


Employment-oriented Industry Studies

Resource-based Technology Innovation in South Africa:

Pre-paid Metering Technology – Systemic Innovation in the South African Energy Sector

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HSRC Human Sciences Research Council

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RESOURCE-BASED TECHNOLOGY INNOVATION IN SOUTH AFRICA:

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1. Introduction

In 1989 Eskom embarked on an ambitious programme for the electrification of over 1 million households in previously disadvantaged communities. The socioeconomic conditions in these areas made the use of existing technology credit-based metering difficult and expensive: the targeted consumer base generally had no access to banking, postal or other infrastructure, was engaged in the informal employment sector, and was subject to high levels of crime. Eskom identified Pre-Paid Metering (PPM) technology as a way of mitigating the impact of these problems on the costs and administration of the electrification.

However, at the time PPM technology internationally was still in the early stages of development, and did not meet Eskom's operational requirements. Consequently, Eskom led a strategic alliance of domestic manufacturers for the development of a South African pre-paid metering technology. Once the technology had matured sufficiently, Eskom withdrew from active participation in the technology's development, focusing on driving the cost of the product down. Today, the objective of extending electricity to one million households has been achieved, with 2.6 million South African households using the PPM technology. The South African manufacturers and developers of PPM technology have successfully grown export levels and attracted Multinational investment in the industry. The standard underlying the technology has received international recognition through its adoption as the basis for a new International Electrotechnic Commission standard for pre-paid metering technology.

The PPM industry represents a case of successful local development of cutting edge global technology, based on the creative combination of inherited local technological capabilities, imported knowledge, and strong collaboration of public and private sector actors, incentivised and co-ordinated by the public sector's strategic purchasing pre-commitment for large and long-term purchases of the resulting technology. Many of the elements of this strategy could be replicable on the level of public industrial and innovation policy. It also holds many lessons for private sector actors seeking to upgrade their innovative capabilities and find a growth market in the context of an emerging economy.

The chapter begins by a brief overview of the various components of the PPM technology. I then provide an outline of the different phases of the PPM industry's history. This is followed by a discussion of several aspects of the PPM industry's development, including the institutional environment within which the industry developed the role of inherited capabilities from the military and communications sectors, the role of strategic alliance leader in paradigm-changing innovations, and the role of Multinational entry in South Africa's PPM industry. A brief discussion of the methodology used in this case study is followed by some concluding remarks.

2. The prepaid metering system: a brief overview

Most of the readers of this paper will have experienced the traditional *credit-based system* of electricity delivery, where the customer consumes electricity continuously, and makes periodical payments to the utility provider. The amount consumed is measured by an electricity meter. Representatives of the utility company periodically inspect the meter, and the customer is invoiced for the energy consumed. Depending on the terms of payment, customers have various periods of time to settle their accounts. Non-payment may result in customers being disconnected. The basic principle of the *prepayment system* is the reverse of the credit-metering system: customers decide how much energy they require *before* they consume it, and pay the relevant amount to the utility beforehand. The household is then credited with the purchased amount of electricity. After the prepaid amount of electricity is consumed, electricity is automatically disconnected unless the customer makes a further prepayment[1].

Credit-based metering and billing is still the dominant mode of utilities delivery. The technology involved is mature and relatively cheap, and its organisational procedures are all in place. However, credit metering is also characterised by high labour intensity, high credit and financing risk, and other cost-related factors (which will be discussed at length below). Thus, in principle, prepaid metering offers utility providers the possibility of decreasing the administrative and financing costs of electricity delivery, which in turn will bring down the cost of electricity delivery, or yield higher returns to the utility, or both. Utility providers have long been aware of the *potential* advantages of prepaid electricity delivery over credit metering,[2] but it was not until the mid-1990s that (partly as a result of the technology development led by Eskom) the PPM technology evolved to a level that would allow its widespread implementation.

As illustrated in Figure 1 and Figure 2, the PPM system has several important components. First, there is the prepaid meter (or 'electricity dispenser' - ED) which is installed in the household. The ED is activated by the input of a 'token', which indicates how much energy the customer has purchased. The token comes in a variety of physical forms, but essentially it represents a string of numbers that are entered into the ED to authenticate the transaction. In the early stages of the industry, the tokens were disposable cards with magnetic strips, but in the late 1990s keypads became more popular as input mechanisms (as shown, for example, on the ED in Figure 3). The token used for keypad activation is just a string of numbers, communicated to the consumer orally, in written form, or even via an SMS or e-mail. A crucial aspect of the non-transferable token system developed in South Africa is that the tokens used are uniquely coded to work with a specific ED. Since the token has value only for the customer who has purchased it, the incentives for theft are removed, thus increasing the security and convenience of the process for the consumer.

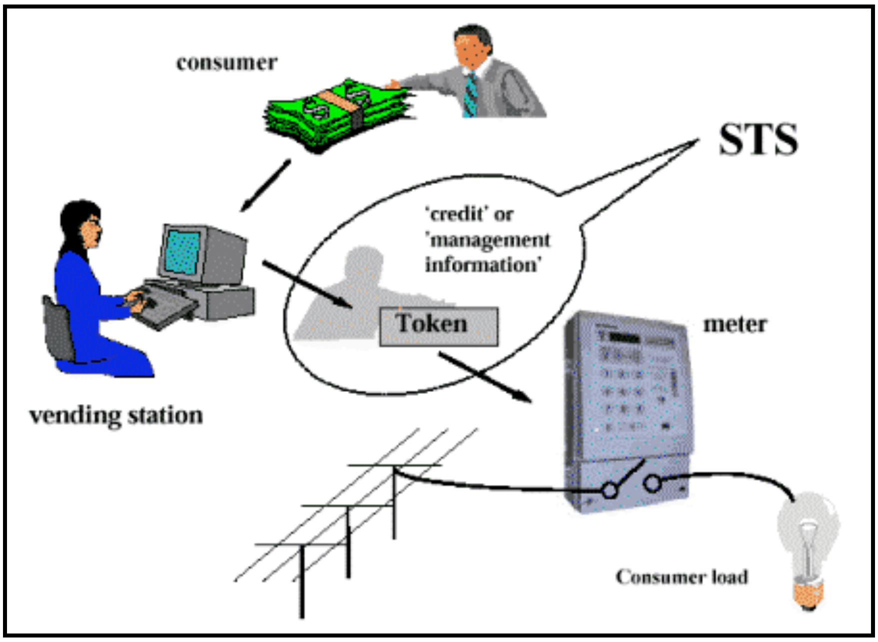
[1] This is referred to in the industry as a 'self-disconnect' mode.

[2] Prepayment is used on a limited basis in the UK. Prepayment is made through coin-operated or magnetic card meters.

The consumer purchases electricity from the vending station, also called the 'cash dispensing unit' (CDU). Given Eskom's monopoly supplier position, the CDU effectively acts as a vending outlet on behalf of the monopoly; it purchases electricity in bulk according to estimated sale needs[3]. Eskom's system master stations (SMS) download the information necessary for the bulk crediting of the CDUs with electricity, while CDU bulk information on individual customer purchases is periodically uploaded to the SMS. The system can operate continually where a good communications network is available, but, if necessary, data can be transferred via a floppy disk (particularly useful in areas lacking good communications infrastructure)

The SMS consolidates the pooled information on the various CDU activities and uploads it to the Eskom's mainframe computers, where Eskom's credit and tariff management system and its information and billing system (CRP system) consolidate and reconcile the figures for the electricity consumed and the amounts paid. This completes the full supply chain, from generation to distribution to final consumption of pre-paid electricity sales.

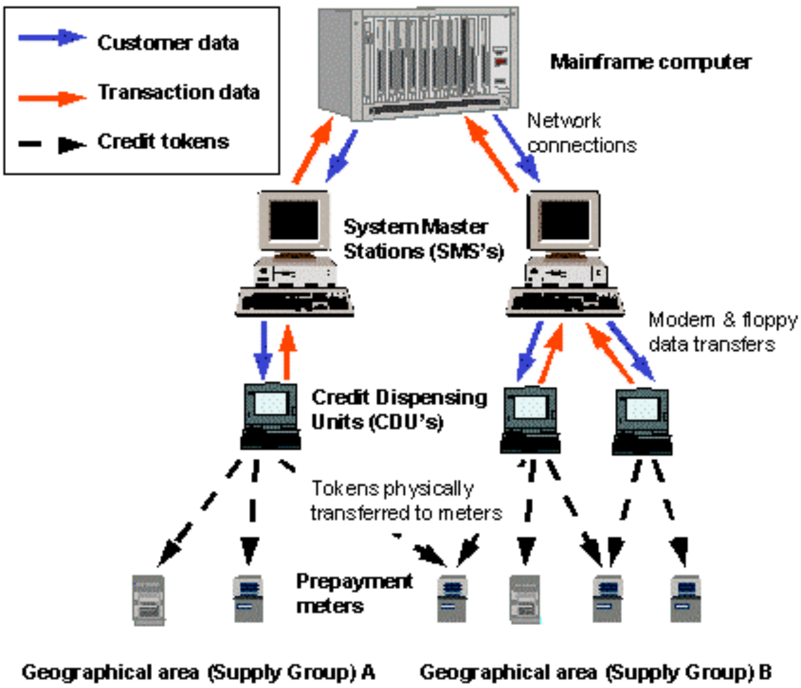
Figure 1 – The basic process of prepaid metering



Source: STS Website

[3] Before 2002 CDUs used to purchase electricity on credit, but high financing costs and fraud led Eskom to change to a prepaid system (Eskom, 2002).

Figure 2 – Prepaid metering system structure



Source: Eskom website

3. The history of the development of the PPM technology

3.1 Strategy development: background to Eskom's choice of PPM

Prior to the 1990s Eskom's electricity distribution activities were limited to direct sale to large commercial and municipal clients. As a vertically integrated state monopoly, Eskom was in a unique position of control of the energy economy from power generation to distribution. As a parastatal, it was also subject to political influence from the government at the time. As a monopsonist in the electricity industry, it was a key market for large segments of the electrical equipment industry. In addition, Eskom's strategic role in South Africa's industrial development lent it a powerful standing in the electricity industry and the economy as a whole. Prior to the 1990s Eskom sold energy directly to large commercial customers and to municipalities. It was municipalities that sold electricity to residential consumers. As municipal electricity distribution was concentrated on the affluent and largely white areas, large parts of the township population were left without electricity. In the context of the political situation at the time, this was identified as a significant problem, and consequently in 1989 Eskom launched the 'Electricity for All' programme, which aimed to extend electrification to one million households in traditionally underprivileged areas[4].

Electricity-provision involves not only the installation of the physical infrastructure and equipment, but also the effective operation of the administrative infrastructure which would allow the metering, billing and payment for household energy consumption, as well as for maintenance. At the time credit-based metering and payment was the dominant mode of residential electricity distribution (both in SA and internationally). The technology components used in credit-based metering were cheap and widely available, which in turn meant low *per household* installation and maintenance costs.

A combination of factors (summarised in Table 1), such as the high administrative costs of administering a credit-based system, the low income levels of the targeted households, and the lack of physical and communications infrastructure, led Eskom to search for alternatives to the traditional credit-based metering system used in the municipal and commercial markets[5]. Before Eskom settled on PPM technology, some

[4] In rural areas where it was unfeasible to distribute power from Eskom's main grid, an off-grid generation programme was implemented, which used solar power to provide basic electricity to households. This is examined in detail in chapter 5 of this book.

alternative technologies were considered that could mitigate one or another factor. For instance drive-by metering technology could use radio transmissions for taking meter readings without the need to gain access to the household. Fixed-rate meters could help avoid the credit system administration problem[6]. However, neither of these solutions would have solved all of the challenges faced by Eskom. While drive-by metering decreases the direct costs of inspection, the high administrative and financing costs and infrastructure-related problems noted above would remain. While the fixed-rate meter would have solved Eskom's problems, it would have done so at the expense of the autonomy of the customers, as the amount they could consume would be restricted[7]. Consequently, Eskom began investigating the possibility of using PPM technology for the electrification programme.

[5] An early Eskom internal document states: 'pre-payment metering systems allow the customer to be in control of the use of the electricity purchased and may budget accordingly. This will overcome the misconception which has arisen that there is no relationship between what customers are asked to pay and the amount of electricity consumed.' (Theron, 1992:2)

[6] These provided the customers with a small amount of electricity, and disconnected when the fixed rate was exceeded (World Bank, 2001).

[7] Respondent 1 explained that Eskom wanted to provide the same quality of service to traditionally disadvantaged areas as it does to affluent areas, and that a flat-rate meter would have been seen as an inferior service. In addition, there would be limited scope for growth in consumption as household incomes grow.

Table 1 – Credit-based vs. pre-paid metering system

Credit-based system	Pre-paid metering (PPM) system
General factors	
Meter-reading is labour intensive; need for access to household	There is no need for meter reading in PPMs
Loss of time and resources for clients and distributor due to connection and disconnection	Self-disconnection of PPMs avoids such costs; lower level of customer complaints and communication around re-connection
Credit-based system business processes are very resource-intensive: invoicing, information processing, customer feedback, support, client monitoring, etc.	Self-administration of PPM system cuts many of these costs; PPM provides a basis for the development of innovative revenue management systems
Low-income households have low levels of energy consumption but the same level of administration and maintenance costs	Once-off installation and maintenance costs are only major individual user costs
SA-specific factors	
Debt-management is expensive, especially for low-income parts of society	PPM shifts the income-monitoring cost to the client; extension of electricity to the non-bankable; elimination of the bad debt risk
Politically motivated non-payment culture	Not a problem with PPM
Lack of basic infrastructure (post offices, banks, even street numbers)	Still a problem for maintenance but not a burden for administration
Difficult physical environment for installation" dwellings may consist of mud, corrugated iron, wood, plastic, bricks; electricity brown-outs	PPM EDs were designed specifically to deal with such problems

Once Eskom settled on prepaid metering, the availability of appropriate PPM products domestically and internationally was explored. The leading PPM technology was used in the UK, but that was seen as inadequate for Eskom's aims: as the prepayment meters were operated either coin or transferable magnetic strip cards, the security level was low and the fraud risk was seen as very high. Eskom decided that a transferable token system would carry a very high level of theft and fraud risk, and that a non-transferable system would be most appropriate to the market environment[8]. It was recognised that internationally there was no satisfactory solution to Eskom's specific requirements. The crucial decision was then taken that Eskom would co-ordinate the development of a non-transferable token PPM system domestically, with the help of the private sector.

3.2 Initial stages of development (1989 - 1992)

In April 1990 Eskom released the NRS 009 specification which provided the technology concept outline of the basic product features with which potential products would have to comply. On the basis of this specification Eskom issued a call for proposals to industry, in order to gauge the level of market interest and capabilities for the development of PPM technology. To expand the scope for innovation by

[8] In transferable credit systems any meter can use the credit. That is, one household could purchase credit, and another could use it. For instance, a person could 'borrow' a card from a neighbour if she ran out of electricity. Eskom judged that in the context of high-crime areas this would expose households to the risk of theft, as the magnetic strip would have a value.

producers, Eskom kept the NRS 009 specification was very short, consisting of 2-3 pages of general functional requirements.

Key aspects of the specification were that the new prepaid meters would be based on kWh measurement, that vendor-user credit transfer would be via a non-transferable token, and a long-term purchasing pre-commitment for over 1 million meters (for 1 million households). The release of the call for proposals resulted in up to 27 different manufacturers expressing an interest for participation in the programme. From this initial pool Eskom started further negotiations with a group of six companies. In July, 1990 Eskom called for a tender for 30 000 EDs, and awarded the contracts to three suppliers, namely Angcontech, Conlog and Spescom (Theron, 1992).

The initial years of the project were aimed at stimulating innovation by the producers, and the development of different technology options around the initial functional specification. To provide the incentives for producers to invest in the development of different solutions, Eskom committed to purchasing early product models of different technological solutions at relatively high prices, as long as these met the basic technological and engineering specification of NRS 009 (1,2,5,7). The following list of producers' credit transfer mechanisms in compliance with NRS 009 illustrates the level of technological diversity that developed rapidly: disposable magnetic card (Angcontech, Conlog), smart card (Altech), bar code/keypad (Ash Brothers), re-usable magnetic card (Cumcon), keypad (Plessey, Spescom) (Theron, 1992). Similar variety in design existed in the ED's design, support infrastructure and other aspects of the technology.

The first years were characterised by a steep learning curve for all parties. There was intensive interaction between Eskom and the manufacturers. This resulted in the development of strong relationships between the various participants of the strategic alliance and Eskom, with some even describing Eskom as 'grandfatherly'. At this early stage of the technology's development, Eskom played an information broker role, which was important in the rapid diffusion of preferred technology solutions between the different members of the alliance. Eskom's R&D activities benefited the industry, as the company made the results of its research freely available to the participants in the alliance. It also co-ordinated minor technological changes and enhancements by liaising between the producers. The feedback it provided to the producers allowed defects to be corrected before mass production, and saved the industry from having to pay large amounts for replacements and returns.

Eskom's TRI division played an important role in the testing and benchmarking of different manufacturers' models, while also conducting R&D into problems affecting the whole industry. TRI (Technology Research Investigations) is a multidisciplinary science, engineering and technology consultancy focusing on the power sector and related industries, currently with a staff of over 600[9]. As TRI engaged in very frequent and intensive testing of the different model prototypes and the incremental technological changes, it was in a position to compare the different technologies and

[9] After the formation of Eskom Enterprises, it was renamed to Technology Services International (TSI), and it began to expand its activities beyond Eskom (even though Eskom remains its primary client).

to encourage early adoption of best solutions by the manufacturers[10]. Where Eskom was the initiator of a testing round, it paid for the tests, and disseminated the results of the tests to the manufacturers, which in turn allowed a rapid diffusion of best practice knowledge. Beyond testing, the R&D activities in which TRI engaged resulted in a number of important innovations that facilitated the growth of the PPM industry (summarised in Table 2). While Eskom allowed producers significant leeway in their design solutions, it expected alliance participants to rapidly adopt its preferred technological solution. The company retained the ultimate right to approve or reject any technological improvement proposed by the various manufacturers, as it could ultimately stop purchasing a particular model.

A good example of the importance of its role is TRI's development of an innovative lightning protection standard through the use of an on-board 5kA gapped arrester. During the early stages of the industry's development, Eskom identified a very high failure rate due to lightning strikes among virtually all manufacturers' models. Even though the EDs were in compliance with international standards for withstanding to power surges, impulse, noise and over-voltage for electronic equipment, there was a failure rate of up to 30%. A CSIR investigation subjected several manufacturers' EDs to a lightning test and confirmed that all models shared the problem. TRI's investigations showed that the cause for the failures was due to low-quality installations in the overhead reticulation, clearly not the responsibility of the ED manufacturers (Theron, 1992). In collaboration with the CSIR, TRI developed a novel lightning protection standard, which manufacturers had to integrate in future designs. Consequently, ED lightning failure rates dropped to negligible levels. In addition to solving this problem for the PPM industry, the standard's development resulted in the TSI's development of an internationally leading competence in this area[11].

An additional example of the standardisation role played by Eskom through the TRI was the development of a software maturity standard in 1993-4. Following an investigation into high-failure rate of meters, the TRI narrowed down the problem to many EDs' on-board software. The different software platforms operated by the various manufacturers, and the lack of systemic quality control led to inconsistent reliability and performance of the EDs. The TRI sought to address this problem by developing a software auditing tool which could identify ED software problems quickly and reliably (in collaboration with Wits University). Simultaneously, TSI pushed manufacturers to increase the levels of 'software maturity' in the ED on-board

[10] For instance, TRI conducted a simple but ingenious experiment to decide between the adoption of the swipe-through and slot-in cards of different manufacturers. A sample of meters were installed at the exit of TRI's building, and a sample of both types of cards were given to TRI's employees, who were encouraged to use them as often as possible. This allowed the TRI to statistically test the superiority of each model, and established the swipe-through mechanism as superior.

[11] Other important innovations that TRI has introduced in the PPM industry are the development of: an Accelerated Life Testing procedure, which enables the generation of failure modes for EDs under simulated extreme environmental conditions; a methodology for testing the ED software, leading to increased levels of software maturity and standardisation of quality; an improved failure classification system; meter obsolescence planning procedures, which have smoothed Eskom's ED replacement process.

software[12]. As a result, the level of meter failure due to software problems has declined dramatically.

3.3 Standardisation of technology (1993 - 1994)

Eskom's focus on stimulating a rapid rate of innovation in the development of the EDs resulted in a proliferation of design layouts, vendor systems, as well as widely diverging levels of performance of different EDs. In addition, as the various manufacturers had developed proprietary communication protocols and vendor software, there were multiple standards on a system level too, which meant that different manufacturers' EDs could not operate on each others' payment networks.

As discussed above, diversity in technological solutions was beneficial in the early stages of the technology's development, as it provided a choice of solutions and reduced the danger of developing path-dependence in inferior technologies. However, as Eskom's levels of procurement increased, the burden of operating multiple PPM systems and the danger of lock-in increased. In addition, as part of its push for user adoption of PPM, the early design of EDs specified that a faulty ED would go into free-supply mode (so as not to inconvenience the customer). Thus the utility had strong incentives to minimise faults in EDs due to multi-standard operation, due to the additional costs of fee-supply of electricity.

There are a number of costs associated with the operation of multiple standards: the duplication of infrastructure, high replacement costs, incompatibility between vending systems and other manufacturers' EDs, difficulty in performance measurement and control, and higher maintenance costs. Conversely, standardisation facilitates the maturing of the industry, increased specialisation and competition, and the development of economies of scale. By 1992 the number of EDs deployed by Eskom was approaching 200,000, leading to a rapid increase in operational costs due to the parallel running of multiple hardware and software standards.

Eskom decided at this point that the level of understanding of the technology was sufficiently developed to justify a strong push for standardisation in the industry. As standards and designs on both the hardware and software side were multiplying, the push to standardisation would have to take place across several dimensions. On the hardware side, the proliferation of proprietary ED models meant that meters made by the different producers simply had different *physical* designs, and consequently needed different connection and installation layouts in the household. The replacement of a meter model required significant rewiring of client residences, which was expensive and inconvenient. Consequently, there was a need for multiple inventories, to allow the swapping of faulty models. Standardisation of the physical layout of the EDs would allow inter-changeability of faulty EDs, without a need to rewire the household's installation. Eskom developed a 'common plug-in base' standard which it

[12] 'Software maturity' refers to the degree to which software modifications are done systematically, and documented. At the highest level of maturity all changes are documented, so that at later stages newcomers or other parties can follow changes and are better able to fix problems (Cf. Engineering GSAM Version 3.0).

included in its future specifications. It meant that meters could easily be plugged in and out, saving expense and time when they were being replaced.

Table 2 – The technical and industry impact of PPM standardisation

Standardisation type	Technical impact	Impact on PPM industry
Standard plug-in base	Interchangeability of meters in households with the same installation.	Less disturbance to households when changing meters; lower installation costs; no need for multiple inventories to be kept; increased competition on performance factors.
Standard Transfer Specification (STS)	Standardisation of the entire vending process and the security of the credit transfer: interchangeability of EDs; high and uniform security of transactions.	Interchangeability of Eds on different vendor networks allows economies of scale to develop; increases competition; increased security of credit transfer; increases international attraction of technology; standardisation of different components of system allows specialisation of manufacturers and software developers; client influences knowledge of encryption key infrastructure; Eskom-controlled key management infrastructure increases confidence in the system.

But Eskom faced a more complex problem for standardisation on the software and systems side of the PPM technology. As the early efforts of Eskom were focused on stimulating the development of the EDs, the support systems were largely left to the manufacturers. This led to a situation whereby each manufacturer developed a proprietary credit transfer and encryption algorithm and vending system. As credit transfer was only possible between EDs produced by the manufacturer of the Credit Dispensing Unit (CDU) installed in the specific area, this meant that ED installation would not be inter-changeable. By 1991 50,000 meters had been installed under five proprietary systems, and by 1993 the number of installed units would grow to over 200,000 (Johnson, 2002). Lack of standardisation of the credit-transfer and encryption process could force Eskom to maintain at least five separate infrastructures, and inventory of the producers' EDs. Standardisation of the credit-transfer mechanism would make the EDs installed independent of the CDU installed in a specific area.

In addition, proprietary software systems made the benchmarking of the quality of different systems' performance more difficult, while the type and strength of the encryption of the credit transfer system differed between manufacturers. This was of significant concern to Eskom, as the whole reason behind developing a non-transferable token system was to achieve a higher level of security. A 1992 Eskom report notes that 'many good systems were developed, but they were all non-standard and not compatible with each other. There is now a definite need from the major users to move towards standardised solutions to address the current operational problems experienced where various different types of EDs and vending equipment have to be operated simultaneously' (Burger *et* al, 1992:2).

Consequently, in 1992 Eskom began a push for the standardisation of the communications process between EDs and CDUs, the security of the credit transfer mechanism, and the vending systems. The company identified two alternative routes to achieving these tasks: (i) a universal credit-dispensing system, which would dispense a number of *different* types of tokens, covering the different payment technologies developed by the market; and (ii) a standardised communications protocol between the various components of the PPM system[13]. The first option would have been best from the manufacturers' perspective, as it would require few changes to their products' design. Eskom would bear the bulk of the standardisation costs, while a multi-standard CDU would also be more expensive than a single standard CDU. The long-term costs of this strategy were deemed as too expensive, so Eskom decided to pursue the development of a new and universal standard, which was named the Standard Transfer Specification (STS).

The development of the STS standard had many advantages for Eskom: it would minimise the need to follow and control multiple standards, lower standard development costs and subsequent running costs, as well as provide it with control over the functionality of the standards. The development and roll-out of the standard had several aims: (i) ensure inter-changeability of ED models (achieved by the standardisation of the format of instructions from the vendor to the meter); (ii) ensuring high and uniform security of the transactions (achieved by the employment of increased quality of encryption keys); and (iii) the provision of encryption-key management infrastructure to industry and clients (Johnson, 2002).

While Eskom retained control over the STS development process, key parts were subcontracted to external organisations or experts. For instance, the encryption key system was developed in collaboration with a Cambridge University academic. Prism Payment Technologies was contracted to develop the security module for the STS-compliant models. Prism's work was facilitated by their previous experience in developing secure transaction mechanisms for the banking industry. Conlog, already a major supplier of prepaid meters and support systems, was contracted by Eskom to develop the communication protocols for the transfer of credit from CDUs to the EDs.

Eskom's leadership and control of the STS development allowed it to retain control over the IP of the standard. When formulating an IP strategy, Eskom was faced with a broad choice of keeping the standard as an open platform (allowing free use of the standard by manufacturers), or seeking to gain a return on its IP asset through licensing. Eskom chose the former strategy, as keeping access to STS open was seen as critical in facilitating the further dynamic development of the industry. The release of the STS standard in 1993 was followed by its successful integration in the manufacturers' models and vending systems. As shown in Table 3, by 2002 proprietary systems accounted for only 14% of installed EDs. This is seen today as a major component of the success story of prepaid metering. (Theron, 1992; Burger *et al*, 1992).

[13] There are three possible communications combinations: ED-CDU (household ED to Credit Dispensing Unit (CDU), between different CDUs, and between CDUs and System Master Stations. Integration of the communications protocols over the whole chain ensures that the possibilities for fraud and mismatches are minimised.

Table 3 – Composition of installed EDs around 2002

	Numeric token meters	Magnetic token meters	Total
Proprietary meters	118,000	249,000	14% ; 367,000
STS meters	1,480,000	772,000	86%; 2,252,000
Total	61%; 1,598,000	39%; 1,021,000	2,619,000

Source: Eskom website

3.4 Maturing of the PPM industry and Eskom's exit from the alliance

The standardisation of the technology allowed the independent benchmarking of the quality of different components of the system. In particular, it allowed Eskom to adopt a more hands-off approach to procurement, as it was no longer necessary to be closely involved in the design aspects of the different manufacturers. Manufacturers now had to comply with a set of standards around the supply of PPM components, and the burden was on them to ensure compliance. The open standards system allowed the entry of new players in the industry, as well as the disaggregation of the value-chain in the PPM industry.

An additional important factor was the widening of the customer base in the PPM market, since by the mid-1990s SA's municipalities entered the market, as they began to roll-out PPM infrastructure (and especially as post-1994 municipal authorities began extending municipal services to disadvantaged communities). In addition, manufacturers started seeking an expansion into foreign markets. The exposure to different markets' competitive pressures increased manufacturers' awareness of different product operational requirements, the need for flexibility in product and service design, as well as the need for continuous improvements and innovation to the STS standard. The manufacturers' concern was that if the STS standard and infrastructure (such as the key management centre) remained under Eskom's control, necessary changes would not take place, while also potential customers could be concerned about allowing a non-accountable 3rd party to control the infrastructure.

Manufacturers began pressurising Eskom to release control over the standard, and spin-off the STS management into an independent organisation. However, Eskom was concerned that loss of control over the standard would result in changes in the specification that would impact the operation of the existing metering base, and the backward compatibility of future models. A compromise solution was the joint creation of the STS Association by Eskom and a group of manufacturers in 1997[14]. By this arrangement, Eskom transferred its IP rights to the STS standard to the STS

[14] The founding members of the STS Association are Eskom, Conlog, Energy Measurements (now L&G), and Schlumberger (now Actaris).

Association for free. In return, Eskom gained a permanent seat and a veto voice in the STS Association's management structure. In turn, the manufacturers gained an important influence on the future development of the standards, which would allow them to modify/update the standard in a way that would allow them to enter the international stage.

The STS Association would be in charge of the control, further development, and promotion of the use of the STS standard globally. It would also accredit manufacturers' compliance with the STS standard and maintain a network of approved testing organisations[15]. In addition, the STS Association would control and improve the key management infrastructure, and ensure that accredited manufacturers make encryption keys available to the industry to allow clients to find alternative sources of vendor and metering equipment. Thus the STS Association would become the nerve centre of the PPM industry, controlling the encryption and standards infrastructure, and act as an intermediary between differing industry needs (STS Association Handbook, 1,5). The Key Management Centre acts as an escrow for the keys underlying the encryption of the algorithms used in the transfer of credit to EDs. It is still operated by Eskom, on behalf of the STS Association[16].

In 2003 the STS standard was adopted by the International Electrotechnical Commission as a Publicly Available Specification, and is currently considered as the *de facto* industry standard for pre-paid metering[17]. This followed the formation of an IEC working group The STS Association has also been busy with the development of STS2, with modifications aimed at increasing the type of functions possible on an STS-compatible meter. This would improve the ability of STS EDs to deal with complex tariff structures, while also facilitating prepaid metering for water and gas. The Association aims to complete the STS2 standard in time to allow for its inclusion in the expected release of an official IEC standard in 2006. Work is also under way for the development of an internationally oriented Key Management System, to be operational by 2006. The aim is to include multilingual, automated support services for clients all around the world on a 24/7 basis, distributed architecture of Key Management Services, the building up of processing capacity, and other measures aimed at making the standard more appealing to international users.

3.5 MNE entry in the industry

The re-entry of Multinational Enterprises (MNEs) post-1994 coincided with the increasing international acceptance and export sales of the PPM technology. The main reasons for entering an alliance or seeking investment by MNEs were listed as: gaining export markets, access to distribution networks, and branding. This allowed two of

[15] At present, the TRI continues to do the bulk of the testing and certification on behalf of the STS Association. TRI is now a for-profit consultancy, part of Eskom Enterprises, the non-regulated part of the Eskom group.

[16] Some industry participants currently see Eskom's continued control of the centre as a problem, in particular for exporters who face a credibility problem when selling to foreign utilities.

[17] IEC/PAS 62055-41 entitled 'Electricity metering – Payment metering systems – Part 41: Standard Transfer Specification'.

the major manufacturers in the PPM industry being bought by MNEs: Spescom's metering division was bought by Siemens, while Conlog was acquired by Schneider Electric. The history of these takeovers illustrates both the benefits and problems with pursuing a MNE strategy to expansion.

Spescom, a former supplier of high-end electronics equipment to the military, was one of the leading participants in the PPM industry. A key innovation was its development of a keypad as a credit transfer mechanism, which is now a standard feature of EDs. In 1994 Spescom's metering division formed a joint venture with Siemens, and was renamed Energy Measurements. This move aimed to provide Energy Measurements with a support channel for its international expansion, through access to the marketing and distribution resources, as well as the brand name of a global player like Siemens. In 2001 Spescom sold its 50% stake in Energy Measurements to Siemens for R35-million, and exited the PPM industry entirely (R35-million)[18]. Siemens combined Energy Measurements, L&G, and its existing metering division into Siemens Metering[19]. While sales continued to grow, respondents reported that the expected benefits of the association of Energy Measurements with Siemens have not materialised: there was limited integration of Energy Measurements into the Siemens global production network, little additional access to resources. A similar situation was seen at Siemens's other metering divisions globally, with an overall lack of strategic focus, lack of access to marketing and distribution resources, and corporate culture clashes.

In 2002 Siemens sold its metering division to Kohlberg Kravis Roberts & Co, a global private equity fund. The resulting firm was rebranded under the globally recognised L&G brand, and the former Energy Measurements in South Africa consolidated its position as the principal producer and developer of prepaid metering. In 2003 L&G reported global sales of €388-million. In 2004, L&G (as a global firm including the SA division) was sold to Bayard Capital (KKR website).

By contrast Conlog, another leading PPM manufacturer acquired by an MNE, experienced a much tighter integration into its MNE parent company, and consequently achieved a greater performance. The core business of Conlog, an electronics company founded in 1965, was originally focused on automotive electronics. However, it became a core participant in the PPM industry. Its position in the PPM industry was strengthened when Eskom contracted it to develop the vending system specification as part of the STS standard development. It was also involved in the development of solar pre-payment systems for the off-grid electrification programme.

There are over 2 million Conlog pre-paid meters in SA and internationally. In 2000, Schneider Electric purchased Conlog's pre-paid metering division for R88-million. Schneider sought to establish it as the group's 'Centre of Excellence for Pre-Payment

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[18] As part of its strategic refocus to the ITC industry Spescom was divesting of non-core assets and Energy Measurements was seen as lying outside of its core focus area.

[19] Through an earlier purchase in 1997 Siemens Metering had obtained control of the Electro-Watt group in Europe, which also included the Swiss-based Landys & Gir (L&G), the oldest metering company in the world.

Solutions', and continued to use the Conlog brand name. Conlog focused on developing a more comprehensive service offering, such as entering water metering, establishing a training centre, and international help line. In 2002/3 Conlog secured 80% of Eskom's national contract for PPM supply, valued at R100-million, a €10-million contract in Sudan, and continued its expansion elsewhere in Africa.

4. Analysis of the framework and processes of the PPM technology's development

A lot has changed in the structure of the South African SI since the beginning of the PPM industry in 1989, most significantly the end of the large military industry programmes, the opening up of the economy, the liberalisation of the energy market, the separation of Eskom in regulated and non-regulated entities, and less government support for R&D (to a large extent because there is no need for self-sufficiency). All of these conditions were key parts of the mechanisms that facilitated the development of the PPM industry. Does this mean that policy makers and innovators can draw no useful lessons from this case study? If one looks for one-to-one lessons, there would be none. But through this case study many mechanisms and strategies can be identified that could be of interest to both policy makers and market actors, which can be used, modified and applied in other contexts and sectors.

4.1 The institutional framework and firms' capabilities

A precondition for the development and implementation of a complex technology development strategy is the availability of actors with the necessary capabilities in the SA system of innovation (SI). In terms of the manufacturers that would be involved in developing the technology, Eskom's technology specification called for secure and encrypted credit transmission between vendors and EDs. Hence some of the capabilities necessary for entry into the strategic alliance were advanced engineering and design capability, high-quality production facilities, hardware control software development skills, and knowledge of encryption technologies.

In the context of a developing economy and the sanctions in place at the time, it is remarkable that Eskom was able to access all of the required capabilities domestically. A number of historical and institutional factors specific to South Africa coincided, ensuring that both the technological capability and institutional setup existed, in the context of which an ambitious technology development programme could be put in place. The migration of capabilities from the military-industrial and communications SSIs to the energy SSI was an important element in the development of the PPM industry.

As one respondent noted, 'there was in South Africa a just-about-adequate technology base, thanks to a number of factors: Armscor, sanctions, and the requirements of the local primary industries… [in addition] as the solutions involved crypto, a then heavily controlled technology, and imported solution wasn't an option'). As illustrated in Table 4 below, at least two of the key manufacturers involved in the PPM industry's development had a strong history in the military communications industry, while other manufacturers often relied on the knowledge and experience of personnel that had formerly worked in the military industry. The civilian communications industry appears to have been an equally important source of capabilities, both for hardware manufacturers (such as Tellumat, with capabilities developed both the military and communications industry), and software developers (such as Prism Technologies, with capabilities developed in the banking and communications industry). It is also significant that local actors developed the entire software and communications aspect of the PPM industry. The vending-systems software, different revenue management systems, encryption and communications protocols, and the on-board software carried by the EDs were all developed locally[20]. Hence the successful mobilization of organisations with the appropriate capabilities relied on the possibility of horizontal migration of technology and capabilities South Africa's innovation system from one Sectoral System of Innovation (SSI) – military and/or communications – to the Energy SSI.

Table 4 – Sectoral membership of key PPM industry firms

Company Name	Landys & Gir	Tellumat/Syntell	CBI	Conlog (Groupe Schneider)	Prism Technologies
Original Name(s)	Spesscom	Plessey	CBI	Conlog	MBO from Linkdata
Founded	1980s	1950s		1965	1994
Core PPM Product	Pre-paid meters, vending systems, CDUs	Meters, CDUs, vending systems (through JV Synapse)	Pre-paid meters	Pre-paid meters, vending systems, CDUs	Encryption units in CDUs
Pre-1990s Sector Involvement	Military electronics equipment	Military communications	Electrical industry	Automotive electronics	early electronic banking and payment networks
Details	A supplier of high-specification metering equipment to the military. The numeric keypad input mechanism that is currently standard on most EDs is derived from Spesscom's military applications	Developing communications, control and monitoring equipment for the military industry. Continues to be involved in the military industry (both in SA and internationally)	During Apartheid era had practical monopoly on circuit breaker manufacturing in SA. *But* key personnel working on PPM came from military industry		Development of secure transaction mechanisms for the banking industry.
Post-1990s non-PPM activities	Off-grid solar pre-paid metering systems. The parent company - L&G - is the global leader in metering.	Military & civilian communications applications; municipal services (including PPM); contract manufacturing	SA's leading circuit breaker manufacturer	Conlog is entirely focused on PPM systems. Groupe Schneider is a leading global provider of electrical equipment	Secure online payments in internet, wireless communications, banking, other areas.

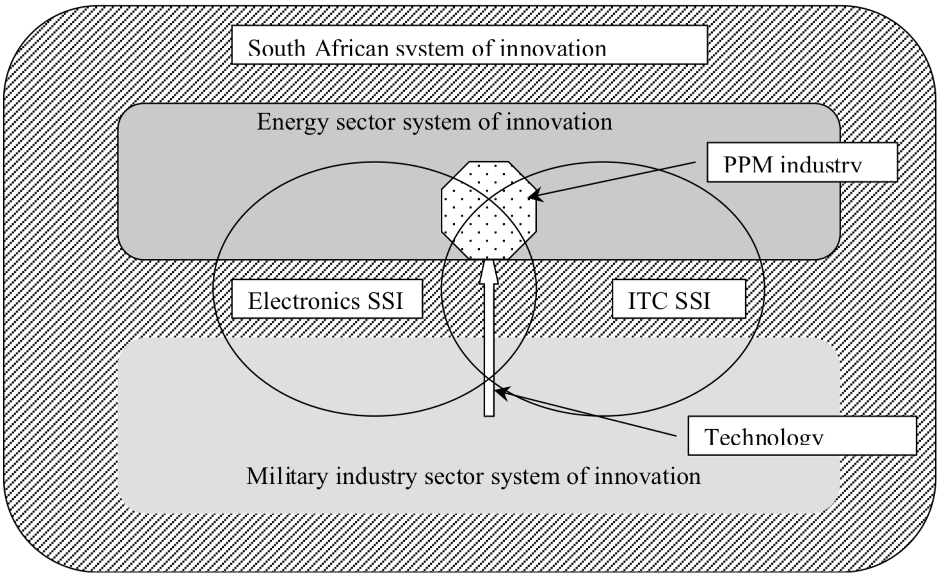
Two aspects of SA's system of innovation are of particular interest: the central role that the energy sector plays in the economy; and the state's role in building up an autonomous military industrial capacity (cf. Fine & Ragtime, 1996). Thus in the late 1980s both the Energy Sectoral System of Innovation (SSI) and the military-industrial SSI were important locations of innovation and technological development.

SSIs refer to persistent patterns of the organization of innovative activity within a particular industry. These arise from the dominant role that the technological paradigm within which production takes place plays in determining the dominant

[20] Although with occasional foreign expert help for key high-level aspects of the technology, such as the use of a UK expert in developing the encryption keys.

forms of organization of production. Thus the technological paradigm places limits on institutional diversity within the industry, which in turn explains similar organization of production within the same industry internationally. Thus auto manufacturers or pharmaceuticals globally are organized in remarkably similar ways, despite the variety of national institutional regimes within which they operate (Carlsson, 1995).

Figure 3 – The PPM industry's relationship to SA's system of innovation



Eskom's dominant role in the energy SSI and previous experience in large-scale R&D projects & technology deployment provided it with the coordinating capacity to mobilise actors in its sector for the development of innovative projects. The horizontal migration of capabilities was facilitated by the cross-membership of many of the organisations in these SSIs: there were technology transfer channels available for capabilities to migrate from one sector to another. Decline in military expenditure in the late 1980s appears to have been a 'push' factor leading electronics and ITC firms to search for other markets where their capabilities could be applied. Spescom is one such example, as it quit the military industry entirely once it entered the PPM industry. Furthermore, decline in military expenditure is likely to have driven highly qualified personnel into the civilian sector. But at the same time, some larger companies (such as Tellumat) continue to work in both the military and civilian sectors.

After the initial formation of the strategic alliance around Eskom, cross-sectoral access to capabilities continued to be important. The availability of strong IT capabilities has allowed the continuous 'smartening up' of traditional products, such as metering and control equipment. It has also allowed a differentiation of the strategies pursued by the different companies. Prism Technologies has used the strong capabilities in secure payments mechanisms it developed from the banking and PPM industry to push into other e-commerce and other markets (Prism website). Also, traditional industry distinctions have become less rigid, as hardware manufacturers have entered the software development.

For instance, Syntell Networks (the JV between Tellumat and Algorithm Software) was aimed at developing vending software for the prepaid meters. This software product has become an independent and significant source of revenue for Syntell. Conlog and L&G have equally strong in-house software development capability, again resulting in the strong performance of their vending systems products. Both Conlog and L&G market themselves as a one-stop-shop for municipal clients, where they can purchase the entire system, from hardware to vending software. For these companies the convergence between electronics engineering and software systems development has been key for gaining market leadership. Other firms (such as CBI) that have stronger base in electrical engineering manufacturing has used the ready availability of IT skills on the market to focus on design and manufacturing of meters, while relying on third party software developers for the vending systems. .

Another important factor has been the presence in SA's system of innovation of strong research institutions, and the PPM industry's development of strong linkages with these. Joint work was conducted with most of the major SA universities (the universities of the Witwatersrand, Stellenbosch, Cape Town and Pretoria), and the CSIR. Such interactions can be separated into several categories: high-level once-off projects (such as the development of the encryption technology underlying the STS standard, or enlisting the CSIR's help in developing a lightning protection system for the EDs); frequent low-level contract research projects (most of these involving manufacturers subcontracting academics to solve particular low-scale problems); and the development of routine organisational linkages (such as the working relationship between Eskom and the CSIR and electrical engineering departments at universities).

Eskom's relationship with universities and research institutes differs from that of other manufacturers in several aspects. Eskom has established long-term strategic relationships with universities and research institutes. It supports university electrical engineering departments at universities by financial, organisational and technical resources in exchange for a departmental focus of research and teaching activity to Eskom's priority areas.

4.2 The evolving role of a strategic alliance leader

The key role of the energy sector in South Africa's industrialisation and resources sector, combined with the monopoly position of Eskom in the post-1950s allowed Eskom to develop a uniquely powerful position in the economy. This gave it the resources, credibility and market power to carry through large technology and industrial programmes. The scope and investments that went into the PPM industry are relatively minor compared to the resources that were committed to the Pebble-Based Modular Reactor (PBMR) programme, or the coal power station deployment in the 1970s. Experience with such large programmes also gave Eskom the project management capability over a sufficiently large scale and time horizon. These skills and resources are crucial for the success of any organisation that seeks to play the role of a strategic alliance leader.

Dosi provides a useful distinction between technological *paradigms* and *trajectories*, where a technological paradigm is defined as a 'pattern of solutions of *selected* technological problems based on *selected* principles derived from natural sciences and on *selected* material technologies', while a technological trajectory is 'the pattern of "normal" problem solving activity on the ground of a technological paradigm' (Dosi, 1982:152). Thus a paradigmatic change constitutes a major systemic disruption that makes previous patterns of research and innovation in a particular area obsolete. The development of the PPM industry can be seen as paradigmatic change for both the electrical manufacturing industry (as it would displace traditional credit-based meters), and for utility providers due to the displacement of the whole credit-based metering and billing infrastructure. Within this paradigmatic change a number of trajectories could develop, based on patterns of design features which could accumulate into a dominant design.

In periods of radical technological change not even the participants in the industry have a clear understanding of the boundaries of their own industry, nor who the relevant players are. Under such conditions actors that have the capacity to interact with and shape the environment become key players, and are responsible for the framing of the environment that is taken as a given by later entrants to the industry. Clark and Tracey (2004, ch.5) argue that success in industries characterized by significant technological upheaval is premised on multiple-loop learning processes between groups of actors, and interacting with the environment aimed at both decreasing the level of uncertainty and impacting the environment in the interest of the actor. And of course, where the state plays a strategic role (for instance due to strategic interests in the military industry, social considerations in health care or environmental technologies), state-backed actors are in a position to impact heavily on an environment in flux.

Hence Eskom needed the role of a strategic alliance leader in order to be in a position to co-ordinate resource allocations to the different actors, push technology development in the preferred direction and close off some avenues of innovation. An important aspect of Eskom's strategic alliance leader behaviour is that it was highly dynamic in nature, and changed quite radically through time. The changes were timed with the different phases in the development of the PPM technology, and in line with Eskom's vision of what the long-term PPM industry should look like.

As the initial stages were characterised by high technological uncertainty and a large array of possible outcomes Eskom maintained a highly active role. Once the level of technological uncertainty declined As the early stages of development were characterised by a high-level of technological uncertainty and learning by all actors, Eskom wanted to stimulate the development of multiple trajectories of PPM hardware and systems design, while at the same time retaining ultimate control over which features are retained in a final dominant design. Once the level of technological uncertainty subsided and Eskom developed a better understanding of the needs of a well-functioning PPM system, it was in a position to push for standardisation and commoditisation of key aspects of the PPM value chain. As discussed already, the key aim of this was to accelerate the maturing of the industry, avoid lock-in into individual manufacturer's technologies, increase competition, allow specialisation and the development of economies of scale. This would then allow Eskom to exit the strategic alliance leader, and focus on cost minimization of its electrification programme.

In short, as a respondent characterised it, Eskom's strategy boiled down to 'heavy involvement in the early stages, a push for standardisation, and thereafter reliance on the market mechanism'.

4.2.1 Strategic alliance leader – active involvement in the early stages

The manufacturers that entered into a strategic alliance with Eskom possessed the initial technological capabilities to begin product development, but this required a significant level of sunk costs for initial R&D and prototype development. Furthermore, while the innovation was taking place there would be a need for constant interaction between the different actors to enable knowledge to flow both horizontally and vertically, and to prevent innovation being diverted to areas outside the leader's strategic aims. Thus there was a need for both strong and credible incentives to justify the manufacturers' commitment to long-term investment, and dynamic interaction between the various members of the alliance.

Eskom relied on a combination of active and passive measures in developing and sustaining an innovative environment for the manufacturers in the early stages of the technology's development. There were three main elements to this strategy: (i) precommitment to purchase diverse solutions; (ii) dynamic interaction and knowledge dissemination; and (iii) threat of lockout if non-compliant with Eskom's requirements. Eskom's precommitment to the procurement of over one million EDs provided the long-term assurance that a market for PPM would exist. This precommitment was made credible by Eskom's dominant position in the electrical industry, as well as its past history of large and long-term industrial investment programmes in the energy industry. But there was also a need for short-term incentives that would reduce the risk for manufacturers whose investment horizons (or at least cash flow) were much shorter than Eskom's. This was satisfied by Eskom's pre-commitment to purchase initial product models at a high price, and with different design features.

Throughout the initial stages of development Eskom was actively involved, and played a role in 'correcting' trajectories of innovation when there was significant deviation from its strategic aims. So while the incentive structure promoted technological diversity, Eskom's active management process allowed it to choose early on between the different designs each manufacturer was working on. On occasions Eskom would be forceful in pushing a particular technology if it was convinced that this would improve the reliability of the technology as a whole – such was the case with Spescom's keypad solution, different types of magnetic card readers, or the development and adoption a new lightning protection standard. Eskom also used its monopsonist power to block the entry of technology and design features that were not in line with the PPM strategy.

For instance, the company blocked the adoption of a flat-rate meter developed by CBI, because it did not fit in with Eskom's strategic aims for the electrification drive. The flat-rate meter was a potential rival to the PPM technology in its early stages of development, as it was cheaper and easier for the utility to operate than prepaid metering systems. CBI decided not to patent the technology, but to publicly disclose it, and promote its adoption internationally. However, both Eskom and the STS Association are reported to have blocked the adoption of the technology in SA because it conflicted with Eskom's PPM electrification strategy. Similarly, the company's push for low-cost devices prevented the introduction of a variety of enhanced features; for example, on-board customer messaging systems were excluded under Eskom's pressure. Thus there are elements of ambiguity in the role of monopsonists as leaders of strategic alliances: on the one hand they have the capacity to stimulate and co-ordinate radical innovation by multiple actors; but on the other they have the power to set up strong barriers to innovations that are not in line with their strategy.

4.2.2 Strategic alliance leader: standardisation as the first step of disengagement

As discussed, the generation of technological diversity in the initial stages of the technology's development was associated with the development of proprietary technological standards and systems by the different manufacturers, with up to five proprietary PPM systems in operation by 1992. Initially Eskom had committed to absorb the cost of running several systems, as it wanted the additional technology options it expected to get from the different manufacturers' independent innovative efforts. However, with the maturing of the technologies, less was being learnt from the continued operation of multiple standards, while the costs of running a multiple standard technology were increasing rapidly. The point at which the costs of running multiple standards are higher than the benefits of doing so is when standardisation becomes necessary.

As discussed earlier, standardisation would resolve a number of the costs of running multiple standards by eliminating duplication costs, opening up the industry's value chain for competition and further innovation, and allowing the consolidation of the market and the emergence of economies of scale. Standardisation allows the consolidation of the market size, which in turn allows producers to reap economies of scale, in turn leading to a decrease in the unit costs of production and prices. In addition, the emergence of economies of scale allows individual producers to focus on core capabilities.

As the technological requirements for the various components of the PPM system are harmonised, the different segments of the industry can specialise. Specialization allows the development of economies of scale and further incremental innovation, declining costs and improved quality of production. For instance, as the introduction of the STS standard standardised the communication between CDUs and EDs, CDUs could operate third-party vending software. In turn this facilitated the emergence of vending software as an autonomous market segment, in which software development could take place independently from the ED manufacturers. For the firms that had developed in-house vending software (such as L&G) or collaboration with a software company (such as Syntell), standardisation allowed the development of vending software as a strong and independent line of business.

Another rationale for a push to standardisation is to avoid a lock-in of the industry into an inferior technology. In the context of the PPM industry, this is a somewhat complex issue. To begin with, Eskom's standardisation efforts were at least partly motivated by a desire to avoid such a lock-in. The decision to develop the standard in-house, with key work subcontracted to academic experts and industry participants can be seen in light of this desire to maintain control over the standard. So in this sense Eskom was successful in avoiding a lock-in to an *externally* developed standard. Furthermore, it does appear that the STS standard is performing comparatively well, both in terms of its growing adoption within SA and internationally and its support by the IEC. Conceptually of course the adoption of the STS standard prevents alternative standards from emerging. This is an issue that will always be relevant when technological standards are set, as the open-ended and evolutionary nature of technological change means that it is always possible that path-dependence effects lock-in industry into inferior technology (Arthur, 1989).

It is here that the setting up of the keeping of the STS standard open to industry, and the setting up of the STS Association as an independent custodian of the standard, charged with its continuous update and spread internationally. As discussed in the history section, the STS Association has been successful in promoting the adoption of the STS standard by the IEC. The STS Association provided a forum where interaction between users and producers could take place, and where changes to the standard that would affect multiple participants could be negotiated and formulated.

The STS Association's current development of STS2 illustrates this point: the aim is to include many new features that were underdeveloped or not even present in the original STS standard, such as multiple tariff support; simultaneous electricity, gas, and water metering; or internet connectivity. These are features that were identified by the changing client composition of the PPM industry, as well as brought by changing infrastructure and technology needs. So while some level of path-dependence and lock-in is inherent in any standardisation process, keeping access to the standard open and having an appropriate arrangement for the standard's maintenance and evolution helps minimise the lock-in costs to industry. It is likely that following disruptive innovation the presence of an independent standards organisation representing the interests of the various stakeholders in the industry could facilitate the responsiveness of the technological standard to changes in the industry and novel technological opportunities.

The importance of a co-ordinating actor in the implementation of standards is also illustrated by the adoption of the 'plug-in base' standard. In terms of technological intensity the plug-in base was not very innovative – it was designed by a single person at Eskom. However, this standardisation was an inexpensive way of removing a major physical barrier to ED inter-changeability, as now the installation base in a wall would be the same for all EDs. Thus, at least in this case, the importance of an innovation was not so much its level of its technological complexity, but rather the ability of a coordinating actor to push through the adoption of this design as a standard.

Several of the respondents suggested that Eskom had expected from the beginning that the multiple-standards problem would arise, and that it would have to push for standardisation at some point. There is no way to ascertain to what extent the problems were expected, but it does make sense to see a coherent and dynamic innovation strategy, which involves the sequential switching of technology management techniques at crucial points. Importantly, due to the technological uncertainty implicit in innovation, it would have been impossible to know the type and timing of the standardisation consisting *a priori*. But what the strategic alliance leader benefited from was an awareness of the likelihood that the multi-standards problem would arise, which in turn would have guided the search activity of the technology managers.

As a speculative note, industry participants could have been aware of the two options facing Eskom: (i) choose a standard as close as possible to the existing standards to minimise the switching costs; and (ii) develop own standard, combining 'best of' industry. Prior knowledge or expectation of any of these two options would have set different incentives in place for the manufacturers. Prior knowledge or belief in the first strategy could incentivise firms to push for gaining early market share, instead of higher levels of innovation; that is, the larger the market share captured early on, the more likely that the manufacturers' standard would be adopted later on. Expectation of the second strategy would set 'better' incentives for innovation: since the bulk of the procurement would come *after* standardisation, then the early stage focus should be on developing better technological solutions and innovation, rather than early capture of market share.

In the case of Eskom, early commitment to the latter strategy would be credible, as its size (and possibly state backing) meant that it could 'take the pain' of losing a somewhat large base of meters. This dynamic could have interesting implications for other similar cases of technology and standards development, but where the strategic alliance leader chooses a more 'static efficient' strategy, or the large purchaser does not have the credibility to carry through a painful standardisation strategy. At the very least, a lesson for large organisations engaging in strategic technology development is to focus on setting the right expectations from the beginning of the technology development strategy, as a way of ensuring alliance participants focus their resources on innovation rather capturing early market share.

4.2.3 Strategic alliance leader: technology maturing and disengagement from the alliance

The success of Eskom's standardisation means that it could reduce its level of engagement with manufacturers. The evaluation of their products was simplified, as benchmarking was easier, and there was no need to maintain close links to direct multiple technology development efforts. At this point Eskom could begin a push for a decrease in costs and consolidation of its supplier base. Manufacturers began a push for other markets (both exports and domestic municipalities). While this shift to a diversification in the customer base was a likely response to Eskom's changing strategic role in the industry, it was also made possible by the presence of an internationally credible standard.

So the standardisation facilitated the development of an external market, which in turn weakened Eskom's power in the strategic alliance. But at this point Eskom was ready to rely on more 'passive' interaction with the manufacturers, through open-market tenders. Eskom's reduced support and increased cost pressures on the manufacturers reduced the incentives for staying in the alliance. Eskom has moved from what was described as a 'grandfatherly' role in the industry to a more classic monopsonist role characterised by increasing cost pressures on producers. Industry respondents indicated that owing to price pressure from Eskom the SA domestic market is no longer sufficient to sustain the local industry, making them dependent on exports for survival.

The entry of South African local authorities into the PPM industry in the mid-1990s allowed many of the manufacturers to diversify their client base, which appears to have weakened Eskom's negotiating power. The diversification of the market also stimulated further innovation, as municipal metering needs stimulated the development of the combined water and electricity meter, the development of STS2, as well as further innovation by vending software developers, aimed at accommodating different tariff schedules[21]. In the long run the most important diversification channel would be through exports. But while many of the manufacturers were successful in gaining export orders, some of the respondents were of the opinion that SA's PPM manufacturers were not sufficiently quick and aggressive on the foreign markets, and as a result there was a mismatch between the maturing of the industry domestically and the growth in the South African manufacturers' presence internationally.

Possibly in anticipation of this need to access export markets rapidly to avoid the cost pressures by Eskom, some PPM industry participants sought alliances and mergers with MNEs. But, as discussed earlier, this did not produce the significant positive effects expected. This could have contributed to the mismatch between the timing of Eskom's price pressures and the ability of the participants in the industry to fund further R&D through a growth in export earnings, thus compensating for the increasing pressures on domestic prices[22]. The domestic squeeze on the manufacturers' margins and the lack of a countervailing increase in resources from international expansion in turn appear to have led to a decline in manufacturers' investment in innovation, and a loss of key skilled personnel from the industry.

4.3 The role of MNEs in the local industry

The decade since 1994 has been characterised by a significant policy emphasis on Foreign Direct Investment (FDI) as a source of investment, employment and productivity growth for the SA economy. A significant part of the FDI that has entered South Africa has done so not through greenfield investments, but through

[21] For instance, the first combined water and electricity meter was developed by Tellumat, which at that time had quit the Eskom market to concentrate on the local authorities market.
[22] One of the respondents felt that the SA industry had already missed its window of opportunity for developing a dominating presence in the international market, and expected Chinese and East Asian manufacturers to dominate the industry in the future.

mergers and acquisitions (M&As) of existing enterprises. Whereas there is broad agreement among economists on the positive effects of greenfield investment, there is still relatively little understanding of the effects FDI through cross-border M&As. There is a substantial literature on MNEs (which are the main actors in cross-border M&As), in which there are conflicting views on issues like international technology transfer in MNE networks, effects on innovation, employment, pricing structures, impact on domestic competition and market structure, crowding out of domestic R&D, and the possible severing of the links of domestic innovative SME from domestic system of innovation. This is not the place for an extensive discussion of this literature, but suffice it to say that current international evidence concerning the impact of M&As and MNE entry on domestic economies is ambiguous, and its costs and benefits are still being debated (Lall, 2000; Haller, 2004).

The PPM case study has raised important questions on many of these issues. As discussed earlier, many actors in the PPM industry saw entry into MNE networks as an important way of gaining access to international markets. The limited work done makes it difficult to generalise, but at the very least it is clear that the industry had very high expectations of the benefits of MNE entry, and that these expectations were not satisfied. While Schneider's takeover of Conlog was followed by improved export performance, Siemens's takeover of Spescom as an overall failure. The research conducted is insufficient to accurately determine the extent to which access to MNE resources helped these firms' performance, as the other manufacturers that remained independent have performed well despite the lack of MNE support. Firms such as CBI and Tellumat have remained strong participants in the PPM, and have experienced significant expansion on the international markets.

Overall, it appears that the industry has misunderstood MNE's motivations for entry, and the benefits and resources that could realistically be expected. What should be of interest is that MNE investment is translated into substantially different strategies for the acquired companies, and not necessarily dramatic improvement in performance. It is also important to highlight the late entry of MNEs into the industry at a point where the technology had already matured. While MNE entry may have resulted in inward technology transfer, the primary motive for MNE acquisition of PPM manufacturers was access to a globally unique set of capabilities which would complement those elsewhere in the MNE's production network.

5. Conclusion

Given the lack of prior research in this area, a major task of this project was to reconstruct the history of the development of the technology, and what was the role played by the different actors. Several phases of development were identified in the history of the PPM industry. The preliminary stage, in which Eskom formulated its overall technology needs in the context of the electrification programme, resulted in the identification of the requirements for the technologies to be used in the electrification of households. The recognition of the socioeconomic and infrastructural limitations that Eskom was facing led to the selection of PPM technology as a way of overcoming these problems and achieving lower electrification and running costs.

This was followed by the development of a strategic alliance between Eskom and various innovative firms that had the technological capabilities to develop a systemic innovation. The release of the NRS 009 specification in 1989 marked the beginning of the early stage of technology development, during which Eskom gave the manufacturers strong incentives to invest in new technologies and technological diversity. As the technology matured, Eskom was able to formulate its technological requirements in detail, which in turn allowed it to push for a standardisation of the technology. The implementation of the STS standard in 1993 (along with other lesser standardisation measures) allowed different manufacturers' products to be substituted for one another, and made the vending software applicable across hardware platforms. This was followed by a period of consolidation, with Eskom gradually decreasing the degree of its involvement in the industry, and relying more on the market mechanism.

At the same time, manufacturers were seeking to diversify, first turning to local authorities as an alternative market, and then to export markets. The manufacturers' growing focus on alternative markets put pressure on Eskom to allow independent management of the STS standard; this eventually led to the establishment of the STS Association in 1997. The next few years saw the continued decline in the amounts procured by Eskom, the use of the STS-compliant metering technology in gas and water applications, the growing role of MNEs, and an increasing focus on the export markets. By 2003 the International Electrotechnic Commission released the STS standard as a Publicly Available Specification, recognising South Africa's PPM technology as a *de facto* international standard. While PPM industry players face many challenges, the industry has matured to a level where it is largely autonomous of the initial strategic alliance leader, with the technology being diffused internationally.

Based on this, I was able to analyse the various processes that characterised the PPM history. The key finding would be that the PPM industry provides a powerful example of the possibility of developing a successful novel technology in developing economies. In particular, the combination of generic capabilities (such as software development skills, electronic and electrical engineering) with *specific* local conditions led to a novel recombination of knowledge sets, the generation of unique capabilities, and ultimately the development of innovations. Antonelli (2003) notes that both knowledge complexity and fungeability are the cause of increasing returns in the generation of knowledge. Complexity matters when the production of new knowledge requires the combination of diverse and yet complementary bits of knowledge. Fungeability is found when some units of knowledge can apply in a variety of different contexts, different products and different processes. In the context of the PPM technology, the fungeable knowledge required for the development was general principles of electronic engineering, programming, cryptology and communications.

The elements of complexity specific to the South African situation were various aspects of the highly complex and exacting operational environment. The combination of these two aspects of knowledge allows the generation of globally unique innovations. From a policy perspective, this should be of interest, as it illustrates that the mobilization of scarce technology skills and resources toward the solution of locally specific problems that are deemed of strategic importance can result in the development of strong domestic technological capabilities and novel products that are marketable globally. This is not only so in the energy sector (increased efficiency, off-grid generation, renewables), but also in other important sectors such as healthcare.

Some of the key 'lessons' identified, which are likely to be of relevance in other contexts of policy analysis and innovation strategy are:

- *Institutional framework* – the system of innovation within which the actors operate explains their inherited capabilities, network linkages, access to resources, and constraints on their activities. Migration, or cross-membership of Sectoral Systems of Innovation (SSIs) was particularly important in allowing the recombination of capabilities developed in the military-industrial and Information Technology and Communications (ITC) sector to the civilian energy sector.
- *Strategic alliance leader* – in the context of radical or systemic innovations, the presence of an actor who could play the role of a strategic alliance leader facilitated the coordination of investments by innovative actors.
- *Role of procurement* – for innovators investing in radical or systemic innovation, a precommitment to long-term procurement plays an important role in decreasing uncertainty by ensuring the continued existence of a market. Such assurances allow the innovators to make a long-term commitment of resources to a priority area.
- *Technological diversity* – high levels of technological uncertainty characterise the early stages of technology development. The cost of this can be mitigated by the presence of a strong co-ordinating actor that can both provide the incentives for innovation and close non-desirable paths of innovation at an early stage.
- *Technology standardisation* – the development of diverse technological solutions may culminate in the development of multiple standards, which means running multiple networks. A strategic actor with strong market power can push for

standardisation at an early phase of the technology's development, which can result in the rapid maturing of the industry, development of economies of scale, specialisation, and access to other markets.

- *Evolution of the strategic alliance leader role* – the behaviour of the strategic alliance leader changes with the different phases in the development of the technology. In early stages the leader sets up incentive structures that are favourable to other alliance participants, with resource transfers and intensive interactions, and tolerance of high prices set by other members of the alliance. As the technology develops, the leader pushes for industry maturity. This may involve a push to standardisation, disengagement from the alliance, a consolidation of industry actors, and lower prices.

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