Local effort and global connections

The role of international linkages in the evolution of technological capabilities at SASOL

by

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To what extent are international business connections useful to facilitate technological upgrading, and to what extent are they essential? And what types of international business connections are most appropriate in supporting firms' capacity development? The most successful examples of upgrading in the recent era, the Asian Tigers, were all outward-looking in their orientation, although the specific development strategies of the economic regions differed[1]. Although some type of international business connection was important for all of them, they all invested in local capacity building. This article investigates the co-evolution of firm capacity and international linkages by looking at the South African chemicals firm Sasol.

This article demonstrates how a firm develops technological expertise that increases the resilience of the firm to various external shocks like changing economic conditions and the absence of

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1. S. Lall, "Technology development policies: Lessons from Asia", in S. Lall (ed), *Learning from the Asian tigers*, London, 1996

new inputs from abroad. However, international linkages remain essential to sustain innovation, not only because they introduce new knowledge into the firm, but also because a developing country firm typically lacks a large enough local skills base to fully support its knowledge creating efforts. Moreover, the nature of international linkages changes over time. They evolve from predominantly individual to predominantly institutional linkages, and from primarily arm's length interactions with other for-profit entities (for example, consultants or other firms) to include interaction with foreign public research institutes.

The positive role of international business connections in enabling technological and economic development has been known since at least the early work of Dunning.[2] Such connections can be primarily internalised through alliances or the entry of multinational corporations or externalised through franchising or licensing,[3] and can even take place through the flow of people.[4] However the connections take place, the contact with the managerial and technological innovations of the foreign partner helps to accelerate local technological development.

Even though the absence of international linkages can hamstring development, the presence of such linkages is worth little with-

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2. J.H. Dunning, *American investment in British manufacturing industry*, London, 1958
3. S. Lall, "MNCs, technology and export competitiveness", in S. Lall (ed), *Competitiveness, technology and skills*, Cheltenham, 2001
4. See for example J. Vang & M.L. Overby, "Transnational communities, offshore outsourcing and offshore subsidiaries: The case of the Indian IT industry", in B-Å. Lundvall, P. Intarakumnerd & J. Vang (eds), *Asia's innovation systems in transition*, Cheltenham, 2006; and A. Saxenian, "Transnational communities and the evolution of global production networks: The cases of Taiwan, China and India", *Industry and innovation*, 9, 2002

out local commitment and investment in technological development. There is by now an extensive literature documenting how "spillovers" from foreign investment occur best where there is also investment in the local development of quality tertiary education and research institutions.[5]

1. METHODOLOGY

This article sets out to highlight at which junctures and through which mechanisms international expertise contributed to the technological advancement of Sasol, a firm that was founded in 1950 as a synthetic fuels producer to help promote energy security for South Africa. Technology development at the firm is followed from its founding until 2005, when the then Managing Director Pieter Cox concluded his term. Sasol was a science-based firm from the outset – its origins lie in the Fischer-Tropsch (FT) process for generating fuel from coal and gas, so named after the two scientists who patented the process in 1925 in Germany.

A variety of data sources are used to track the relationship between Sasol's own efforts and foreign linkages in the technological evolution of the economy. First, Sasol's synthetic fuel reac-

5. See for example M. Blomström, A. Kokko & S. Globerman, "The determinants of host country spillovers from foreign direct investment: A review and synthesis of the literature", in N. Pain (ed), *Inward investment, technological change and growth*, Houndmills and New York, 2001; M. Haddad & A. Harrison, "Are there positive spillovers from direct foreign investment?", *Journal of Development Economics*, 42, 1993 & A. Marin & M. Bell, "Technology spillovers from foreign direct investment (FDI): The active role of MNC subsidiaries in Argentina in the 1990s", *Journal of Development Studies*, 42, 2006.

tors are discussed as physical evidence of the firm's ability and effectiveness in transforming coal into fuels and chemicals. Secondly, Sasol's scientific publications and patenting are interpreted as evidence of advances in its underlying science base. Finally, the discussion is contextualised by using newspaper articles, company publications and annual reports from 1957 onwards to highlight the economic, socio-political and technical drivers in the evolution of Sasol.

2. FIVE ERAS

Sasol's history can be divided into five stages (see Table 1), initially corresponding to the development of different plants, and only in the last period, to an international acquisition. Given the significant investment in human and financial resources required to develop a plant, these plants embody not only the most advanced technology of the firm at the time, but also punctuate Sasol's history. Recognising that technology development is an ongoing evolutionary process, and that important milestones are also found outside individual stages,[6] analyses of average journal impact factors (see Table 2) and forward citations of Sasol patents[7] (see Table 3) nonetheless suggest that there were meaningful differences in Sasol's technological expertise in the different stages. Scientific publication took off only in the Secunda stage,

6. For example, G. Verhoef points out numerous strategic changes that took place in the mid-1990s. See her article "Innovation for globalisation or globalisation of innovation: Sasol in the chemical industry during the 1990s", *South African Journal of Economic History*, 18 (2003), pp 188-212.
7. Forward citations are a common indicator of the value of patents. For a discussion, see D. Harhoff, F.M. Scherer & K. Vopel, "Citations, family size, opposition and the value of patents", *Research Policy*, 32, 2003, pp 1343-63.

TABLE 1

Technological stages at Sasol 1950-2005

Stage		Achievements
±1950-1975	Synthol	• German Arge reactor or Low-Temperature Fischer-Tropsch process replicated • Kellogg reactors or the High-Temperature Fischer-Tropsch process commercially developed
±1976-1985	Secunda	• Fourfold upscaling of Synthol-based plant in each of Sasol II and Sasol III
±1986-1990	SAS™	• 16 existing reactors replaced with 8 SAS™ reactors with lower capital cost, increased flexibility and lower operating costs
±1991-2000	SPD™	• SPD™ reactor with six times the capacity of German Arge reactors • Diversification into higher value chemicals: n-butanol, anode coke, ethylene recovery, propylene and polypropylene plants
±2001-2005	Globalisation	• Acquisition of German Condea • Research partnerships with University of Twente (Netherlands) and St Andrew's in Scotland

and after a dip in quality (not volume) of publications in the immediate post-Apartheid years, the quality of scientific output improved during the SPD and globalisation stages. The statistically significant difference in the forward citations of patents from the pre- and post-SPD stages (see Table 3) suggests an acceleration of technological development during the 1990s.[8]

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8. This point is also made by Verhoef.

TABLE 2

Sasol publications in peer-reviewed journals

	1966-1970	1971-1975	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001-2005
	(final stage of) Synthol stage		Secunda stage		SAS™ stage	SPD™ stage		Global-isation stage
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

TABLE 3

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

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

*Stages 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 first stage of Synthol is the longest and spans a quarter century. It was characterised by an incremental process of transferring and integrating foreign expertise and is best described as an incubation period for Sasol. The decade-long second stage (Secunda) reflects the consolidation and replication of technology. The development of substantially new technology only occurred in the third stage, SAS. The SAS stage took place during the turbulent last years of Apartheid and was characterised by intense efforts to make sure that Sasol limited the negative consequences of the economic and academic isolation of that period on its technology development. The subsequent SPD period coincided with political normalisation, when Sasol not only migrated into higher value-added product but also devoted considerable efforts to (re-)establish international contacts in terms of both technology development and markets. With the Condea acquisition in 2001, the globalisation stage, Sasol became a fully-fledged, albeit small, multinational corporation. The subsequent sections detail the role of both foreigners and local management in the different steps in this evolution.

2.1 The Synthol stage: ± 1950-1976

Foreign technology was central to the founding of Sasol. Because there was no local expertise available, a number of German (from the Aktiengesellschaft and Lurgi Gesellschaft fur Warmetechnik) and American (from MW Kellogg Corp.) technicians and engineers came to SA to commission the units. Indeed, early annual reports refer to the High and the Low Temperature Fischer Tropsch processes as the "American" and "German" syntheses respectively, reflecting the strong association with the foreign suppliers of the technology.[9]

However, problems were experienced not only during commissioning, but also in realising the full production potential of the Kellogg design. Researchers from Germany, Great Britain and USA were consulted, contractors from MW Kellogg brought in to assist, and an American expert "of world repute on catalysis" hired as a consultant.[10] Recognising that the foreign experts were not able to solve the problem, in 1957 the engineers and scientists at Sasol decided to take over responsibility for the American unit. They made significant changes to the original Kellogg design, which resulted in the proprietary Sasol Synthol circulating fluidised bed reactor technology.[11]

This also triggered the founding of a formal R&D department in 1958, ending the practice of conducting ad hoc research at external laboratories. Sasol developed local capacity not only in terms of R&D, but also established internal colleges offering training in mechanical and electrical engineering and the use of industrial equipment and laboratory skills. A government-supported technical training college was also opened in Sasolburg in 1959, reflecting Sasol's extensive need for skilled employees.[12] As the discussion of the subsequent stages also shows, the challenges in getting skilled personnel are a leitmotif in Sasol's history and an important explanation for the significant role of foreigners.

9. *Sasol Annual Report*, 1957
10. *Ibid*
11. L.P. Dancuart & A.P. Steynberg, "Fischer-Tropsch based GTL technology: A new process?", paper presented at the ACS National Meeting, Anaheim, 2004
12. *Sasol Annual Report*, 1960

By 1959, Sasol fuel was sold across South Africa, and chemicals were exported to countries like Great Britain, Germany, the Netherlands, USA, Canada, Australia and New Zealand. In 1960 Sasol realised its first profit and demand had grown to such an extent that expansion was required. By then local technological capacity had expanded to the extent that two-thirds of the costs of expansion were in South African rand, compared to the initial commissioning which was quoted entirely in British pounds.[13] In 1971 an inland petroleum refinery, Natref, was constructed as a joint venture between Sasol (52,5%), Total (30%) and the National Iranian Oil Company (17,5%).[14] In the same year, Sasol became a consultant on gasifying lignite to a company in North Dakota in the USA in what has been described as the first international recognition of Sasol's expertise in gasification technology.[15]

Sasol drew extensively on international networks to develop the skills of its own people: senior employees were sent abroad on a regular basis to gain knowledge, chemical engineers and draughtsmen were sent for training to the US and Great Britain, and in 1964 Sasol offered one of the first internationally recognised management training courses in South Africa. During this period, Sasol had access to international knowledge networks as and when needed, but Sasol's strong national orientation is reflected in the fact that most internal reports and research reports (except when written by or for foreigners) were written in Afrikaans.[16]

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13. *Ibid*
14. *Sasol Annual Report*, 1972
15. J. Collings, *Mind over matter: The Sasol story: Half a century of technological innovation*, Johannesburg, 2002
16. Review of company archives

TABLE 4: Geographical distribution of filings of Sasol-developed and Sasol-acquired patents

	Synthol stage (±1950-1975)		**Secunda stage** (±1976-1985)		**SAS stage** (±1986-1990)		**SPD stage** (±1991-2000)		**Globalisation stage** (±2001-2005)	
	Sasol	Acquisition	Sasol	Acquisition	Sasol	Acquisition	Sasol	Acquisition	Sasol	Acquisition
AFRICA	**31**	**0**	**38**	**5**	**30**	**27**	**245**	**40**	**195**	**4**
• South Africa	16	0	27	5	24	27	151	38	118	1
• Other SADEC, including “homelands”	15	0	11	0	5	0	58	0	25	0
• Other Africa	0	0	0	0	1	0	36	2	52	3
PERSIAN GULF	**0**	**0**	**0**	**1**	**0**	**0**	**92**	**10**	**117**	**3**
NORTH AMERICA	**9**	**2**	**21**	**64**	**8**	**85**	**134**	**207**	**210**	**8**
• USA	8	2	11	43	4	57	78	142	140	5
• Canada	1	0	10	20	4	26	36	57	47	2
• Mexico	0	0	0	1	0	2	20	10	23	1
SOUTH AMERICA	**8**	**0**	**10**	**8**	**2**	**14**	**105**	**32**	**163**	**9**
WESTERN EUROPE	**21**	**4**	**26**	**131**	**21**	**291**	**403**	**646**	**263**	**18**
• UK	5	0	6	14	2	22	48	78	58	2
• Belgium & Netherland	5	1	2	10	2	34	41	91	42	2
• Germany, Switzerland & Austria	7	2	10	36	6	75	112	194	59	6
• Scandinavia	0	0	2	42	4	50	76	64	37	2
• Southern Europe	0	0	0	12	1	52	55	77	22	0
• Italy & France	4	1	6	17	3	58	71	142	45	6
CENTRAL AND EASTERN EUROPE	**2**	**0**	**2**	**11**	**3**	**27**	**116**	**32**	**55**	**1**
• Russia	0	0	2	4	1	13	21	6	25	1
• Other Central and Eastern Europe	2	0	0	7	2	14	84	26	30	0
ASIA	**9**	**0**	**5**	**24**	**1**	**75**	**209**	**157**	**217**	**5**
• Japan	4	0	5	24	1	40	37	88	65	4
• China	0	0	0	0	0	16	35	25	78	0
• India	3	0	0	0	0	5	13	14	48	0
• Other Asia	2	0	0	0	0	14	124	30	26	1
Australia & New Zealand	**2**	**0**	**12**	**4**	**4**	**13**	**61**	**44**	**89**	**2**
TOTAL	**82**	**6**	**114**	**248**	**69**	**532**	**1365**	**1168**	**1309**	**50**

Source: Sasol database of patents

Although there was extensive investment in the development of local scientific and engineering capacity, the first patent on the Sasol FT process was filed in South Africa only in 1968. Sasol invested little in the codification of knowledge, but what was done also reflected an internal orientation. In the period 1971-1975, their 15 patent re-filings did not take place in leading chemicals producers such as the USA, UK and Germany, but instead took place in neighbouring countries like Botswana, Lesotho and the so-called 'independent homelands', the subsections of South Africa that had been designated black areas.[17] (See Table 4) In this stage, Sasol displayed a limited awareness of the potential value of patents and scientific publications.

Although no attempts were made to publish peer-reviewed research, this was not because Sasol's research was too weak. The fact that Sasol's reactors were operational and by 1960 profitable provides perhaps the most concrete evidence of the quality of the research. In addition, 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 an influential text on the Fischer-Tropsch process published by Elsevier discussed the development of the proprietary SAS™ and SPD™ processes.[18]

To summarise, the very long initial period in the history of Sasol served as a type of "incubation" period. International expertise

17. See Appendix A for a summary of the number and location of Sasol patent filings.
18. A.P. Steynberg & M.E. Dry, *Fischer-Tropsch technology*, Amsterdam, 2004

laid the foundation of Sasol and the company often sought the advice of a range of foreign consultants. Although they were affiliated to institutions, Sasol tended to highlight the contribution of individuals rather than institutions, from Franz Fischer to the "world expert" on catalyst technology. Sasol was fundamentally nationalist in its orientation, and focused its efforts on transplanting the foreign technology to South Africa: the firm deepened its understanding of the FT process. The basic structure of the organisation (eg the plants, R&D department, and technical training) was established. Although skills shortages were (and remained in later eras) significant, a critical mass of people with the capacity to manage Sasol was developed. Indeed, the main concern and main achievement of Sasol during the first stage was to take root in South African soil.

2.2 The Secunda stage: ±1976-1985

In 1974 the government announced that the Sasol Synthol technology that had been successfully commercialised at Sasolburg would be expanded fourfold for the Sasol II plant. The plant would be based in a newly proclaimed town, Secunda (after the Latin word for "second"). Although subsequent reports claim that the chairman, Dr Rousseau, was concerned whether there were adequate research skills to execute the decision,[19] he defended the secrecy surrounding the decision by stating in the annual report: "We always knew SA would need more oil-from-coal capacity and we wanted to be ready to meet the challenge".[20] In 1978, after the deposition of the Shah of Iran,

19. Reported in an anonymous article, "40 years of Sasol, 1950-1990", *Sasol News*, 3, 1990.
20. *Sasol Annual Report*, 1974

TABLE 5: Review of the nature of international linkages, 1950 - 2005

	Synthol stage	**Secunda stage**	**SAS stage**	**SPD stage**	**Condea stage**
Services of paid consultants	Franz Fischer, other German, British and US-based researchers	None significant	None significant	None significant	Heterogenous and Homogenous Catalysis Advisory Boards
Services rendered by foreign firms	• Ruhrchemie Aktiengesellschaft • Lurgi Gesellschaft fur Warmetechnik • MW Kellogg Corp.	• Fluor (managing contractor) • Linde • Badger • Lurgi • UPO • Deutshce Babcock • L'Air Liquide	Badger / Raytheon	• BASF and Linde for world's largest superfractionator for the Alpha Olefins plant in Secunda • Kvaerner (Alpha Olefins) • Mitsubishi Chemical Company (n-butanol)	None significant
Importation of foreign practices / training at foreign institutions	Management courses, chemical engineers, draughtsmen sent for training to the US and UK	Crosby Quality Concept	None significant	None significant	PhD and MSc studentships at leading international research institutes and foreign universities

	Synthol stage	Secunda stage	SAS stage	SPD stage	Condea stage
Research collaborations with foreign firms	None significant	Fluor Engineering and Construction, Inc.Sulfolin process designed jointly with German firm Linde. Lurgi Kohle Gmbh	Raytheon Engineers and Constructors. Hatorex Aktiengesellschaft; Orica Explosives USA	Participation in OTM (oxygen transport membrane) alliance	Mostly through acquisitions and JVs
Research collaborations with foreign universities / research institutions	None	None	None	Research collaborations with groups in UK, Netherlands, Spain	Establishment of satellite research facilities at St Andrew's University (Scotland) and University of Twente (Netherlands). Collaborations with Research groups in Netherlands, UK, Germany, USA, Spain, Canada
Patenting abroad	Extremely limited and haphazard	Only key patents in the major trading partner countries	Broader footprint, both in terms of quality of patents and number of countries of filing	More territories than needed in business terms	Strategic decision based on resource and market profile of country

	Synthol stage	Secunda stage	SAS stage	SPD stage	Condea stage
Outbound investment	None	None	First international chemical marketing office established in Birmingham	Acquisition of two-thirds of Schümann to form wholly owned Sasol Wax. JV with US-based Merichem to form Merisol, world leader in phenolics	Condea acquisition (€1.3bn) to support goal of 50% of cash genstageted outside SA. Two projects in Malaysia with JV partners cost US$212m. Mozambique Natural Gas pipeline cost US1.2 bn. Capex for two major projects (Qatar and Iran) exceeds US$1bn
Global recognition of expertise	Assistance to North Dakota gasification plant	World's only commercial coal-based synfuels facility	None	Leading global supplier of hexene	Through JV with Chevron Texaco will develop world's first commercial GTL plant outside SA

the government went ahead with plans for Sasol III, a duplication of the Sasol II plant.

Table 5 documents the various sources of foreign technology over the different eras. During the Secunda stage, Sasol relied heavily on foreign expertise, and Sasol II and III were developed by eight foreign contracting companies under the lead of the German firm Fluor. There was some research collaboration, for example the development of the Sulfolin plant jointly with scientists from the German firm Linde AG, but Sasol II and III were essentially vastly scaled-up versions of previously developed technologies. Most learning during this phase consisted of incremental learning-by-doing in the course of production rather than in significant technological advances and was focused on the construction of the two plants. For example, construction of Sasol III took only three years (compared to the five years or 100 million man-hours required for Sasol II) as a result of leveraging the learning curve of Sasol II.

Managing the inadequate human resource base soon proved to be a significant challenge, and improving local skills became a major concern. After productivity at Sasol I declined by 8,6 per cent in 1978 because of the combined effects of the loss of expertise to Sasol II and demotivation of the remaining workforce, the corporation defined its main task in 1980 as the restoration of full operational and technical competence at Sasol I.[21] By the end of that year, R29m had been spent on training operations personnel.[22] In addition to the redeployment of skilled personnel from Sasol I, nearly 10 000 unskilled labourers were trained as

21. *Ibid*, 1979
22. *Ibid*, 1980

fully skilled and many thousands more as semi-skilled workers for Sasol II. The cost of training was expected to exceed R63m by 1983, representing almost five per cent of the annual turnover of R1 500m for that year.[23]

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 53 papers were published in journals with an average impact factor of 0,44 (see Table 2) and 31 patents were filed over the Secunda period (Table 4). About half of the patents were filed abroad, mainly Europe although in certain cases also in 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. However, the milestones during this stage were not technological. Indeed, the rather low number of patents filed in the early 1980s reflected a somewhat inward-looking policy of technology development. The steps taken to fund Sasol's ambitious expansion represented the major achievement of this second stage.

Substantial demands were made of Sasol – a type of 'crisis construction'[24] that resulted in extensive organisational learning; but whereas internationalisation played a central role in the South Korean crisis construction and learning process documented by Kim, the crisis prompting Sasol's learning was a deepening *local*

23. *Ibid*, 1980
24. L. Kim, "Crisis construction and organizational learning: Capability building in catching-up at Hyundai Motor Corporation", *Organization Science*, 9, 1998

orientation. And whereas the internationalisation of Hyundai resulted in an upgrading of capabilities, the outcome of learning at Sasol at this stage was the consolidation of existing local operating capacity. Because technology development projects tend to have long time frames, with a number of ongoing initiatives, the expansion forced Sasol to shift its main focus from creating new knowledge to expanding the application of existing knowledge – a set of choices that carried important implications in the next stage.

2.3 The SAS™ stage: ±1986-1990

In 1987, amid considerable political turbulence, the South African government decided to expand further the fuel self-sufficiency of South Africa by developing Mossgas, a natural gas exploration and conversion project, based on the Fischer-Tropsch technology. Mossgas provided a local market for Sasol's know-how – for example Sasol's Synthol technology was licensed to Mossgas for the conversion of natural gas into liquid fuels – but also siphoned off some of the scarce petrochemical research skills in South Africa.[25]

The difficulty of procuring technology for recovery and upgrading increasingly required in-house technology development.[26] Verhoef has documented the impressive achievements of the small coterie of Sasol researchers,[27] including an improved cata-

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25. Documented in "SA50L, Sasol 50th birthday special edition", a supplement to the *Financial Mail*, 22, September 2000.
26. *Sasol Annual Report*, 1990
27. Verhoef, *op cit*

lyst that led to a substantial increase in the production of hard wax and the world class polypropylene and propylene plants. Sasol also did extensive research into a conventional fluidised bed reactors and commissioned a 100 bbl demo reactor in 1983, followed by that of the first commercial scale SAS™ (Sasol Advanced Synthol) reactor (3 500 bbl/day) in 1989. The new generation HTFT SAS™ reactors afforded lower capital cost, increased flexibility and lower operating costs. R&D also made great strides with anode coke produced from pitch and the production of better fuels.[28]

These developments continued to require greater research capacity than Sasol possessed, despite local capacity development programs through bursary schemes. Sasol relied 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 SFFB reactors, and ultimately the commercial development of the HTFT SAS™ reactors.[29]

Sasol was maturing into a company that was technologically able both to contribute to and benefit from being a fully-fledged participant in the global knowledge creation processes in its industry. Indeed, Sasol was involved in a number of ongoing initiatives for which access to foreign expertise was essential. 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 patent filings in Table 4, 1986-1990). However, 1986

28. Steynberg & Dry, *op cit*
29. Collings, *op cit*

also saw the beginning of official economic sanctions against South Africa accompanied by academic boycotts. Foreigners risked global censure for continuing economic and intellectual engagement with South African firms.

Faced with potential exclusion from knowledge creation networks because of a lack of political legitimacy, Sasol sought to increase its perceived technological legitimacy in those networks. In response to the creation of Mossgas, Sasol had already accelerated patenting to more effectively support knowledge exchanges in the emerging South African petrochemical industry. Sasol accordingly increased the number of local patent filings and extended its list of country filings abroad (see Table 4), and published articles in more influential journals (Table 2). Yet, as is evident from Table 7, the number of official collaborations declined sharply reduced. Although the political context made it virtually impossible to enter into official academic international collaborations, Sasol accelerated global patenting and scientific publishing in order to maintain informal relationships and thus visibility in the wider scientific world..

Sasol's response highlights the importance of patenting and scientific publication as signalling devices: by disclosing some of its most interesting research results to the research community, Sasol was able to remain visible in that community. However, its position was based on individual rather than on institutional connections. The case of R.W. Silverman from Raytheon who first co-authored papers with Sasol researchers in 1986 is illustrative. After 1986 there is no evidence of collaboration between Silverman and Sasol researchers, until 1997, shortly after institutional relationships between Sasol and Raytheon were restored. Much as researchers work within the context of institutional relationships, collaboration takes place between individuals and individual relationships were especially important when institutional collaborations were not possible.

However, Sasol was not able to escape a loss of momentum in its knowledge creation processes, as became clear in the period immediately following the turbulent 1980s. After the Secunda stage, when Sasol had consolidated its technological capacity, the firm needed access to a much wider range of sources of expertise in order to accelerate its technological development. South Africa simply lacked the type and extent of resources Sasol needed to sustain its growth. Sasol did what it could to access those resources internationally, and its actions demonstrate how firms can use their own knowledge bases as "bargaining chips" to get access to the knowledge of others. Contact with individuals – the visits of Fischer and various consultants from Germany and the US – was adequate in the initial phase of developing Sasol, but in the SAS stage the need for more comprehensive institutional contact with foreigners was required. Ironically because Sasol was much larger and technologically more developed, the inputs of individual experts were no longer adequate. Rather, larger-scale institutional interaction with foreign entities was needed.

2.4 The SPD™ stage: ±1991-2000

Prior research demonstrates that the capacity base of firms evolves through a constant interplay between the firm's own capacity and inputs from other sources.[30] A change in either the

30. See for example, Marin & Bell, *op cit*; W.M. Cohen & D.A. Levinthal, "Absorptive capacity: A new perspective on learning and innovation", *Administrative Science Quarterly*, 35, 1990.

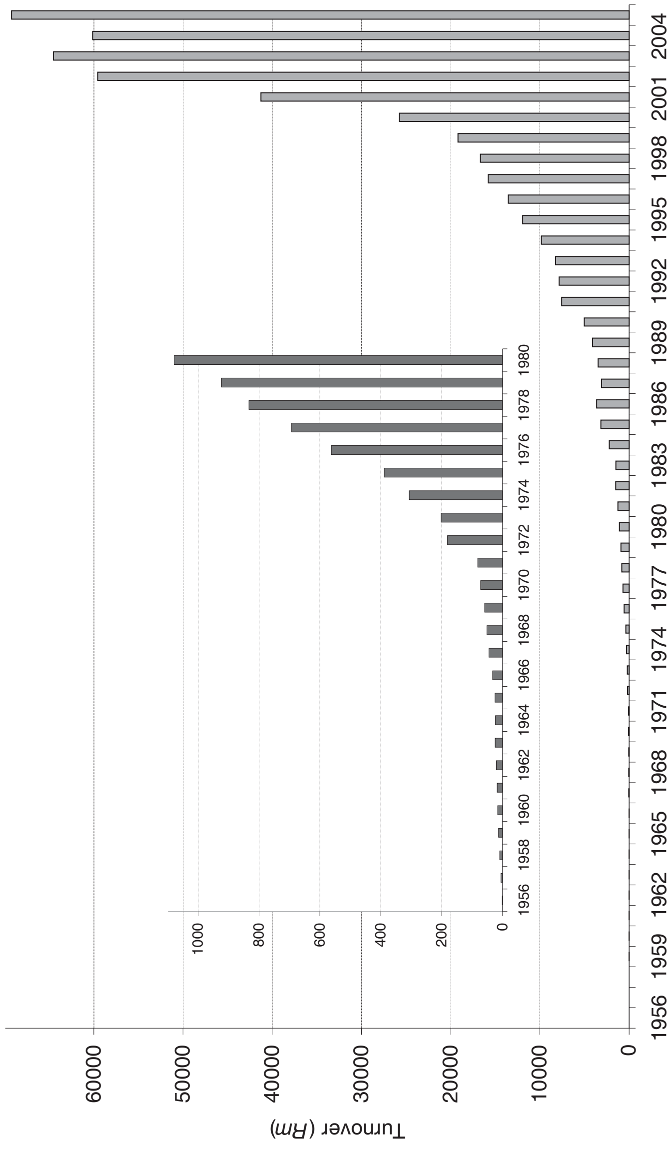
local capacity or foreign linkages can be expected to affect the other, but because both local expertise and foreign connections develop over time, the effects of changes will probably not be immediately felt. The case of Sasol demonstrates how local relative to international expertise was affected differently by the introduction and then, after the release of Nelson Mandela in 1991 and subsequent political transformation, the lifting of economic and intellectual sanctions. Projects using the local capacity base proved to be much more stable than those requiring foreign inputs. The portfolio of patents, scientific publications and ultimately the turnover of the corporation (Figure 1) provide clear evidence of organisational evolution in local production and R&D capacity, with advances in Sasol's core technologies over decades finally culminating in a range of commercially viable project options.

The Sasol Slurry Phase Distillate (SPD™) process was developed during the mid-1980s on a small bench scale at R&D and scaled up to pilot plant size.[31] In 1990 a one meter demonstration unit was developed and in 1993 the commercial SPD was commissioned. The SPD™ reactor has approximately six times the capacity of the old German Arge reactors and greater than 98 per cent online availability was achieved in the first year of operation.[32] Sasol was able to draw on a depth of local expertise developed over decades to successfully carry through a long-standing project.

In the first (Synthol) stage, Sasol focused its technology development fairly narrowly on addressing the problem of the poorly

31. Sasol, *The Slurry Phase Distillate Process*, Johannesburg, 1998
32. Steynberg & Dry, *op cit*

FIGURE 1: Annual turnover, 1956-2005



Note: The inset is an enlargement of the 1956-80 period

Source: Sasol Annual Reports and Financial Statements 1956-2004 performing Kellogg reactor, and the Synthol plant embodied almost the entire in-house technological capacity of Sasol at the time. In contrast, the SPD™ process was developed over three stages – the Secunda, SAS™ and SPD™ – and also reflected only part of Sasol's technological capabilities. Because it has long been known that the evolution of firms is characterised by technological diversification,[33] the Sasol trajectory is therefore typical. What is different in Sasol's evolution compared to that of the standard multinationals is that the rest of the world had little awareness of most of Sasol's capacity development, first because of Sasol's nationalist, inward-looking orientation, and then because of political sanctions. The apparent meteoric rise of Sasol reflects more a rise in awareness than in capabilities! In interpreting the rise of multinationals from previously isolationist countries, it is worth considering whether there is a prior history of hidden capability development.

Mainly as a result of the success of the SAS™ and SPD™ processes, the 1990's heralded a change in strategy, with the announcement of diversification into higher value chemicals.[34] These included an n-butanol plant, an anode coke plant and an ethylene recovery plant expansion at Secunda, as well as the full commissioning of propylene and polypropylene plants in Secunda. Both the migration into higher value products[35] and the

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33. For example, as documented by J. Cantwell, *Technological innovation and multinational corporations*, Oxford, 1989; O. Granstrand & S. Sjölander, "Managing innovation in multi-technology corporations", *Research Policy*, 19, 1990.
34. *Sasol Annual Report*, 1990
35. See for example S. Lall, "What "competitiveness" is and why it is important", in Lall (2001), *op cit*; L. Kim & R.R. Nelson, *Technology, learning and innovation*, Cambridge (Mass), 2000; F. Sachwald, *Going multinational: The Korean experience of direct investment*, London, 2001.

nuanced interplay between strategy and a firm's capabilities[36] are associated with technologically more mature companies. The investment in training and R&D locally had clearly resulted in a sufficiently deep local capacity base at Sasol to sustain innovation.

However, the disruption and in some cases severing of relationships with foreigners had an immediate negative effect. In spite of the re-entry of South Africa into the global economy, the lingering effects of the isolation are evident from the low impact factor of journals in which Sasol published during this time (see Table 2), and the difficulties experienced in (re-)establishing collaborative research relationships. The negative effects of the lack of international relationships may in time have limited further technological advance, but Sasol moved swiftly to restore international connections.

Recognising the urgency of this and the need for institutional rather than individual linkages, Sasol put a high priority on international joint ventures. These included a joint venture with the German firm Schumann in 1995 (now Sasol Wax) and the merger of Sasol Phenolics with the US-based Merichem to form Merisol in 1997. The impact of both of these ventures on the patent portfolio of Sasol in terms of acquiring access to technology and markets and sources of future innovation can be seen in Table 4. The number of patents acquired (rather than filed) by Sasol during the SPD stage reflects a very clear push on the side

36. H. Mintzberg & A. McHugh, "Strategy formation in an adhocracy", *Administrative Science Quarterly*, 30, 1985; H. Mintzberg & J. Rose, "Strategic management upside down: Tracking strategies at McGill University from 1829 to 1980", *Canadian Journal of Administrative Sciences*, 20, 2003

of Sasol to gain access to relevant technologies. Many of the 48 West European original patent filings in this period represent inventions related to the Sasol Schumann joint venture.

In 1997, a Memorandum of Understanding was signed between Sasol, Qatar General Petroleum Corp and Phillips Petroleum Company for the proposed construction of an SPD facility in the Escravos Delta in Nigeria with a capacity of 20 000bbl of fuel per day, and in 1999, Sasol and Chevron agreed to form a joint venture for the identification, development and implementation of gas-to-liquids ventures worldwide based on Sasol's FT technology. In sum, Sasol's actions suggest that it recognised the importance of international linkages in supporting capacity creation and sustained growth.

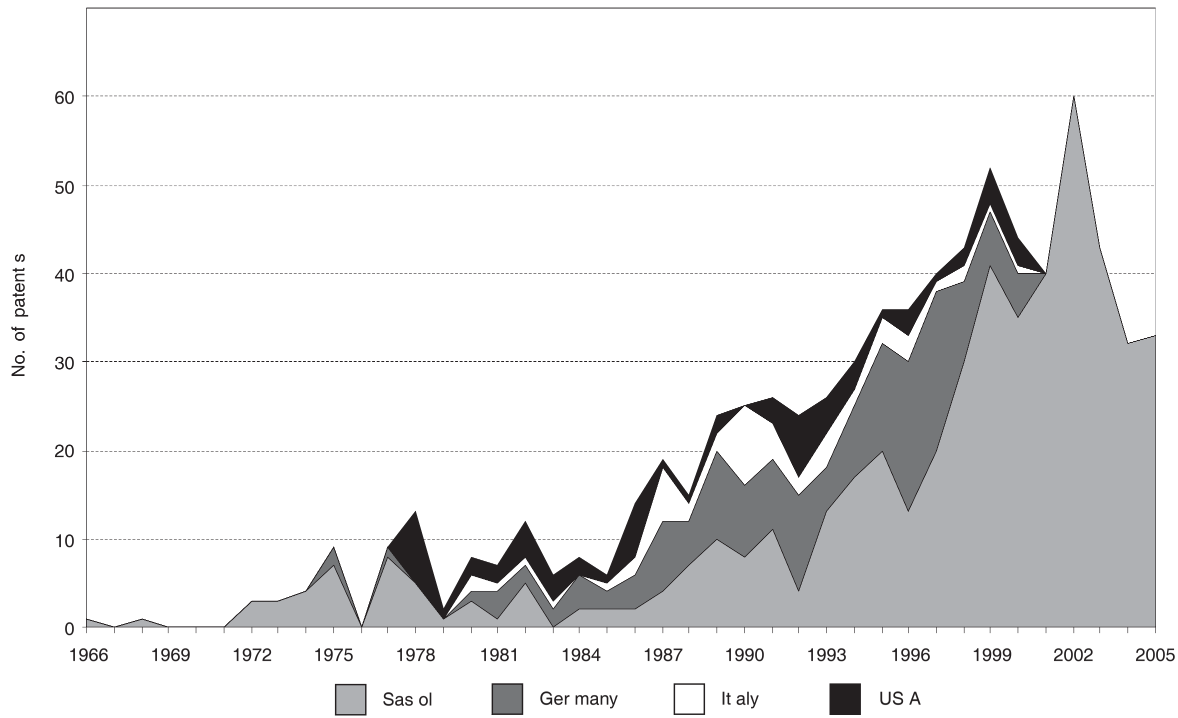
2.5 The globalisation stage: ±2001-2005

In 2001, Sasol announced a new corporate vision, starting out with the desire "to be a respected global enterprise." Four years later in 2005, Sasol CFO, Trevor Munday set as its goal the ability to generate 50 per cent of the company's revenue from outside South Africa by 2010.[37]

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). At the time, Condea employed 4 500 people and had annual sales of €2,6bn. Condea's excellent product portfolio and world class human capital offered critical mass in Sasol's

37. *Sasol Annual Report*, 2005

FIGURE 2: Impact of acquitition of CONDEA on Sasol's patent portfolio



Source: Sasol patent database

TABLE 6

Geographical location and technological specialisation of R&D laboratories

Corporate R&D	Sasolburg (South Africa)
	Twente (Netherlands)
	St Andrews (Scotland)
Sasol Oil	Sasolburg (South Africa)
	Cape Town (South Africa)
Merisol	Sasolburg (South Africa)
Sasol Olefin and Surfactants	Sasolburg (South Africa)
	Lake Charles (USA)
	Moers (Germany)
	Brunsbuttel (Germany)
	Marl (Germany)
	Paderno (Italy)
	St Andrews (Scotland)
Sasol Solvents	Sasolburg (South Africa)
	Moers (Germany)
Sasol Nitro	Sasolburg (South Africa)
Sasol Polymers	Modderfontein (South Africa)
Sasol Wax	Sasolburg (South Africa)
	Hamburg (Germany)

drive to diversify and expand its international portfolio of higher-value chemicals. The Condea acquisition had an immediate effect on Sasol's turnover (Figure 1), while Sasol also gained access to Condea's R&D laboratories and patent portfolio, dramatically expanding its technological reach (See Figure 2). Figure 2 also depicts the location of the assignees of the patents following the integration of Sasol Chemie, and the formation of Sasol Germany, Sasol Italy and Sasol North America. Germany and the USA were especially important sources of new patents for Sasol. Table 6 highlights the geographical location and technological specialisation of R&D laboratories that resulted from Sasol's various acquisitions, while the impact of these dispersed facilities on the output of scientific publications from Sasol can be

Table 7

Sasol publications and notable conference proceedings developed at sites other than the Sasol R&D department and Sasol limited

Sasol site	Year	Journals	Impact factors
Sasol Mark. Co. Ltd.	1977	Chemsa	0.42
	1982	J. Oil Colour Chem. Assoc.	0.32
Res. Div., Sasol One Ltd	1980	S. Afr. J. Sci.	0.57
	1982	Hydrocarbon Process., Int. Ed.	0.25
	1992	Oil Gas J.	0.13
Sasol Two (Pty) Ltd	1981	Oil Gas J	0.13
	1984	.Int. J. Refrig.	0.39
Natl. Pet. Refiners South Africa (Pty.) Ltd.	1978	Oil Gas J.	0.13
Sasol Austin Texas	2002	Journal of Surfactants and Detergents	1.11
	2002	Environmental Toxicology and Chemistry	1.81
	2002	Handbook of Applied Surface and Colloid Chemistry	N/A
	2003	Surfactant Science Series	2.99
Sasol North America, Inc., Westlake, LA	2002	Chemical Engineering Progress	0.42
Sasol Germany, Marl	2002	SOFW Journal	N/A
	2002	SOFW Journal	N/A
	2003	Comunicaciones presentadas a las Jornadas del Comite Espanol de la Detergencia	N/A
	2004	European Journal of Lipid Science and Technology	0.74
Sasol Olefins & Surfactants, Bad Homburg	2002	World Conference on Detergents, Switzerland	N/A
Forschung/Entwicklung/Anwendungstechnik Spezialprodukte, SASOL Germany	2002	Gummi, Fasern, Kunststoffe	0.08
Sasol Germany	2001	Ber. Tech. Wiss.	N/A
	2003	Chemie Technik	0.36
	2003	IP.com Journal	N/A
	2003	IP.com Journal	N/A
	2004	Chemie Technik	0.36
SASOL Germany GmbH, Hamburg	2002	Prace Naukowe Instytutu Chemii i Technologii Nafty i Wegla Politechniki Wroclawskiej	N/A
Schumann Sasol GmbH, Hamburg	2000	Erdoel, Erdgas, Kohle	0.38

Sasol site	Year	Journals	Impact factors
Sasol Servo BV, Delden, Netherlands	2002	Chimia	0.84
	2002	Proceedings of the Annual Meeting Technical Program of the Fedstagetion of Societies for Coatings Technology	N/A
	2002	Chimia	0.84
	2003	Surface Coatings International, Part A:	N/A
	2004	Surface Coatings International, Part A	N/A
	2002	Verfkroniek	N/A
	2002	Macromolecular Symposia	0.61
	2002	Advances in Coatings Technology, ACT '02, International Conference, Poland	N/A
Sasol France	1996	Inf. Chim	N/A
Sasol Italy	2003	Journal of Surfactants and Detergents	1.11
Sasol Chevron Global Joint Venture, UK	2001	Hydrocarbon Engineering	N/A
Sasol Chevron Consulting Ltd, Perth, Australia	2002	APPEA Journal	N/A

seen from Table 7. The breadth of the portfolio of both patents and scientific publications suggests that globalisation triggered not only a greater global spread of R&D facilities, but also accelerated technology development.

Sasol also finally managed to enter into a variety of relationships with foreign public research institutions. In the case of for-profit entities, the rationale for and mode of entering into collaborative partnerships is quite clear: the goal of both parties was to maximise profit, and typically one party exchanged some payment in return for some new knowledge, for example direct project assistance or the right to use certain patents. By contrast, a central goal of public research institutions is to enhance their research status by doing "interesting" research. In practice this means that universities or public research institutions are more likely to collaborate with firms that they perceive as able to contribute to their own status.[38] For this reason, only firms that have established their credibility in the knowledge networks in their field are likely to enter into collaborations with public research institutions, even though the firm may also make a substantial financial contribution to the university, through the development of laboratories and the funding of post-graduate students.

Only during this period of globalisation after 2001 did Sasol achieve that level of credibility in terms of its research standing. Recognising its limited awareness of the global research landscape, Sasol constituted the Homogeneous Catalysis Advisory Board in 2000, following the appointment of Dr Mike Green, formerly from BP. He accessed his network of international experts to obtain advice and guidance on setting up a research group to focus 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 such a world-class research group. The Advisory Board met four times annually with the brief to assist in knowledge transfer, competency development, establishing international networks, recruitment, training, and the technical auditing of research programmes. The board was also active in helping to establish local groups before being disbanded in 2003, having completed its original remit of helping to create a new research group. Although the Homogeneous Catalysis Advisory Board has formal-

38. The role of status and knowledge in alliances is explored by both Podolny and Stuart. See for example J. Podolny, T. Stuart & M. Hannan, "Networks, knowledge and niches: Competition in the worldwide semiconductor industry, 1984-1991", *American Journal of Sociology*, 102, 1996, pp 659-89; E. Toby & T. Stuart, "Interorganizational alliances and the performance of firms: A study of growth and innovation rates in a high-technology industry", *Strategic Management Journal*, 21, 2000, pp 791-811.

ly disbanded, Sasol maintained relationships with many of its members both as individual consultants and through co-publications.

Another advisory board, 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.[39] However, because the main purpose of this board was to provide access to international groups with specialised skills or techniques, only one South African, a retired Sasol employee, Prof Mark Dry, was represented on this board.

In addition to research partnerships with the University of Cape Town and University of Johannesburg in South Africa, in 2002 Sasol also embarked on the establishment of satellite R&D groups in the Netherlands and Scotland. The focus of the group in the Netherlands, based at the University of Twente, is reactor engineering. 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 four years in agreement with the Scottish Enterprise Fife.[40] At the launch of the facility, officials from both St Andrew's and Fife emphasised the potential contribution

39. "Your guide to the world of Sasol", *Sasol Facts*, 2005
40. "Launch of multi-million pound research venture", 2002, http://wwwcalvin.standrews.ac.uk/external_relations/news_article.cfm?reference=390 (accessed 26/04/07)

of this partnership, whereas Sasol had viewed this collaboration as a means of supplementing its in-house research capacity.[41] A number of patents have since been co-invented by members of the STUK laboratory (Table 4, 2000-2005). In acknowledgement of Sasol's status as a world leader in coal-to-liquids technology, the 18th World Petroleum Congress was held in Johannesburg in 2005 – the first time in its 72 year history that the congress was held on the African continent.[42] Further recognition of the contribution made by Sasol to the global petrochemical industry came with the decision to host the 15th International Symposium on Homogeneous Catalysis in South Africa in 2006.[43]

The nature of the South African context remain important in explaining the evolution of Sasol as the challenges presented by the local shortage of skills have become greater rather than smaller in post-apartheid South Africa. The local economy had experienced more than 10 years of uninterrupted economic expansion[44] that required increasing numbers of skilled people. At the same time various employment equity laws increased the requirement and competition for skilled black employees, which, coupled with the fact that research skills develop over time, have presented Sasol with enormous difficulties in finding adequate local skills. Added to this, the persistent high crime rate resulted in extensive emigration by skilled South Africans.[45] To counter these

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41. "First Minister launches innovative business partnership", 2002 http://wwwcalvin.standrews.ac.uk/external_relations/news_article.cfm?reference =354 (accessed 26/04/07)
42. http://www.world-petroleum.org/18thwpc/Copy%20of%2018thabout.htm (accessed 27/05/09)
43. http://www.euchems.org/Divisions/DOC/OCMA.asp (accessed 27/05/09)
44. http://www.statssa.gov.za/keyindicators/GDP/FactSheet_2.pdf (accessed 27/05/09)
45. http://www.sairr.org.za/press-office/archive/newsweek_feb.pdf (accessed 27/05/09)

developments Sasol invested extensively in local skills development. It worked with the government on a number of forums concerned with restructuring national education and training and in 2000, 450 students were supported by Sasol bursaries,[46] in contrast to 1971 when only three[47] and 1974 when 13 bursaries were awarded![48] Despite this local initiatives remained unable to meet Sasol's skills needs.

Developing country firms typically internationalise in search of new markets.[49] Sasol differed from the more typical internationalisation pattern of developing country multinationals in that knowledge-seeking became an important part of its motives for going abroad quite early in its development. Its knowledge-seeking expansion should be interpreted in the light of the fact that Sasol, as a science-based firm, was especially sensitive to knowledge constraints in its home country. In addition, internationalisation offered Sasol the opportunity to continue to benefit from the expertise of South Africans who had chosen to emigrate. Expatriate South Africans have played an important role in the start-up of both the Dutch and Scottish research facilities and researchers from South Africa continue to move into the company's foreign research laboratories.[50]

By the end of 2005, Sasol had matured into a fairly typical although small multinational. Much as the first stage of Sasol's

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46. "Your guide to the world of Sasol", *Sasol Facts*, 2006
47. M. Collins, "Sasol's building filling stations outside SA", *Financial Mail*, Special survey, 30 June 2000, pp 75-79
48. *Sasol Annual Report*, 1974
49. UNCTAD, *World investment report: FDI from developing and transition economies: Implications for development*, New York & Geneva, 2006
50. Interview with Dr Chris Reinecke, Managing Director, Sasol Technology R&D, personal communication, 2007

history had served as an incubation period allowing the firm to transfer assimilated technology and evolve into a truly South African company, this fifth stage concluded an incubation period that heralded the start of Sasol's identity as a multinational firm. The firm had diversified its technological capability base beyond the FT process by drawing on expertise from across the world. The basic structure of its multinational organisation, the plants and R&D departments, had been established and by the end of 2005, Sasol was actively working to expand operations into China and Qatar.

3. CONCLUSION

Although the notions of path dependency and firm evolution have been key theories of business since the work of Edith Penrose,[51] business research is still dominated by cross-sectional studies. Indeed, Jones and Khanna argue that one of the major gains of a historical perspective is that researchers can follow the evolution of a firm over time.[52]

The history of Sasol reveals similarities to a small number of other developing country firms that rely heavily on advances in the underlying science base, for example the Brazilian aerospace firm Embraer[53] and electronics firm Samsung from South

51. Edith Penrose, *The theory of the growth of the firm*, London, 1959
52. G. Jones & T. Khanna, "Bringing history (back) into international business", *Journal of International Business Studies*, 37, 2006, pp 453-68
53. R. Bernardh & L.G. Oliviera, "Building up complex productive systems in developing countries: The Embraer experience", in M.L. Maciel (ed), *Systems of innovation and development: Evidence from Brazil*, Cheltenham, 2003

Korea.[54] Some of the themes of research on those firms recur in the case on Sasol: the importance of local capability development, the importance of an inflow of foreign knowledge, the fact that foreign knowledge is embodied in a variety of different sources, and the changing relative importance of these different sources over different periods in the evolution of the firm.

This article also identifies important nuances in the playing out of those broad themes. The first is around the purpose of local versus international knowledge creation. The importance of a firm's own efforts at local capacity development is confirmed. Indeed, evidence supports the notion that they increase the "absorptive capacity"[55] of the firm: by investing in its own capability development, a firm can better benefit from the knowledge of its foreign partners. Although local and foreign knowledge co-evolve, the roles of these two types of knowledge creation are quite different. The knowledge that had already been assimilated into the routines of the firm[56] continued to develop, even during politically and economically disrupted eras. In contrast, the departure of foreign partners had an almost immediate negative effect on the creation of completely new areas of knowledge. This occurred not only because it takes time for foreign knowledge to be absorbed into the local capacity base, but because foreign partners are sometimes also used to *supplement* inadequate local capacity. Especially in the case of developing country firms, foreign partners may be used to help the firm to achieve the goals that it would otherwise not be able to achieve.

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54. K-R. Lee, "Technological catching-up through overseas direct investment: Samsung's camera business", in Sachwald, *op cit*
55. Cohen & Levinthal, *op cit*
56. R.R. Nelson & S.G. Winter, *An evolutionary theory of economic change*, Cambridge (Mass), 1982

The evidence from the Sasol case also highlights the need for pinpointing the specific types of foreign linkages, as there is a clear evolution in the types of foreign partners consulted. In the initial period, the most important contributions were made by foreign individuals operating without explicit reference to an institutional home. It seems that in order to have meaningful institution-to-institution interaction, the firm receiving the knowledge needs to be sufficiently strong *organisationally*. Although the young Sasol did not yet have a strong institutional infrastructure, there were a number of talented people working at the firm. They were able to engage meaningfully with the experts and consultants brought to South Africa. However, once an institutional infrastructure is in place, collaborations seem to be more productive if they take place between two institutions. This allows both organisations to appropriately support and resource the interaction. By the mid-1980s, Sasol had already developed a substantial indigenous knowledge base. It was able to remain a participant in the knowledge creation networks by disclosing its capabilities at conferences and in publications. Sasol researchers were able to develop interpersonal relationships with foreign participants in the field, but because of economic sanctions and the academic boycott, institutional interaction was not possible. This had a clear negative effect on the creation of new knowledge.

In addition to the evolution from individualised to institutional foreign linkages, there is also an evolution from interaction with only private, for-profit entities to interaction with public, not-for-profit knowledge bodies. The limitations of a market transaction-based approach within the context of knowledge acquisition are well understood[57] and form some of the central arguments why

57. B. Kogut & U. Zander, "Knowledge of the firm and the evolutionary theory of the multinational corporation", *Journal of International Business Studies*, 24, 1992

less developed countries stand to benefit from investment by leading multinationals.[58] However, the transaction-based exchange of knowledge is an accessible – if not optimal – mechanism for upgrading. The Sasol case demonstrates that a firm's initial international linkages are with other for-profit entities: at first they procured knowledge from individual consultants and then by collaborating with and acquiring other firms.

Sasol's interaction with public research institutions started only in its fifth stage after 2001. Universities and research institutions are motivated primarily by the desire to enhance their status as creators of new knowledge. When interacting with foreign firms, such institutions look for partners with a proven track record in research that offer potentially productive research avenues. In addition to being an important resource for future technological development, the involvement of a foreign public research institution also reflects the achievement of a significant level of expertise on the part of the foreign firm.

In contrast to foreign partners that served as sources of new knowledge and expertise, the evidence from the Sasol case suggests that an important contribution of local capacity development was to increase the resilience of the firm in the face of sudden environmental changes. Because routines are self-reinforcing, they can inhibit a response to changing conditions.[59] In ad-

58. Lall (2001), *op cit*; R. Narula & J.H. Dunning, "Industrial development, globalization and multinational enterprises: New realities for developing countries", *Oxford Development Studies*, 28, 2000
59. See for example M.C. Becker, "Organizational routines: A review of the literature", *Industrial and Corporate Change*, 13, 2004; M. Zollo & S.G. Winter, "Deliberate learning and the evolution of dynamic capabilities", *Organization Science*, 13, 2002; D. Leonard-Barton, "Core capabilities and core rigidities: A paradox in managing new product development", *Strategic Management Journal*, 13, 1992; D. Dougherty, "Managing your core incompetencies for corporate venturing", *Entrepreneurship Theory and Practice*, Spring, 1995.

vanced economies, this is typically interpreted as one of the negative characteristics of routines, but it is important to remember that developing countries have constantly to deal with political, institutional and economic instability. For developing country firms confronted with environmental shocks, the benefits of the relative predictability of routines may be greater than the risk of "lock-in" into a given technological or market trajectory.

The case of Sasol reconfirms the importance of both local capacity development and foreign inputs in the evolution of a modern science-based firm. By tracking the firm from its founding through increasingly isolationist periods to the current day, it is possible to better understand the nature and role of foreign relative to local knowledge creation. It cannot of course be claimed that upgrading in the current, far more globalised stage will take place in a similar way. There are the effects of the changes in the world environment since 1950. Sasol's development has not been driven only by South Africa-specific and Sasol-specific evolution and change, but also by the increasing imperative for internationalisation and international connections over the course of the period. This article examines some of the logic underlying the patterns of change observed in Sasol and helps to understand how and why foreign linkages are so important to developing country firms.

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