the evolutionary process of striving to extract value from patenting. The primary function of this team was to carefully consider the reasons for patenting, which included both the need to patent as well as the country filing strategy to be followed. For example, the decrease in Putnam's Value Index to 0.3 per patent, (corresponding to 18 countries per patent) for the years following 2000 (Figure 17), indicates a heightened awareness of the purpose of patenting since each potential patent was put through a rigorous selection process prior to being filed.

In prior years, even low-value inventions were patented (albeit only in RSA or USA). Hence, the mandate of the IP review team was to consider alternative vehicles for disclosing information when patenting was not appropriate. The approach followed was very much in line with the decision tree model of Daizadeh *et al* (2002) as shown in Figure 1.

As shown in Figure 11, the increase in journal publications is a direct consequence of the selection criteria applied at the IP Review meetings. This increase is against the trend observed by Tijssen (2004) of declining corporate publications during the period 1996-2001 at the expense of an increase in patenting. Interpreting his findings, Tijssen cited a world-wide shift in emphasis from dissemination of knowledge towards appropriation of R&D effort for commercial gain (Tijssen, 2004). It is conjectured that the rise in patenting at Sasol over this period is as a result of a strategy to align with global trends, following the formalisation of the IP function. However, at Sasol, the dominance of patenting in the tension between publications observed by Tijssen is replaced (at least in the period following 1997) by a mutually reinforcing relationship, built on an increasing understanding of the value in creating linkages to the global research community through publication in high quality journals, together with having a portfolio of patents covering key markets.

The formalisation of IPR is a global phenomenon which started in the 1990's, and has precipitated a change in the "knowledge flow balance" (Tijssen, 2004, p. 710) with re-focusing of in-house R&D towards commercially relevant activities. As a result, many firms in the US and Japan downsized their in-house R&D, and the emergence of a results-oriented R&D culture deterred scientists from publishing their findings in scientific journals (Varma, 2000). It is noteworthy that the formalisation of IPR at Sasol did not come at the expense of an in-house R&D division or a decline in the propensity to publish findings (Figure 11).

Thus, the evidence presented in this study suggests that, within the evolution of capability upgrading at Sasol, the formalisation of intellectual property enabled a more focused approach to patenting and publication in scientific journals. In support of Proposition I, this deepening awareness of the purpose of disclosure was manifested in an increased propensity to patent and publish scientific findings in a more appropriate manner, so as to fully exploit the value in disclosure.

6.2 Proposition II: Effective international connections are enabling factors in deriving value from intellectual property

The concept of technology absorptive capacity supports the resource-based view of the firm in that the research base is an important driver of innovation capability (Tijssen, 2004). Yet, in the absence of a strong internal capability, firms need to depend on externally developed science and technology (Mansfield, 1998). However, a central argument in the study by Barnard (2006) is that developing country multinationals do not fully exploit their international connections for strategic benefit.

Certainly, the presence (and absence during sanctions) of international connections has emerged as a key theme in capability upgrading at Sasol throughout the firm's history. However, in arguing that these foreign connections enhanced the capture of value from intellectual property, it is necessary to examine the Sasol case for evidence of 'connectedness' (Wagner and Leydesdorff, 2005). According to the literature, a requisite condition for the evolution of the MNC into an integrated network organisation is connectedness to the global science community (Cockburn and Henderson, 1998) and a supportive national system of innovation. That the NSI in South Africa was not supportive of Sasol in terms of technology development has been established in the preceding discussion on Proposition I.

Having formalised the IP function in 1997, Sasol initiated various major interventions at the turn of the century which were aimed at capability upgrading. These included the establishment of satellite research laboratories in Scotland and The Netherlands, and the constitution of Advisory Boards. Both of these interventions are seen as mechanisms for exploiting location-specific R&D advantages (von Zedtwitz and Gassmann, 2002). The satellite laboratories were located at universities that are held in high regard for their research in homogeneous catalysis (St Andrews) and reactor technology (Twente). Not only were these facilities well-equipped, but attracted first-rate researchers, who were not prepared to ply their trade in South Africa. Given their specialised set of capabilities, these two satellite groups were intended to operate as centres of excellence (Frost *et al*, 2002), and ensure that the frontiers of science and engineering in their respective fields were continuously advanced for Sasol's benefit.

While the establishment of satellite laboratories in Europe can be seen as the internationalisation of Sasol R&D (Nobel and Birkinshaw, 1998), the role of the Advisory Boards was to provide linkages to external collaborators. Given the stature of the members of the boards, these connections were to groups or individuals of the highest standing in academic circles. In terms of the taxonomy of Katz and Martin (1997), these would be classified as heterogeneous collaborations since the parties had nothing in common other than a vested interest in researching a specific aspect of science.

The formation of the advisory boards with respected foreign academics was strongly motivated on the basis that these connections would enhance the quality of research performed at Sasol, given the lack of local academic work in the field of homogeneous catalysis for example. This reasoning was analogous to the role of Western European scientists in upgrading the research of their Eastern European counterparts (Katz and Martin, 1997).

In addition to signalling the production of collective knowledge, co-authored publications also draw attention to the quality of the external network that the firm has established (Tijssen, 2004). As shown in Figure 20, there is a dramatic increase in the number of co-authored scientific publications after 2000. This is mainly due to the efforts of the advisory boards in leveraging their own networks to establish research collaborations with Sasol scientists. There is also a contribution from the satellite research laboratories.

Concomitant with the increase in co-authorships is a rise in the average journal impact factor (Figure 20). Publications in peer-reviewed journals with high-impact factor provide the firm with visibility in the research community, and the opportunity to generate prior art (Nelson, 1990). Such publications also act as signals of R&D capability (Hicks, 1995) and could attract first-rate researchers. Therefore, the value of disclosure extends far beyond the dissemination of scientific information.

Only through the acquisition of Condea did Sasol gain significant in-house capability in the area of high-value chemicals (Figure 9). The acquisition of firms as a means to expand the technology base of firms in the chemical industry has been reported previously (Ahuja and Katila, 2001). As shown in Figure 19, international co-invented patents were mainly in the areas of FT and chemicals, the latter coming as a result of the expertise of foreign laboratories acquired from Condea. International co-inventorships on FT patents are mainly attributed to the Sasol-Chevron joint venture. According to García-Morales *et al* (2007), firms with greater technology absorptive capacity will have greater success at acquisitions and joint ventures.

Therefore, in support of Proposition II, the evidence from the Sasol case suggests that effective international connections function as ‘access relationships’ (Stuart, 2000, p. 791) for accelerating capability upgrading in developing country firms, and enhancing value from intellectual property through legitimacy gains.

7. CONCLUSION

Prior research on capability upgrading in developing country firms has emphasised the need for interaction between science and technology (Bernardes and Albuquerque, 2003), and connectedness to the global research network (Wagner and Leydesdorff, 2005). In the process of developing technological capability, firms acquire and produce tacit and codified knowledge assets that together constitute their intellectual property. The tension between appropriation and dissemination of these knowledge assets is manifested through the desultory attempts at disclosure by developing country firms that lack a formal IP function. Therefore, this research has focussed on the formalisation of the IP process as an indicator of capability upgrading in a developing country MNC.

Following a comprehensive analysis of patenting and publication behaviour at Sasol for the fifty years since its founding, the evidence suggests that the formalisation of IP at Sasol constitutes a discontinuity with respect to awareness of the purpose of disclosure. This heightened awareness was achieved in two fundamentally different ways: the one being the implementation of a formal IP review process, and the other involved international research connections. The complementarity of these seemingly incongruous factors in enhancing value capture from disclosure forms the central argument of this study. As illustrated by the theoretical framework in Figure 21, the evolution of capability at a developing country firm requires absorptive capacity since it is likely that foreign technology will be present at start-up. Thereafter, the firm acquires indigenous technological capability by internalising routines and developing firm-specific competencies. During this period, the firm may experiment with *ad hoc* disclosure of these knowledge assets through patents and publications. However, the evidence presented in this study suggests that the introduction of an internal IP function fosters an awareness of the purpose of alternative forms of disclosure as a means to both appropriate the returns from R&D and promote external recognition of the capability of the firm; this is the basis of the first proposition (P_1).

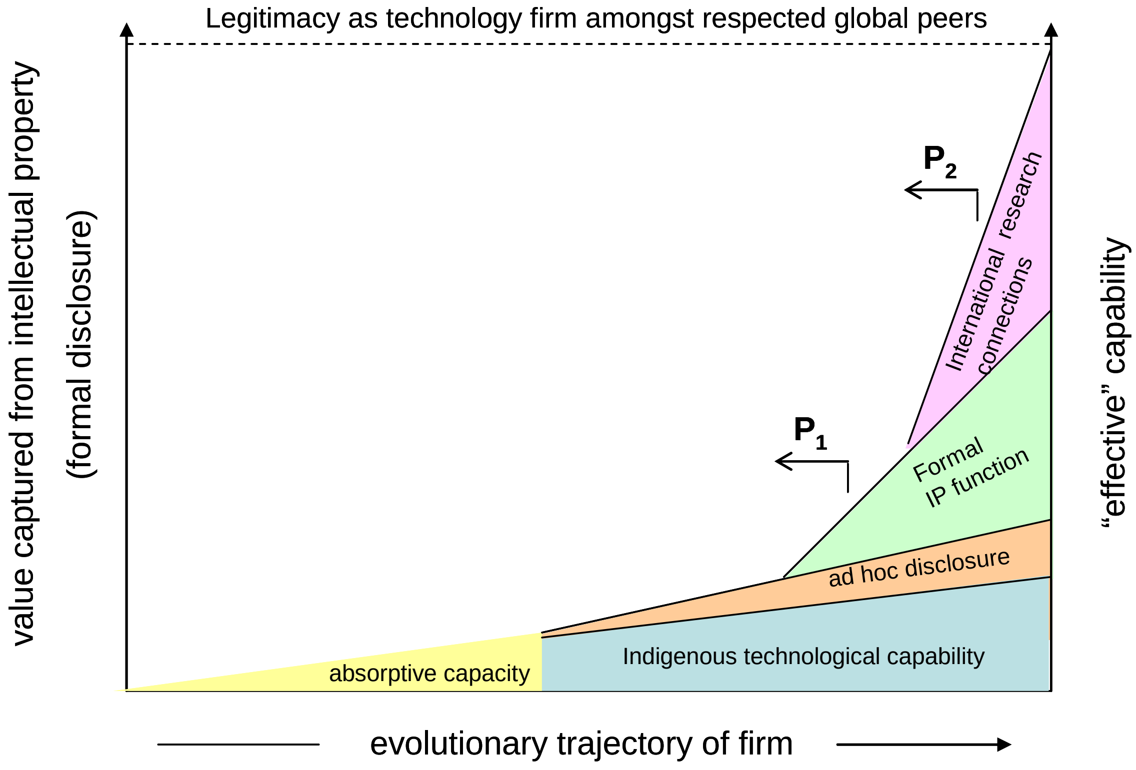


Figure 21: A theoretical framework showing the formalisation of intellectual property and international research connections as indicators of capability upgrading in the evolution of a developing country technology-based firm

Furthermore, it was found that joint publications with first-rate researchers in high-impact journals enable the developing country firm to reflect an 'effective' capability that far exceeds its indigenous capacity. This offers support for the second proposition (P_2) which argues that having established a precedent for formal disclosure through a managed IP function, the developing country firm can accelerate its trajectory towards gaining legitimacy amongst leading technology firms by leveraging effective international research connections.

Therefore, in response to the research question, the findings presented in this study suggest that formalisation of IP is a key indicator of capability upgrading at a developing country MNC, by creating an awareness of the value in disclosure of knowledge assets (via patents or scientific publications) and the benefits of connectedness to the global research community.

The cartoon in Figure 22 appeared in an article entitled "Who owns scientific papers?" published in *Science*, (Bachrach *et al*, 1998) and illustrates the value attributed to scientific publications as a means of disclosure by researchers. This points to a critical insight that emerged from this study in terms of the apportioning of credibility through different forms of disclosure: patents are assigned to firms, and yet it is individual researchers who achieve recognition through publications until their association with the firm becomes common knowledge.

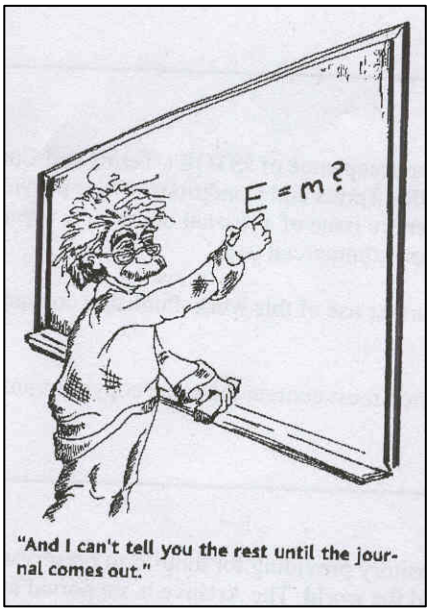


Figure 22: Illustration of the value attached to scientific publications by researchers (Bachrach *et al*, 1998)

Therefore, in leveraging their international collaborations, aspirant developing country MNC's must ensure that the citation profiles of their researchers reflect the capabilities of the firm.

7.1 Recommendations from this study

Capability upgrading of developing country firms is highly topical judging from the plethora of recent literature on the matter. It is hoped that this research has contributed to the debate by advancing the theory on the purpose of formalised disclosure in capturing value from knowledge assets. More specifically, it has offered rare insight into the evolution of intellectual property management at a South African technology-based MNC.

This research highlights the need for technology-based firms to formalise IP protection and manage it as an ongoing process in order to extract maximum value. The work of Tijssen (2004) suggests a global shift towards appropriation of R&D effort (potentially) at the expense of legitimacy in research circles, particularly in Europe. The formulation of an integrated IP strategy will enable developing country firms to strike a balance between patents and scientific publications in order to achieve the optimum level of connectedness without compromising appropriability. Indeed, the intrinsic differences between patents and publications as information transfer mechanisms allow for a synergistic approach to disclosure.

It is argued that, in the Sasol case, a number of costly patenting mistakes could have been avoided had an IP strategy already existed. Therefore, as proposed in the updated theoretical framework in Figure 23, the formulation of an IP strategy should ideally take place prior to any formal disclosure of capability. This strategy should be informed jointly by the indigenous technological capability present at the time as well as the governing business model, in consultation with a recognised authority on IPR. Since it is unlikely that this competency would reside in-house at this early developmental stage, the services of a patent attorney would be required. Thereafter, any disclosure, no matter how infrequent, would take place in accordance with the strategy.

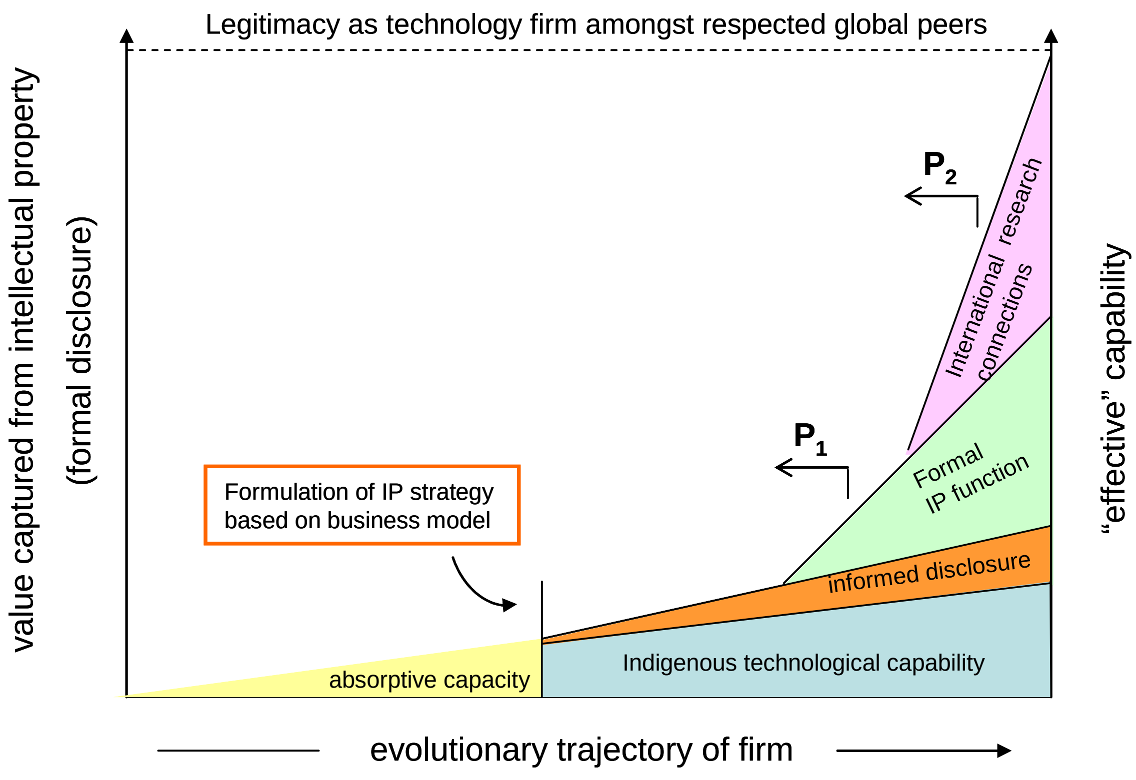


Figure 23: Updated theoretical framework showing the formulation of an integrated IP strategy prior to any disclosure of knowledge assets

This will enable organisational learning (through informed disclosure) and gains in credibility to occur concomitantly, with the reduced possibility of an ill-judged publication. It is highly likely that the IP strategy would dictate secrecy in areas where significant technology development is still required. This approach will also facilitate the introduction of a formal in-house IP function once the firm has developed sufficient capability to justify the associated costs. Thus, by strategically considering the *reasons* for disclosure as well as the *timing* thereof, firms can leverage their intellectual property both offensively and defensively.

In seeking to internationalise their R&D, developing country firms should seek to exploit location-specific advantages, particularly with respect to gaining legitimacy amongst leading companies through scientific publication. However, this will require the developing country firm to contribute jointly to the research, and not simply outsource product development. Since the outflow of FDI for research purposes exponentially increases the cost of R&D, it is imperative that the nature and location of the foreign connection be carefully considered to ensure complementarity of knowledge assets.

7.2 Suggested areas for future research

Case study research always offers gains in terms of the richness of evidence, at the expense of the generalisability of findings (Yin, 2003). The use of a single case in the present study further exacerbates the situation, thus strengthening the argument for similar research into the use of disclosure at other technology-based firms in South Africa. Moreover, although this study is aimed at the firm-level, it is contextualised within the broader South African national system of innovation. Therefore, it would be insightful to evaluate the national policy decisions that shaped investments in engineering and science research over the fifty year period under review in order to track the evolution of industry-university linkages in South Africa. This would enable a more critical examination of Sasol's approach to domestic publications and patents during the Apartheid era.

Maintaining the focus at a national level, it is known that the most successful examples of upgrading in the recent era have emerged from the NIE's of South East Asia (South Korea, Taiwan, Singapore). Although the local strategies of each country differed, they were all outward-looking in terms of national policy. This is sharply contrasted with South Africa, which adopted fiercely nationalist, inward-looking policies for much of the twentieth century. While the Asian Tigers did invest heavily in local capacity, international connections played a significant role in their success. It would be useful therefore, to examine the co-evolution of foreign linkages together with the development of local capacity at Sasol at a broader firm-level, not just from the perspective of intellectual property as in the present study.

The concept of ‘effective’ capability was introduced in the theoretical framework (Figure 21) of the current research in order to indicate the gains in legitimacy as a result of connectedness through formal channels of disclosure and international connections. Hence, this study relied heavily on patent and publication data. However, it would be useful to supplement this quantitative analysis with a qualitative study of the perceived level of capability development by using a questionnaire similar to that used by Hobday and Rush (2007) that incorporated a ‘staircase model’ of capabilities. This instrument is ideally suited to evolutionary studies and would give texture to the concept of ‘effective’ capability and contrast it with indigenous capability as revealed through firm-specific routines and processes.

Further research is also necessary to determine the factors that should dictate the focus of the IP strategy when capability and credibility are limited (Figure 23).

Finally, a shortcoming of the present study is the lack of data on annual R&D expenditure, including the cost of patenting as well as any royalties or licence fees earned as a result of owning patents. Yet, in recommending that IP be managed as an ongoing process, it is implicitly assumed that the value captured from disclosure will justify the input costs, and it would be prudent to confirm the validity of this assumption in a more rigorous fashion.

REFERENCES

Ahuja, G. and Katila, R. (2001) Technological acquisitions and the innovation performance of acquiring firms: A longitudinal Study. *Strategic Management Journal*, 22(3), 197-220.

Albuquerque, E. (2000) Domestic patents and developing countries: arguments for their study and data from Brazil (1980-1995). *Research Policy*, 29, 1047-1060.

Almeida, P. (1996) Knowledge sourcing by foreign multinationals: Patent citation analysis in the U.S. semiconductor industry. *Strategic Management Journal*, 17, 155-165.

Annual Report (1958) South African Coal, Oil and Gas Corporation, Limited, Johannesburg: Sasol.

Bachrach, S., Berry, R. S., Blume, M., von Foerster, T., Fowler, A., Ginsparg, P., Heller, S., Kestner, N., Odlyzko, A., Okerson, A., Wigington, R. and Moffat, A. (1998) Who should own scientific papers? *Science,* New Series, 281 (5382), 1459-1460.

Bar, T. (2006) Defensive publications in an R&D race. *Journal of Economics & Management Strategy*, 15(1), 229-254.

Barnard, H.C. (2006) *Investment from less to more developed countries as a mechanism for capability upgrading in developing country firms*. PhD dissertation, Graduate School-Rutgers, State University of New Jersey, Newark.

Bartlett, C. A. and Ghoshal, S. (1989) *Managing across borders: the transnational solution.* Boston: Harvard Business School Press.

Bernardes, A.T. and Albuquerque, E. (2003) Cross-over, thresholds, and interactions between science and technology: lessons or less developed countries. *Research Policy*, 32, 865-885.

Borokhovich, K. A., Bricker, R. J. and Simkins, B. J. (2000) An analysis of finance journal impact factors. *The Journal of Finance*, 55(3), 1457-1469.

Cantwell, J. (1993) The internationalization of technological activity and its implication for competitiveness, in Granstrand, Hakanson & Sjolander (eds). *Technological Management and International Business*. Chichester: John Wiley.

Cantwell, J. and Janne, O. (2000) The role of multinational corporations and national states in the globalization of innovatory capacity: The European Perspective. *Technology Analysis & Strategic Management*, 12(2), 243-262.

Chen, S-H. (1997) Decision-making in research and development collaboration. *Research Policy*, 26, 121-135.

Chen, Y. and Puttitanun, T. (2002) *Intellectual property rights and innovation in developing countries.* 11th WZB Conference on Industrial Organization “Innovation Policy in International Markets”. Berlin: WZB.

Cockburn, I. M. and Henderson, R. M. (1998) Absorptive capacity, coauthoring behaviour, and the organization of research in drug discovery. *The Journal of Economics*, 46(2), 157-182.

Cohen, W. and Levinthal, D. A. (1990) Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly*, 35, 128-152.

Collings, J. (2002) *Mind Over Matter. The Sasol Story: Half a century of technological innovation.* Johannesburg: Sasol.

Comanor, W. S. and Scherer, F. M. (1969) Patent statistics as a measure of technical change. *Journal of Political Economy*, 77(3), 392-398.

Daizadeh, I., Miller, D., Glowalla, A., Leamer, M., Nandi, R. and Numark, C. I. (2002) A general approach for determining when to patent, publish, or protect information as a trade secret. *Nature Biotechnology*, 20, 1053-1054.

Daizadeh, I. (2006) Using intellectual property to map the organisational evolution of firms: Tracing a biotechnology company from start-up to bureaucracy to a multidivisional firm. *Journal of Commercial Biotechnology*, 13(1), 28-36.

Daizadeh, I. (2007) Intellectual property management in R&D intensive firms. London: Inderscience Publishers. Summary at http://www.inderscience.com/offer.php?id=13554 (accessed 20/08/07)

Ernst, D. (2002) Global production networks and the changing geography of innovation systems. Implications for developing countries. *Economics. Innovation and New Technology*, 11(6), 497-523.

Ernst, D. and Kim, L. (2002) Introduction: Global production networks, information technology and knowledge diffusion. *Industry and Innovation*, 9(3), 147-153.

Fey, C. F. and Birkinshaw, J. (2005) External sources of knowledge, governance mode, and R&D performance. *Journal of Management*, 31(4), 597-621.

Fok, D. and Franses, P. H. (2007) Modelling the diffusion of scientific publications. *Journal of Econometrics*, 139, 376-390.

Forman, R. (1981) History inside business. *The Public Historian*, 3(3), 40-61.

Freeman, C. (1992) Formal scientific and technical institutions in the national system of innovation, in Lundvall (ed) *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*. London: Pinter Publishers.

Frenz, M., and Ietto-Gillies, G. (2007) Does multinationality affect the propensity to innovate? An analysis of the third UK community innovation survey. *International Review of Applied Economics*, 21(1), 99-117.

Frost, T. S., Birkinshaw, J. M. and Ensign, P. C. (2002) Centers of excellence in multinational corporations. *Strategic Management Journal*, 23, 997-1018.

García-Morales, V. J., Ruiz-Moreno, A. and Llorens-Montes, F. J. (2007) Effects of technology absorptive capacity and technology proactivity on organizational learning, innovation and performance: An empirical examination. *Technology Analysis & Strategic Management*, 19(4), 527-558.

Garfield, E. (1972) Citation analysis as a tool in journal evaluation. *Science*, 178, 471-479.

Geroski, P. A., van Reenen, J. and Walters, C. F. (1997) How persistently do firms innovate? *Research Policy*, 26, 33-48.

Greene, J. R. and Scotchmer, S. (1995) On the division of profit in sequential innovation. *The RAND Journal of Economics*, 26(1), 20-33.

Griliches, Z. (1990) Patent statistics as economic indicators: A survey. *Journal of Economic Literature*, 28, 1661-1707.

Harhoff, D., Narin, F. Scherer, F. M. and Vopel, K. (1999) Citation frequency and the value of patented inventions. *The Review of Economics and Statistics*, 81(3), 511-515.

Harter, J. F. R. (1994) The propensity to patent with differentiated products. *Southern Economic Journal*, 61(1), 195-201.

Haveman, H. A., Russo, M. V., and Meyer, A. D. (2001) Organizational environments in flux: The impact of regulatory punctuations on organizational domains, CEO succession, and performance. *Organization Science*, 12(3), 253-273.

Helfat, C. E. (1997) Know-how and asset complementarity and dynamic capability accumulation: the case of R&D. *Strategic Management Journal*, 18(5), 339-360.

Hicks, D. (1995) Published papers, tacit competencies and corporate management of public/private character of knowledge. *Industrial and Corporate Change*, 4(2), 401-424.

Hintze, J. (2004) *NCSS and PASS Number Cruncher Statistical Systems*. Kaysville, Utah, USA.

Hobday, M. (2005) Firm-level Innovation models: perspectives on research in developed and developing countries. *Technology Analysis and Strategic Management,* 17(2), 121-146.

Hobday, M. and Rush, H. (2007) Upgrading the technological capabilities of foreign transnational subsidiaries in developing countries: The case of electronics in Thailand. *Research Policy*, 36, 1335-1356.

Horstmann, I., MacDonald, G. M. and Slivinski, A. (1985) Patents as information transfer mechanisms: To patent or (maybe) not to patent. *The Journal of Political Economy*, 93(5), 837-858.

Jackson, M. C. (1999) Towards coherent pluralism in management science. *The Journal of Operational Research Society*, 50(1), 12-22.

Jaffe, A. B. (1989) Real effects of academic research. *The American Economic Review*, 79(5), 957-970.

Jaffe, A. B., Trajtenberg, M. and Henderson, R. (1993) Geographic localization of knowledge spillovers as evidenced by patent citations. *The Quarterly Journal of Economics*, 108(3), 577-598.

Jaffe, A. B. and Trajtenberg, M. (1996) Flows of knowledge from universities and federal laboratories: Modelling the flow of patent citations over time and across institutional and geographic boundaries. *Proceedings of the National Academy of Sciences of the United States of America*, 93(23), 12671-12677.

Jaffe, A. B., Trajtenberg, M. and Fogarty, M. S. (2000) Knowledge spillovers and patent citations: evidence from a survey of inventors. *The American Economic Review*, 90(2), 215-218.

Katz, J. S. and Martin, B. R. (1997) What is research collaboration? *Research Policy*, 26, 1-18.

Kurata, K., Matsubayashi, M., Mine, S., Muranushi,T. and Ueda, S. (2007) Electronic journals and their unbundled functions in scholarly communications: Views and utilization by scientific, technological and medical researchers. *Information Processing and Management*, 43, 1402-1415.

Lall, S. (1993) Promoting technology development: The role of technology transfer and indigenous effort. *Third World Quarterly*, 14(1), 95-108.

Lanjouw, J. O., Pakes, A. and Putnam, J. (1998) How to count patents and value intellectual property: The uses of patent renewal and application data. *The Journal of Industrial Economics*, 46(4), 405-432.

Lee, C., Lee, K. and Pennings, J. M. (2001) Internal capabilities, external networks, and performance: A study on technology-based ventures. *Strategic Management Journal*, 22(6/7), 615-640.

Levin, R. C., Klevorick, A. K., Nelson, R. R. and Winter, S. G. (1984) *Survey research on R&D appropriability and technological opportunity*, Research Paper (Yale University, New Haven, CT).

Levin, R. C. (1986) A new look at the patent system. *The American Economic Review*, 76 (2), Papers and proceedings of the ninety-eighth annual meeting of the American Economic Association, 199-202.

Levin, R. C., Klevorick, A. K., Nelson, R. R., Winter, S. G., Gilbert, R. and Griliches, Z. (1987) Appropriating the returns from industrial research and development. *Brookings Papers on Economic Activity*, 1987 (3) Special Issue on Microeconomics, 783-831.

Levin, R. C. (1988) Appropriability, R&D spending and technological performance. *The American Economic Review*, 78(2), Papers and proceedings of the one-hundredth annual meeting of the American Economic Association, 424-428.

Lieberman, M. B. (1987) Patents, learning by doing, and market structure in the chemical processing industries. *International Journal of Industrial Organization*, 5, 257-276.

Loch, C. H. and Huberman, B. A. (1999) A punctuated-equilibrium model of technology diffusion. *Management Science*, 45(2), 160-177.

Long, C. (2002) Patent signals. *The University of Chicago Law Review*, 69(2), 625-679.

Madanmohan, T. R. (2000) Failures and coping strategies in indigenous technology capability process. *Technology Analysis & Strategic Management*, 12(2), 179-192.

Malnight, T. W. (2001) Emerging structural patterns within multinational corporations: Toward process-based structures. *Academy of Management Journal*, 44(6), 1187-1210.

Mansfield, E. (1986) Patents and Innovation: An Empirical Study. *Management Science*, 32(2), 173-181

Mansfield, E. (1997) Academic research an industrial innovation: An update of empirical findings. *Research Policy*, 26, 773-776.

Milnamow, J. (1982) The patent system. *APLA Quarterly Journal*, 10, 71-80.

Mina, A., Ramlogan, R., Tampubolon, G. and Metcalfe, J. S. (2007) Mapping evolutionary trajectories: Applications to the growth and transformation of medical knowledge. *Research Policy*, 36, 789-806.

Mowery, D. C., Sampat, B. N. and Ziedonis, A. A. (2002) Learning to patent: Institutional experience, learning, and the characteristics of U.S. university patents after the Bayh-Dole Act, 1981-1992. *Management Science*, 48(1), 73-89.

Murmann, J.P. (2003) *Knowledge and Competitive Advantage: The Coevolution of Firms, Technology and National Institutions*. Cambridge: Cambridge University Press.

Nelson, R. R. (1990) Capitalism as an engine of progress. *Research Policy*, 19(3), 193-214.

Nelson, R. and Rosenberg, N. (1993) Technical Innovation and national systems, in Nelson (ed), *National Innovation Systems: A Comparative Analysis*. Oxford: Oxford University Press.

Nobel, R. and Birkinshaw, J. (1998) Innovation in multinational corporations: control and communication patterns in international R&D operations. *Strategic Management Journal,* 19, 476-496.

Oddi, A. S. (1987) The international patent system and third world development: Reality or Myth? *Duke Law Journal,* 1987(5), 831-878.

Patel, P. and Pavitt, K. (1997) The technological competencies of the world's largest firms: complex and path-dependent, but not much variety. *Research Policy*, 26, 141-156.

Patel, P. and Pavitt, K. (1998) The wide (and increasing) spread of technological competencies in the world's largest firms: A challenge to conventional wisdom, in Chandler, Hgoström & Solvell (eds.) *The Dynamic Firm: The Role of Technology, Strategy, Organization and Regions*. New York: Oxford University Press.

Pickar, J. H. (2007) Do journals have a publication bias? *Maturitas*, 57, 16-19.

Pisano, G. (2006) Profiting from innovation and the intellectual property revolution. *Research Policy*, 35, 1122-1130.

Pitkethly, R. H. (2001) Intellectual property strategy in Japanese and UK companies: patent licensing decisions and learning opportunities. *Research Policy*, 30, 425-442.

Podolny, J. M. and Stuart, T. E. (1995) A role-based ecology of technology change. *The American Journal of Sociology*, 100(5), 1224-1260.

Rappert, B., Webster, A. and Charles, D. (1999) Making sense of diversity and reluctance: academic-industrial relations and intellectual property. *Research Policy*, 28, 873-890.

Reitzig, M. (2003) What determines patent value? Insights from the semi-conductor industry. *Research Policy*, 32, 13-26.

Romanelli, E. and Tushman, M. L. (1994) Organizational transformation as punctuated equilibrium: An empirical test. *Academy of Management Journal*, 37(5), 1141-1166.

Sabherwal, R., Hirscheim, R., and Goles, T. (2001) The dynamics of alignment: Insights from a punctuated equilibrium model. *Organization Science*, 12(2), 179-197.

Schiffman, S. S., Reynolds, M. L. and Young, F. W. (1981) *Introduction to multidimensional scaling: Theory, methods, and applications*. Orlando: Academic Press, Inc.

Schott, T. (1993) World Science: Globalization of institutions and participation. *Science, Technology, & Human Values*, 18(2), 196-208.

Seglen, P. O. (1997) Why the impact factor of journals should not be used for evaluating research. *British Medical Journal*, 314(7079), 498-502.

Sell, S. K. (1995) Intellectual property protection and antitrust in the developing world: Crisis, coercion, and choice. *International Organization*, 49(2), 315-349.

Sherry, E. F. and Teece, D. J. (2004) Royalties, evolving patent rights, and the value of innovation. *Research Policy*, 33, 179-191.

Sorenson, O. and Fleming, L. (2004) Science and the diffusion of knowledge. *Research Policy*, 33, 1615-1634.

Spence, M. (1984) Cost reduction, competition, and industry performance. *Econometrica*, 52, 101-121.

Stuart, T. E. and Podolny, J. M. (1996) Local search and the evolution of technological capabilities. *Strategic Management Journal*, 17, 21-38.

Stuart, T. E. (1998) Network positions and propensities to collaborate: An investigation of strategic alliance formation in a high-technology industry. *Administrative Science Quarterly*, 43(3), 668-698.

Stuart, T. E. (2000) Interorganizational alliances and the performance of firms: A study of growth and innovation rates in a high-technology industry. *Strategic Management Journal*, 21(8), 791-811.

Steynberg, A.P. and Dry, M.E. (eds.) (2004) *Fischer-Tropsch Technology*. Amsterdam: Elsevier.

Subramanyam, K. (1983) Bibliometric studies of research collaborations: A review. *Journal of Information Science*, 6(1), 33-38.

Teece, D. J. (1986) Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Research Policy*, 15(6), 285-305.

Teece, D. J., Pisano, G. and Shuen, A. (1997) Dynamic capabilities and strategic management. *Strategic Management Journal*, 18(7), 509-533.

Teece, D. J. (1998) Capturing value from knowledge assets: The new economy, markets for know-how, and intangible assets. *California Management Review*, 40(3), 55-79.

Teece, D. J. (2006) Reflections on "Profiting from Innovation". *Research Policy*, 35, 1131-1146.

Tijssen, R. J. W. (2004) Is the commercialisation of scientific research affecting the production of public knowledge? Global trends in the output of corporate research articles. *Research Policy*, 33, 709-733.

Trajtenberg, M. (1990) A penny for your quotes: Patent citations and the value of innovations. *The RAND Journal of Economics*, 21(1), 172-187.

UNCTAD (2005) World Investment Report 2005: Transnational Corporations and the Internationalization of R&D. http://www.unctad.org/wir (accessed 30/01/07).

Varma, R. (2000) Changing research cultures in the U.S. industry. *Science, Technology and Human Values*, 25(4), 395-416.

Von Zedtwitz, M. and Gassmann, O. (2002) Market versus technology drive in R&D internationalization: four different patterns of managing research and development. *Research Policy*, 31, 569-588.

Walton, C. C., Hidy, R. W., Overton, R. C. and Williamson, H. F. (1962) Business History: Some major challenges. *The Business History Review*, 36(1), 21-43.

Wagner, C. S. and Leydesdorff, L. (2005) Mapping the network of global science: comparing international co-authorships from 1990-2000. *International Journal of Technology and Globalisation*, 1(2), 185-207.

Wong, P-K. (1999) *National Innovation systems for rapid technological catch-up: an analytical framework and a comparative analysis of Korea, Taiwan and Singapore,* a paper presented at DRUID Summer Conference on National Innovation Systems, Industrial Dynamics and Innovation Policy. Rebild, June 9-12: Denmark.

Yin, R. K. (2003) *Case Study Research: Design and Methods*. 3rd ed. California: Sage Publications.