Working Paper

TECHNOLOGICAL CHANGE AND PRODUCTIVE CAPABILITIES IN THE PLASTICS INDUSTRY

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Abstract

The discontinuous and uneven structural transformation that has characterised the South African economy over the past two decades exacerbated by premature deindustrialisation has had a dramatic impact on employment, productivity and competitiveness. However, Industry 4.0, and the commensurate technological changes, presents an opportunity to regain and improve competitiveness in the industries such as plastics which are a root industry for the technical changes that are taking place. The South African plastic industry has lagged behind these changes and has performed poorly when compared to its upper middle-income counterparts. This lagged performance is due to, among other things, low-levels of investment in machinery and skills with many firms operating with out-of-date machinery. All these imply higher costs in terms of energy usage and raw materials through rejections, scrap and reworking. The paper assesses how the application of industry 4.0 technologies can improve the competitiveness in key segments of the plastics industry through an assessment of firm level capabilities with a focus on technological capabilities and the influence on competitiveness.

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1 Introduction

Over the last two decades, the structural transformation of the South African economy has been discontinuous and uneven. In particular, its premature deindustrialization has had a dramatic impact on employment, productivity and competitiveness. The technological change associated with industry 4.0 presents an opportunity to regain and improve competitiveness in the industries such as plastics which are a root industry for the technical changes that are taking place. Much of plastics products are intermediate products and have linkages to much of manufacturing. As such, it is important to understand how industry 4.0 changes the process of technological change, capability development and diversification in the industry.

Internationally, advances in technologies are changing the landscape of the plastics industry. The growing use of the 'Internet of the Things' which integrates design, development, production and distribution; economic prototyping; advances in materials science to improve properties; robotics; virtual testing; developments in key production technologies such as injection-molding and blow moulding as well as the increasing use of additive manufacturing for production mean that the plastics factory is going through a transformation. This transformation has implications not only for process and production efficiency, but also the landscape of international competition by allowing smaller manufacturers to achieve the market access and technological capabilities that previously could only be attained by medium-to-larger players.[1]

The South African plastic industry has lagged behind these changes and has performed poorly when compared to its upper middle-income counterparts.[2] Years of poor performance have meant that instead of a virtuous circle of investment, increased efficiency, and economies associated with throughput and scale reducing average costs, the South African plastics industry has experienced a vicious circle. There has generally been low-levels of investment in machinery and skills with out-of-date machinery implying higher costs in terms of energy usage and raw materials through rejections, scrap and reworking.[3] Between 2002 and 2016, the industry has experienced increasing levels of import penetration, a loss of competitiveness in export markets and has shed 16163 jobs.[4]

As countries are adopting the advances in technology that are associated with industry 4.0 the South African plastic industry may continue losing competitiveness, placing the current 60 000 jobs at risk. This has wider implications due to linkages with other sectors in the economy. Plastic products are often components of more complex products, as such manufacturing capabilities in plastics are a critical part of much wider manufacturing capabilities. For this reason, the plastics industry has been characterised as a root industry for the fourth industrial revolution.

The paper assesses how the application of industry 4.0 technologies can improve the competitiveness in key segments of the plastics industry. This will include an assessment of firm level capabilities with a focus on technological capabilities (including how to use advanced technologies for more flexible customized manufacturing of high value products) and the influence on competitiveness. The research was conducted by a reviewing existing surveys and studies on the plastics sector and interviews of firms in the key segments, automotive,

[1] Siemens. 2017. SFS-Whitepaper 'The Digitalization Productivity Bonus Plastics.' [Online]
[2] Mondliwa, P. 2018.
[3] We note that the picture is not uniform and some segments, such as packaging, have performed relatively better.
[4] Quantec Data

engineering plastics, homeware and construction products. The interviews will sought to assess how different technologies have contributed to changes in productivity and efficiency of production, the impact on employment, and skills requirements as well as the factors that have aided adoption of the new technologies.

2 Technological change and productive capabilities

2.1 Technological change and structural transformation

Technical change has the ability to help in the process of structural transformation. The idea of the reallocation of resources that underlies structural change is aided, in part, by the use of technologies that can boost the levels of productivity in the economy and, in turn, economic growth. In driving the process of development, it is important to note that changes in technology can come from a variety of different channels. Firstly, through direct investments by the state in new technology or the importation and adoption of existing technologies from abroad. Secondly, through the upgrading of the skill and education levels in the economy. Thirdly, from addressing and correcting market imperfections such as barriers to entry and the high levels of concentration. Therefore, opening markets can encourage innovation and research and development.

The process of technical change requires an upgrading of existing capabilities. As part of the process of upgrading capabilities, Fagerberg et al. (2010) point to the importance of innovation through developing new and improved products and processes. Technological change can also facilitate growth in the quality of output in different sectors. Whether the change occurs in agriculture, manufacturing or services, improvements in technology can be a main driver of capability improvements and capacity growth. However, fully realising the gains from new technologies is dependent on existing technologies and skills which may or may not be available. Any new technologies, however, face competition from existing technology which have benefitted from previous learning and scale economies as well as institutions (Rip & Kemp, 1998). Thus, the successful diffusion and acceptance of any new technology or technical change comes down to, in some degree, to the cost of the technology. Other factors also include the availability of complementary technologies as well as a necessary change in ideas, norms, and values (Rip & Kemp, 1998). Therefore, the arrival of 4IR brings with it a diverse range of possibilities for transformation and growth in the value of global manufacturing.[5] But this similarly presents new problems for policymakers and businesses alike.

The accumulation of productive capabilities is the heart of economic development (Teece, 2000). Growth accounting studies have typically found that a large proportion of growth is due to technological progress, amongst other ‘Solow residual’ factors (Best, 2001 in Mohamed, 2005). Extensive firm and industry level analysis makes clear that these capabilities are not simply about acquiring technology or skills but are to do with the internal ‘know-how’ of the company including routines and working practices, and the linkages within clusters and supply chains (see, for example, Sutton, 2012). It is critical to understand capabilities in specific companies, industries and clusters in order to evaluate how they are developed and the measures which can change the performance of a sector.

The main challenge faced by late industrialisers is to adopt and adapt technologies from industrialised nations, thus the organisational characteristics of firms in late industries are key

[5] https://www.weforum.org/agenda/2018/08/3-lessons-from-the-lighthouses-beaming-the-way-for-the-4ir

for successful development (Amsden, 1997 in Roberts, 2002). Amsden (1997) argues that the key to the development of diversified conglomerates in South Korea was the firms' organisational capabilities which could be transferred across different sectors.

There are strong interdependencies between organisational capabilities, production capabilities, human capabilities (or skills) and technological capabilities (Nelson and Winter, 1982; and Prahalad and Hamel, 1990 in Mohamed, 2005). This becomes clear when the definitions of these concepts are considered. Generally, the term "organisational capability" refers to the important role of management in adapting and restructuring the firm's resources in order to influence its overall competitiveness (Mohamed, 2005). The concept of competitiveness at a firm-level refers to the ability of a firm to produce higher quality products at lower costs than its competitors both in the domestic market and in international markets (Mohamed, 2005). Competitiveness is achieved through investment in product development to improve product quality.

Technological capabilities can be understood as the resources needed to generate and manage technological change (Figueiredo, 2002). Technological innovation and diffusion are the driving forces of economic growth and international competitiveness. Following the Schumpeterian evolutionary approach, Meliciani (2001) has argued that general technological competitiveness and investment activity directly impact on economic growth through product and process innovation and diffusion. Where technological competitiveness and favourable specialisation interact, higher research and development expenditures allow entry into high technology industries and favourable specialisation patterns impact on international competitiveness by creating favourable income elasticity of demand. International competitiveness impacts on growth through the balance of payments. Such that economic growth positively impacts investment activity and technological competitiveness through the accelerator mechanism and demand induced innovation, thus creating the possibility of virtuous and vicious circles of growth.

Production capabilities can be understood as a knowledge acquisition process to create or improve existing products to meet customer needs (Mohamed, 2005). Investment is necessary to support this process. It may also be necessary to upscale production through upgrading machinery and equipment and/or acquiring relevant skills by providing training (Mohamed, 2005). There are also strong spill-over and collective dimensions to these processes meaning that individually companies will under-invest as each will not take into account the shared benefits but only the returns to themselves. Coordination is required as well as understanding the incentives at work for companies to undertake the linked investments. Skills can be understood as the capability for a smooth sequence of coordinated behaviours that result in the desired outcomes under circumstances they are conducted (Nelson and Winter, 1982). The individual performing the tasks may do so instinctively and thus find it difficult to articulate it (Mohamed 2005).

Production and technological capabilities building at the firm level is affected by the broader national learning system (UNIDO, 2013). The role of institutions in building capabilities, and thus competitiveness, is discussed in detail below. This risks over simplification as it combines complex and diverse considerations into these three factors. A similar criticism can be levelled against Lall's technology classifications which effectively places sectors into technology bands, however, this assumes sectors are relatively homogenous in terms of the level of technological sophistication. For example, plastic products are low technology while fertilizers, for example, are medium technology. As is discussed below, plastic products are very diverse. By comparison, fertilizers in South Africa are linked into Sasol's resource-based activities.

The implications of these shortcomings are evident in Kaplan's use of Lall's classifications to assess South Africa's growth of exports and share of world exports (Kaplan, 2004). He found that South Africa's share of medium technology products grew, while there were very low rates of growth in both low technology and high technology groupings. This is largely due to extensive support provided by the government to the sector through the Motor Industry development Programme (MIDP). However, it fails to illuminate underlying developments in sectors designated as low and high technology.

2.2 Understanding technological capability accumulation in firms

The ability of firms to adopt and adapt technologies and in the process develop and grow technological capability influences the firm's performance and competitiveness. The degree of technological capabilities varies across firms. Analysing the technological capability levels of establishments is useful for understanding the origins of the differences they display (Villalobos & Brown, 2004). This is useful for our purposes given that the South African plastics market operates within a global value chain where the presence of large, well-funded multinational corporations with massive scale and newer machinery make it difficult for smaller-scale South African manufactures to compete on quality, quantity, and price.

Technological capabilities represent the ability of a firm to combine, efficiently, several resources to engage in productive activities and attain a certain objective (Amit & Schoemaker, 1997 in Dutta et al., 2005). At the firm-level, technological capabilities should enable a firm to easily introduce new technologies in order to undertake a range of productive tasks (Kumar et al, 1999).[6] These capabilities from a firm's perspective are acquired and transferred through various modes such as a combination of foreign direct investment, joint ventures, turnkey projects, and the purchase of capital goods (Dunning, 1981; Katz, 1985). Yet, the literature sometimes assumes smooth, linear process of accumulating these technological capabilities by a firm.

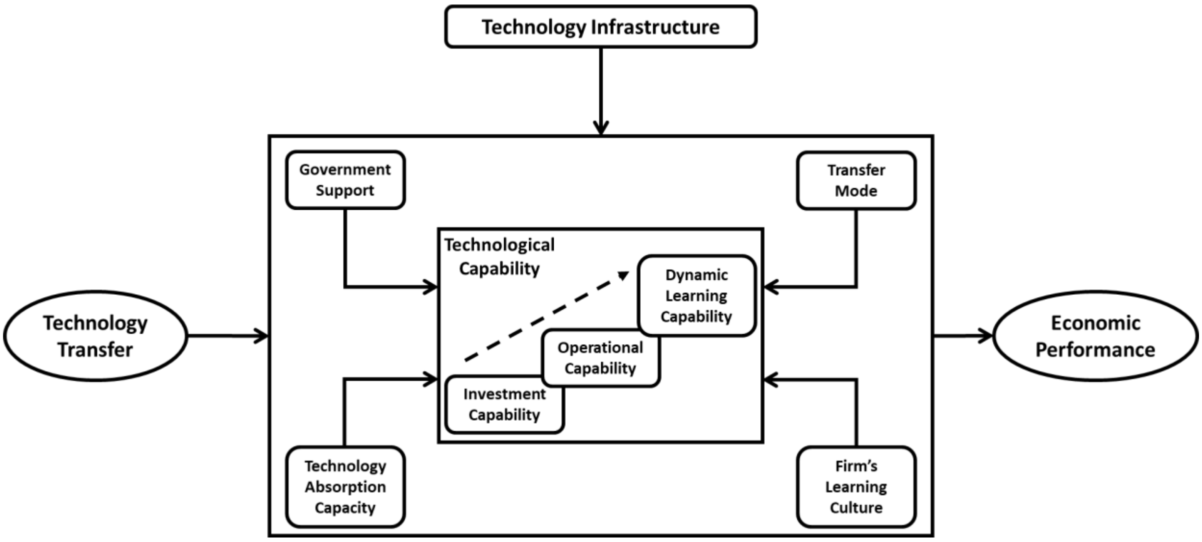
Instead, writes Kumar et al. (1995), there exist three important capabilities, of which all are required, in order to make the accumulation of new technologies integrate seamlessly. These are investment capabilities, operational capabilities, and dynamic learning capabilities. Investment capabilities are the skills and information required to identify investment projects and purchase suitable technologies which contribute to a firm's level of technological capability (Bell, 1987; Lall, 1982; and Wei, 1995). This is the strategic side the company. Namely, it represents the company's ability to think strategically about its current technological infrastructure and how it can utilise new technologies to grow its technological capabilities.

Whereas, operational capabilities consist of the skills needed to operate, maintain, repair and adapt technologies in order to increase production and efficiency (Kumar et al, 1995). This is the technical side, which places a strong emphasis on the skill levels that are required to make any technical change fit seamlessly into the firms' existing capability. Lastly, dynamic learning capabilities represent the skills and information required to generate dynamic technical and organisational changes (Bell, 1987; Mytelka, 1985; Wei, 1995). Specifically, this is how capable the firm is in managing and enacting technical changes within its organisation and whether the management team has the correct structures in place with which to integrate the new technologies into its current capabilities.

[6] The study looks at forty-five Indonesian manufacturing firms in the garment, textile, electronics and footwear industries that had received technology from other countries as well as being export-oriented.

Presented below is a stylised conceptual model of technological capability as in Kumar et al. (1999). This model shows the relationship between technological transfers, technoligical capabilities, and the economic performance of the firm in question. It postulates transfers can and do lead to improved technological capabilities which in turn leads to improved economic performance. It must be noted that the model suggests that growing technological capabities is a continuous process of learning (depicted by the broken arrow) and is heavily dependent on the mix of technology and capabilities obtained through the acquisition. Likewise, the model also suggests that a firm's "technological capability" is dependent on how easily the firm is able to absorb the technology; its ability to learn and adapt its knwoledge network; how the government is fostering technological development through industry-specific policies and support; and the mode through which the technology is transferred, whether informally or formally, throughout the organisation.

Figure 1: A Conceptual Model of Technological Capability



Source: Adapted from Kumar et al. (1999)

It may be that the process of growing technological capabilities depends less on investments in new and imported technologies (Villalobos and Brown, 2004). Put another way, it is not enough to just purchase machinery, or technologically-leading or innovative firms, to narrow the technological gap between firms. What is seemingly more important, is how the technological change is disseminated throughout the firm (Bell and Pavitt, 1992). Thus, the dissemination of technological capabilities involves continuous, and often incremental, technical changes within firms. This is built on by Rush et al. (2007) who argue that technological capability is not a natural endowment. Thus, for a firm to have the capability to manage and depeen their technological endowment results from a combination of an extended learning process, a gradual accumulation process, and the procedures, routines and structures within the specific firm.

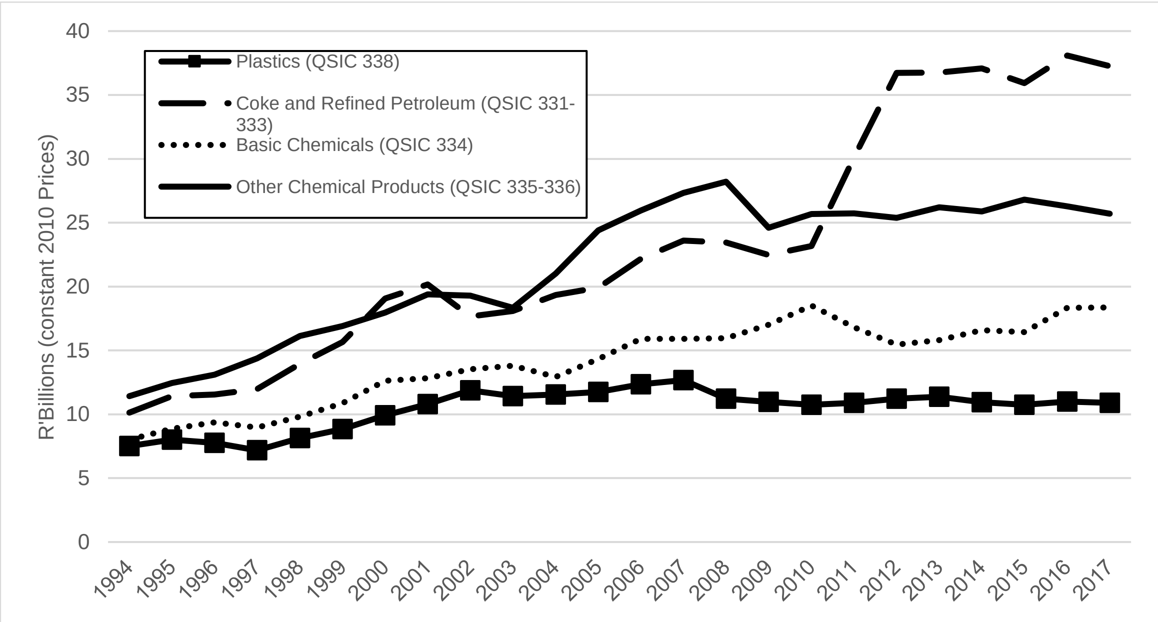
Through an investigation of the dynamics of technological acquisition implementation in firms that attempt to gain new technologies and capabilities through the acquisition of other firms, Ranft and Lord (2002) suggest that the transfer of technologies and capabilities to the acquiring firm is neither simple nor as quick as theory might predict. This is due to there existing issues related to the implementation of the acquired technologies that are distinct to each individual acquisition that may impact the success of a technological change.Therefore, this discussion emphasises the need for the management of a firm looking to adopt a new technology to understand their organisation's existing technological infrastructure and the different capabilities that work together to support its successful implementation.

3 Structural Transformation in the chemicals and plastics value chain

The chemicals and plastic products sectors cover the range of activities from upstream basic chemicals including polymer chemicals as a refinery product to diversified manufacture of plastic products. The plastics sector is particularly relevant as it covers the manufacture of a range of intermediate and final products. It has been growing internationally more rapidly than overall manufacturing as plastics replace other materials.

In South Africa, the upstream industries of the chemicals to plastics value chain have continued to grow strongly (Figure 1). By comparison, the plastic products sector grew up to 2002 and has since stagnated and declined, reflecting the overall picture of deindustrialisation in South Africa.

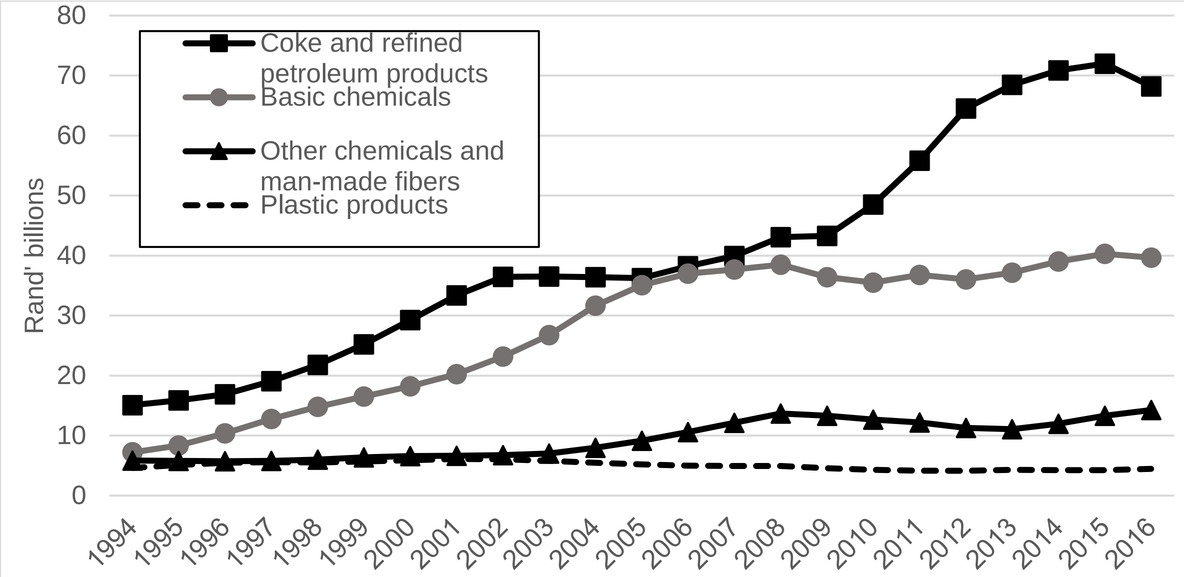
Figure 2: Output Performance (value added, constant 2010 prices).



Source: Quantec data

The plastics sector has also seen substantially lower investment in production capacity (Figure 2). While it is expected that the upstream industries will have substantially higher investment in fixed capital due to the capital-intensive nature of production, the downward trend of the plastics sector relative the others is alarming.

Figure 3: Changes in production capacity (machinery & equipment, constant 2010 prices)

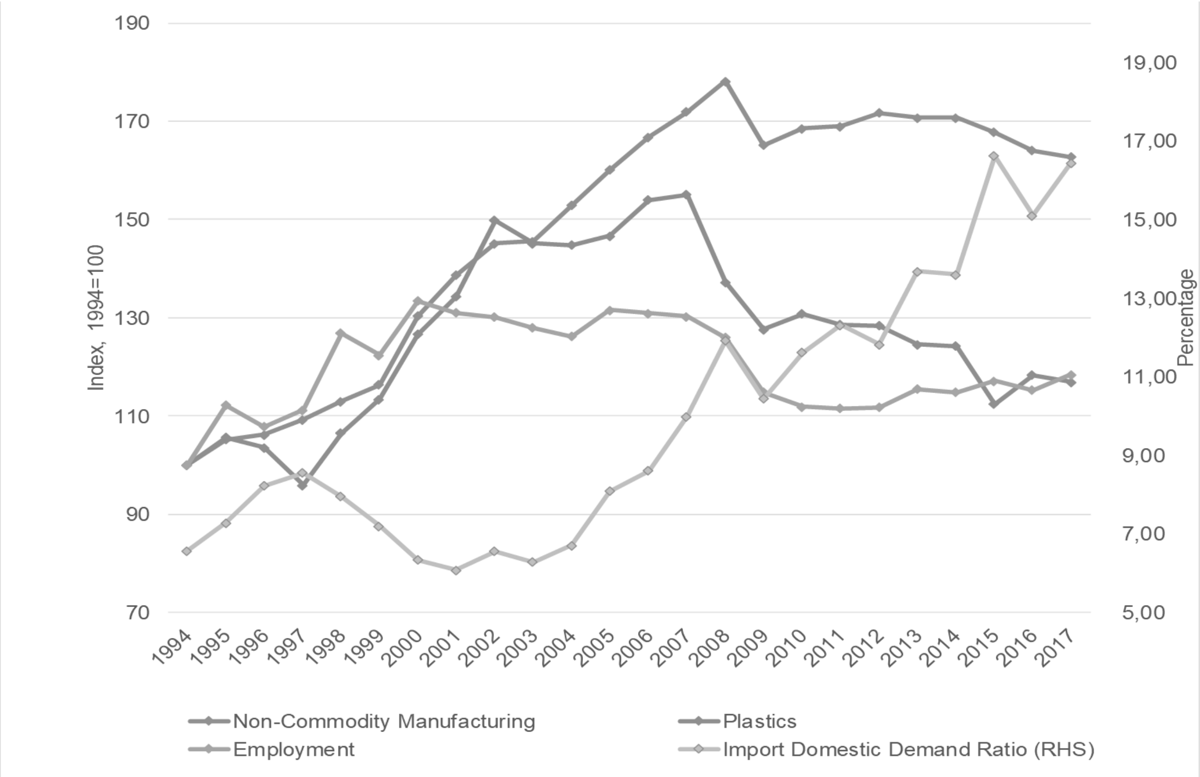


Source: Quantec data

Average investment rates in the plastics sector have also been poor relative to overall manufacturing. On average over the period 2002-2014, investment rates were only 13% of value add for plastics, compared to manufacturing at 26%.

What is most striking, however, is that plastics products recorded relatively good performance from the mid-1990s up to 2002. Since 2002 performance has been poor, in particular, when assessed relative to other non-commodity manufacturing (defined as manufacturing excluding basic metals, basic chemicals, other chemicals, and coke and refinery products) (Figure 3). The poorer performance of plastics from 2002 is associated with rapidly rising import penetration from 2003. The year 2002 thus appears to represent a turning point for plastics products, where its performance deviates from the overall picture for non-commodity manufacturing. From 2002 there was a significant deterioration in the trade performance across most sub-sectors.

Figure 4: Performance of the plastics sector relative to non-commodity manufacturing



Source: Calculated from Quantec

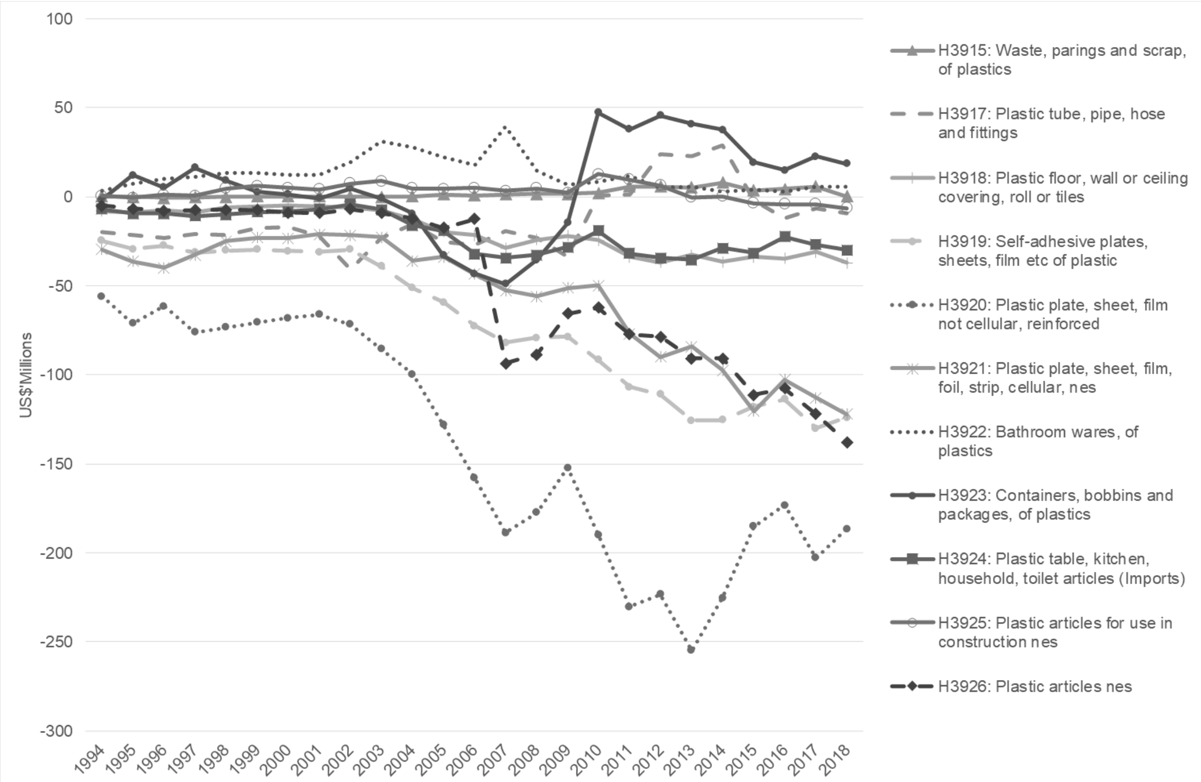
Notes: Plastic products output and employment are indices, as is non-commodity manufacturing

The analysis at the subsector level reveals some differences in performance. For example, a breakdown of import penetration (in terms of volumes, to a sub-sector level reveals that the packaging and construction sub-sectors have had relatively low import penetration (20% and 36% respectively) in 2013, whereas in all other sub-sectors it was much higher (over 70%, according to DTI, 2013).

On the demand-side, three industries in particular – construction, packaging, and automotive – drive growth of the plastics sector as economies grow. But, in South Africa's case, although these industries have been growing, this has not translated into growth for the plastics sector largely because of increasing import penetration in the absence of export growth and diversification. In effect, South Africa has largely de-industrialised in very important segments of plastic products. Given that plastic products are a key manufacturing industry in which to develop diverse capabilities as well as in making components for other industries, this pattern is of great concern.

South Africa's poor competitiveness and declining capabilities in the plastics sector is reflected by the sector's trade performance. In 2018, all but two segments were net exporters namely packaging (HS3923: containers, bobbins and packages of plastics) and bathroomware (HS3922) (Figure 4).

Figure 5: Net trade of plastic subsectors



Source: Authors calculations using TradeMap data

In the rest of the sectors there has been a decline in trade performance from around 2002. The argument that is often made is that South Africa's loss of competitiveness is due to the rise of China as an exporter. At a sub-sectoral it becomes clear that South Africa's loss of competitiveness is not just about China. Homeware (relatively less complex products) is the only sector that experienced high growth of imports from China, while for bumpers and parts thereof, plastics pipes, and baths and basins from 2003 to 2010, the largest imports were coming from other countries, led by Germany and, in the case of plastic pipes, Italy. Indeed, overall, imports from the EU and, in particular, Germany account for a large proportion of the increase in imports (due at least in part to the trade agreement with the EU which came into effect gradually from 2009 to 2012).

The concentration of exports in the plastics sector and implied failure to develop broad based competitive capabilities is consistent with the loss in competitiveness of the sector shown by the increased import penetration. In terms of product complexity, the export performance reflects a move backwards.

The analysis of the performance of the plastics sector has highlighted that the turning point in the performance took place in 2002/2003. We explore what may explain this turning point, as well as the performance over the period as a whole.

The change in 2002 appears to coincide with the change in the pricing policy of the local polymer suppliers. Though the pricing of the input may not be the only factor that led to the decline in competitiveness of sector, it is an important one considering the importance of polymers in plastic production. Raw materials, which are primarily polymers, account for over half of total production costs (Beare et al, 2014).

Unlike the other subsectors, bathroom wares are made from acrylates which are not produced locally and thus would not be affected by the pricing policies of local firms. In Bathroom wares, despite having to import the material input, South Africa has enjoyed a positive trade balance over the whole period with substantial exports having been to Germany and the UK, although with a shift to more exports to the Southern Africa region in later years. Exports of bathroomware declined significantly from 2008 and this reflects the change in tariff regime which led to the introduction of a 10% import duty on acrylates. This had the effect of increasing the cost of the input and appears to have had a significant impact on the international competitiveness of the subsector. The bathroom wares case is an exception which reinforces the overall picture and supports local polymer pricing as an explanation of turning point in the performance of the plastics sector. It is necessary to explore the issue of polymer pricing in more depth.

4 Technological change and production capabilities in the plastics industry

4.1 Technological changes in the international plastics sector

Digitalisation of the plastics factory

Digitalisation of the plastics factory bring about two benefits which include process monitoring and data management and process optimisation.[7] The factors that will lead to increased productivity include shorter setup and changeover times; reduced downtime, improved product quality and reduced energy consumption. Data from plastic machines has been collected and monitored for years now, however, the methods of collecting information were very inaccurate and slow this included excel spreadsheets, scanning barcodes, product information. The digitalisation of the process for example using a Manufacturing Execution System (MES) allows automated real-time and accurate data collection about machines and materials from different suppliers and different time periods. Digitalisation also has the added benefit that of connect plastics manufacturers with geographically diverse sites linking various locations using digitalized MESs. In one example, UK and Thai manufacturing sites were linked with development and sales centers in China, Japan and the United States using Enterprise Resource Planning (ERP) systems to coordinate the diverse systems so they now provide a unified, real-time view of productivity, capacity, inefficiencies and areas for improvement. This allows for optimisation of the shop floor and ensures that there is an efficient supply chain.[8]

Process optimisation through digitisations is often associated with a reduction in scrap rates, downtime and monitoring machines for predictive maintenance. This digitalisation is supported by a range of technologies including sensors installed in machines and other physical assets to collect real time data, this combined with cloud computing allows for complex data analytics and then through machine learning the processes can self-adjust to the observed conditions or notify operators to adjust the system and/or conduct maintenance.

This is important in the plastics industry as a machine that cuts down during a process can result in losses. For example, in most thermoplastic processes polymers are melted and then

[7] Interview with Plastic Omnium
[8] Interview with Plastic Omnium

formed into required shapes using a range of processes. If the machine cuts off during the process then one has to allow the machine to cool down, then remove the materials that were in the machine (in certain industries where re-grinds are not allowed this would be discarded at a loss) and then it takes approximately 3 hours to restart the machine again. Monitoring for predictive maintenance significantly reduced the downtime of the machine as well as the potential scrap from the process. Plastic Omnium estimates that process optimisation through digitilisation can result to increases in efficiencies to the order of 1,5% of turnover.[9]

Potential challenges that arise with digitalization include interoperability of technology platforms, connectivity and data ownership and security. In terms of interoperability, software development companies and machine manufactures are all creating data standards in isolation, which results in difficulties in integrating systems between suppliers, manufacturers and customers. To address this challenge, the European Machinery Association launched a common digital standard that allows machines from different companies to be able to communicate with each other.[10] The standard was developed for injection moulding machines and allows standardized communication between the machine and the MES. The association is currently developing standards for This is an important step forward as, interoperability is important to fully realise the gains from industry 4.0. The association is also working on

Digitalizing the production process makes it possible to capture and retain a detailed audit trail of production. This is enormously important for ensuring traceable safety standards, such as those that apply to toy manufacturing, right through to minute and provable compliance with stringent regulatory standards, such as those that apply to medical device manufacturing.

Design, material science and additive manufacturing for rapid prototyping and tool making

An important technological change associated with industry 4.0 is rapid prototyping and tool manufacturing. Industry 4.0 technologies allow for a more seamless integration of the design and prototyping process and also allows for a significant reduction in the time from idea to prototype. Additive manufacturing together with material science and virtual simulations means that prototypes can be printed in a few days compared to the previous process that took a few months.

Despite various interventions the level of tooling production and maintenance skills in South Africa has not improved significantly.[11] Very few plastics companies have been able to employ people that came out of the tooling initiative.[12] Firms have noted that manufacturing of tooling in South African is very poor, the local tools are more expensive than imports and the lead times are also very slow.[13] For example, a mould that can be manufactured in South Africa for $150 000 (US) with an estimated delivery time of one year while the same mould (in terms of specifications) can be sourced from Taiwan in two months for the same price.

Additive manufacturing for customization and production

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9 Interview with Plastic Omnium

10 http://www.plasticsnewseurope.com/article/20180508/PNE/305089999/euromap-unveils-first-digital-4-0-standard

11 Beare, M., Mondliwa, P., Robb, G. and Roberts, S. (2014). Report for the Plastics Conversion Industry Strategy. Research report prepared for the Department of Trade and Industry.

12 Beare et al, 2014.

13 Beare et al, 2014.

Increasingly additive manufacturing is being used for production of complex components as well as to create individualized, customized component parts as virtually a mass production process, along with shortened development, setup and start-up times. One good example of this is the smart addition of three-dimensional individualized designs on a piece-by-piece basis to deliver personalized products at mass-production speeds and costs. Injection moulding firms, in particular, are also using virtual simulation technology to examine flow simulation in extrusion dies, mainly to optimize process quality and reduce defects, which both have a considerable effect on commercial efficiency and customer satisfaction. As consumers become accustomed with the option to customize products this will become more standard in the industry. Additive manufacturing also introduces an interesting dynamic where products can be remotely printed close to the customer. This may potentially change the patterns of trade. Western countries such as the United Kingdom are leveraging this to support a strategy if reshoring manufacturing. Though this is not widely practiced at the moment it is possible and will likely gain popularity in the near future.

Evolution of plastic processing machinery

There has also been an evolution of plastic processing machinery in the last few years. First, the development in injection moulding machines to make them smart machines has changed the production process. For example, Engel launched Injection 4.0 to meet the demands of the ever-changing production environment. Injection 4.0 is premised on three things namely smart machines, smart services and smart factory. Under smart machines Engel seeks to improve the benefits to operators/manufactures by optimising production the machine by allowing the machine to self-learn, self-correct and ultimately improve precision. The smart machines are able to detect and monitor the injected material volume, control and automatically correct the holding pressure. This represents a solution to manufactures since it reduces wastages as a result of the interruptions of the machine and length of time it takes the machines to return to a rhythm. Importantly this improves the machine stability and guarantees that each product is exactly the same. All this is enabled by the use of sophisticated mathematical algorithms called the iQ weight control deciphers. Other elements of the smart machines that Engel has brought involves the use of machines that can achieve a consistent and efficient temperature control processes and use of intelligent clamp force optimisation. With Smart service the machines are linked to a server which will enable the extraction of information on the behaviour of the machine. This information will be used to detect machine breakdown, identify wear and hence reduce down times.

Smart factory is a whereby there is a central connector which monitors the whole production process with a manufacturing plant. TIG has developed this system which completely integrates all the machines at a manufacturing site. This helps in facilitating traceability of any faults, monitoring performance of each machine. Because of its interface which shows the performance it helps the manufacturer to quickly identify a problem and allow remedial action to be done promptly which minimises production delays.

Flow and temper flow monitoring results in reductions in in power consumption and reduces the risk of defective power.[14]

Second, twin sheet blow moulding machines which allow for the production of blow moulded products in one stage. For example, plastic fuel systems are increasingly produced using extrusion blow moulding. This has various benefits for the automotive industry including weight reduction for better fuel economy and lower carbon emissions. An average plastic tank weighs

[14] Interview with Greentech machinery, date.

on-third less than an average steel tank.[15] The plastics tanks are also more cost effective due to a combination of factors including design, and manufacturing flexibility for complex shapes, mechanical and chemical resistance, the quantity of materials used and plastic processing is undertaken at lower temperatures than steel. The twin-sheet blow molding system (TSBM) developed by Inergy Automotive Systems integrates components into a fuel tank during blow molding, reducing costs and emissions at the same time.[16] This technology could produce plastic fuel systems with more complex designs that will meet the strictest of performance and emissions standards. In the new process already in use in the BMW AG Series, sheets are extruded between a central core and a mold. Core actions attach the components during initial sheet forming. The empty core is withdrawn and the mold is closed to join the formed sheets in a second blowing step. Components that can be attached to the core include baffles, gauges, valves, jet pumps, lines, fuel modules and canisters. TSBM replaces co-extrusion blow molding, which requires boring and welding of externally mounted components. Weight savings could go up by 10% compared to conventional blow molding. The Twin-Sheet Blow Molding process allows improved wall thickness control. There is an additional 10% savings through component simplification and reduction in finishing costs. The most important standard right now is in California, which is requiring vehicles to reduce their fuel emission by a factor of ten, to fewer than 54 mg per vehicle/day.

4.2 South African technology responses

There appears to be some heterogeneity in the South African plastics industry's responses to the observed technological changes. The adoption of industry 4.0 technology advancement are currently in the high value segments of the plastics industry this includes automotive components, medical devices and engineering plastics. The packaging sector is also adopting these changes. Within these segments, firms that are part of multinational corporations (MNCs) and/or part of global value chains appear to be fast followers in terms of adoption and/or development of strategies for adoption. This is driven by the access to the MNC research and development and testing facilities which are often not located in South Africa and pressure on the supply chain to adopt from tier 1 firms in GVCs. An additional advantage of MNCs is the constant benchmarking of various businesses within the group to monitor and improve efficiencies.

4.2.1 The responses of local firms to technological changes and their ability to build technological capacity

The section on understanding firms' abilities to accumulate technological capabilities brought to the forefront the need to properly investigate three supporting capabilities, which together, contribute to ensuring the success of a firm's technological upgrading. These supporting capabilities are respectively a firm's investment, operational, and dynamic learning capabilities. Through a model based on work by Kumar et al. (1999), we can conceptualise how a firm can grow its existing technology infrastructure through technology transfers and the various supporting capabilities needed to ensure the successful adoption of the new technology.

[15] https://www.plasticomnium.com/en/automotive-equipment/auto-inergy-division/innovative-systems/plastic-fuel-systems.html
[16] http://atozplastics.com/upload/literature/Innovative-fuel-tank-twin-sheet-blow-molding-process.asp

This framework is then applied to gain insights into the levels of technological capability of South African plastics manufacturers whilst grounding our analysis on three specific points. Firstly, we focus on the current state of technological capabilities in South African plastic product manufacturers. Here we focus specifically on the investment, operational, and dynamic learning capabilities. Secondly, we examine the role of the broader ecosystem including government departments, institutions, and associations, in supporting technological upgrading in the plastic industry. Lastly, we investigate at a firm-level the governance characteristics that play an important role in determining the firm's willingness for adoption of new technologies.

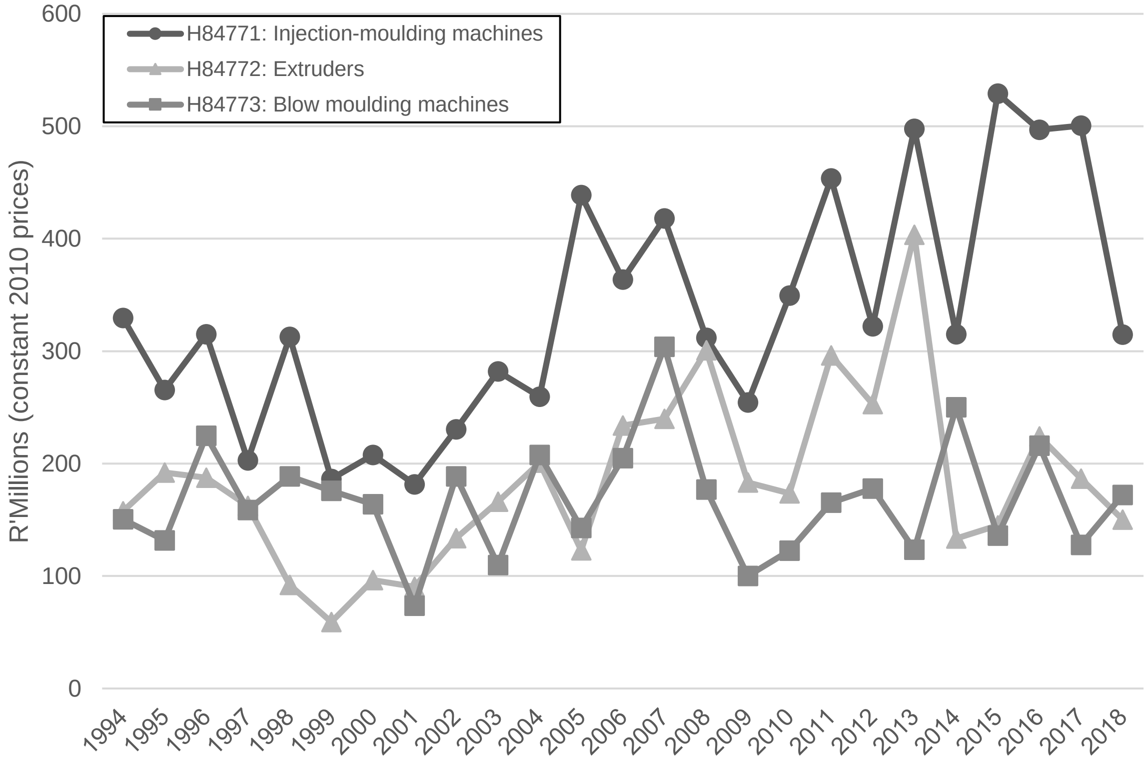
The current state of technological capability in South African plastic product manufacturers

Within the South African plastic industry there exists a large discrepancy between the size of firms and thus the quality and quantity of the technologies and machinery utilised in their respective production processes. A firm's technological infrastructure primarily consists of two components. The first being a physical component which comprises items such as the products, tools, equipment, machinery, blueprints, techniques and procedures used in a firm's production (Kumar et al., 1999). Secondly, there exists an informational component that complements the physical component. This informational component consists of the knowledge of the various physical components and extends to management, marketing, production, quality control, reliability, and skilled labour (Kumar et al., 1999). These will be discussed in turn.

On the physical component of technological infrastructure, we measure the age of equipment, the rate of investment in new machinery, and the origins of that machinery. The average age of machinery varies across the firms that were interviewed. Currently, the physical technological infrastructure of smaller firms operating in the plastics industry within South Africa is aging and lacks the modern machinery and equipment found in larger firms which are usually subsidiaries of multinational corporations (MNC).[17] The importation of technologies[18] by South African plastics firms is one route through which they can grow their technological capabilities. Over the past 28 years, South Africa's imports of plastics machinery in real terms has not grown much since 1990 (Figure ##). Specifically, the compound annual growth rates (CAGR) of these three types of machinery from 1990 are around 10% with the largest growth being in blow moulding machines. Injection moulding and extruders CAGR's are 8.87% and 6.33%, respectively. The growth of the demand for machinery is, however, dependent on the size of the firm's demand as well as where that demand has originated from.[19] This in turn affects the firm's decision of where to purchase such machinery.

[17] Of the firms interviewed, the smaller firms (Calibre Plastics and Plastinternational) machinery is significantly older than that of Rehau. Calibre Plastics has a mix of both older and newer machinery, with the oldest being in operation since 1979.
[18] We use the imports of plastic processing machinery as a proxy for investment in new machinery.
[19] For example, Calibre Plastics has seen poor growth in its turnover in the last three years. This has resulted in Calibre Plastics warehousing much of its stock because of the marked decrease in large orders by many of its cusomters. On the other hand, Rehau has seen significant growth in its sales owing to the role the Automotive Masterplan has played in the development of the South African automotive supply chain.

Figure 6: Imports of Plastic Machinery into South Africa, 1994-2018



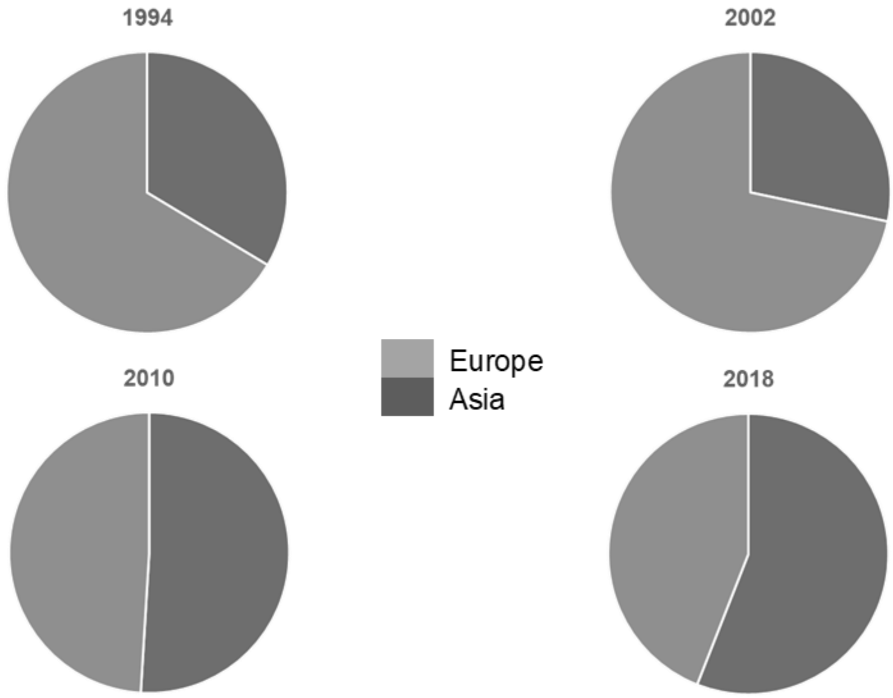
Source: Author's Calculations

Notes: Based on data from Quantec and World Bank Development Indicators

The range of machinery from which South African plastic injection moulding companies can choose is vast and varied with each supplier offering differences in the price, precision, lifespan, and adaptability options of each machine. At an aggregate level, South African imports of plastics machinery from Europe and Asia have changed drastically over the past 25 years (Figure ##). The data shows that South African firms have shifted their preferences away from European machines and towards Asian machines. This possibly is due to the types of products which the South African firms interviewed are producing. For example, Plastinternational has a mix of Asian and European sourced machinery with which it manufactures different standards of products. Calibre Plastics' product range is such that the purchase of expensive European machinery is unnecessary given the lack of enforced standards of the products many of its customers demand. Furthermore, Chinese firms tend to dominate Asian plastics machinery exports into South Africa while from a European perspective, South African firms import mostly from Italian and German manufacturers given their quality and extensive experience in the manufacture of plastic machinery.[20]

[20] Based on data sourced from Quantec.

Figure 7: South African Imports of Plastics Machinery from Asia and Europe[21]



Source: Author's Calculations

Note: Data sourced from Quantec

The high cost of the machinery used in the production process of plastic products is a major hurdle for many South African firms to expand their technological capabilities and infrastructure. Thus, many smaller firms do not have the financial resources with which to invest in newer technologies. Yet despite this, European machines are preferred by most of the firms however, these machines tend to be much more expensive than Chinese equipment.[22] The interviews revealed that European machines also are of higher quality and yield better precision and last for much longer. As a result, firms engaged in high-volume, low-value production show a greater affinity of purchase the cheaper Chinese equipment. [23] For instance, of the 42 machines in operation at Calibre Plastics, approximately one third of them are purchased from ENGEL, an Austrian-based supplier;[24] while the rest are sourced from China.

For the informational component, we look at systems and software that firms are utilising to aide them in their production processes. For our understanding and given the philosophy surrounding production in the 4IR era, it is interesting to examine how the informational infrastructure integrates with the physical. The idea of a firm in the 4IR era is one that combines a combination of software, additive manufacturing, real-time data analysis, and centralised control operations into its production processes in order to achieve greater levels of

[21] The machinery included are Injection-moulding machines (HST847710), Extruders (HST847720), and Blow-moulding machines (HST847730).
[22] However, Calibre Plastics noted that these machines are used for lower quality, mass-produced items.
[23] Calibre's demand is such that all of its higher-end products requiring a greater level of precision can be produced with the 14 machines of that are more precise that the lower precision machines.
[24] Interview with Mr Heinrick Sullward, CEO of Calibre Plastics (Pty) Ltd on 16 May 2019.

productivity and efficiency. These systems include the use of computer-aided design software as well as the integration of additive manufacturing techniques, for example, 3D-printing. The effective use and integration of the informational infrastructure within smaller-scale plastics firms offers an avenue for cost-competitiveness and shorter lead times from design to manufacture.[25]

Likewise, the adoption and use of proprietary software which enable firms to easily control their physical infrastructure in one centralised location with a continuous feed of data and metrics. This gives a firm a real-time birds-eye view of their production and allows them to make changes immediately in order to minimise wastage and ensure that standards are upheld.[26] A hurdle for many firms is the costs involved in procuring licences to use these informational technologies as well as the costs of purchasing additional physical infrastructure like 3D printers.[27] Of the firms interviewed, all utilised computer-aided design software in the production of moulds. This enabled the firms to quickly design and manufacture moulds for prospective customers rather than having to outsource these services and leading to larger costs and loss of business due to longer lead times.

Additionally, larger firms may seek to realise efficiency gains through the adoption of a smart factory initiative which as mentioned above represents the full automated integration of a firm's physical and informational infrastructure. An example of this is Rehau's possible adoption of Siemen's Opcenter system as a replacement for their current legacy system in many of their factories.[28] The Siemen's system would provide a holistic view on a firm's manufacturing enabling the complete digitalisation of Rehau's manufacturing operation.[29] However, given the current manufacturing environment in South Africa the acquisition of an expensive systems unfeasible. This is echoed in Monaco et al. (2019) who note that the domestic and regional markets are not at the scale required for an expensive upgrade in order to integrate their physical and informational technological infrastructures.[30]

Continuous incremental advancements in both the physical and informational technological infrastructure is a way for South African firms to realise a more cost-effective and complete manufacturing processes. However, it appears as if smaller-scale South African plastic product manufacturers, unlike their larger, MNC-linked competitors, face a paradox. One where they desire to grow their scale and utilise the latest technologies but are unable to due to their current level of technological capabilities and other external factors. Thus, at this point it becomes important for us to understand a firm's level of technological capabilities and what enables its growth. The following discussion will delve deeper into the capabilities that are vital for supporting the growth of a firm's physical and informational technological capabilities through the lens of the capability view of the firm.

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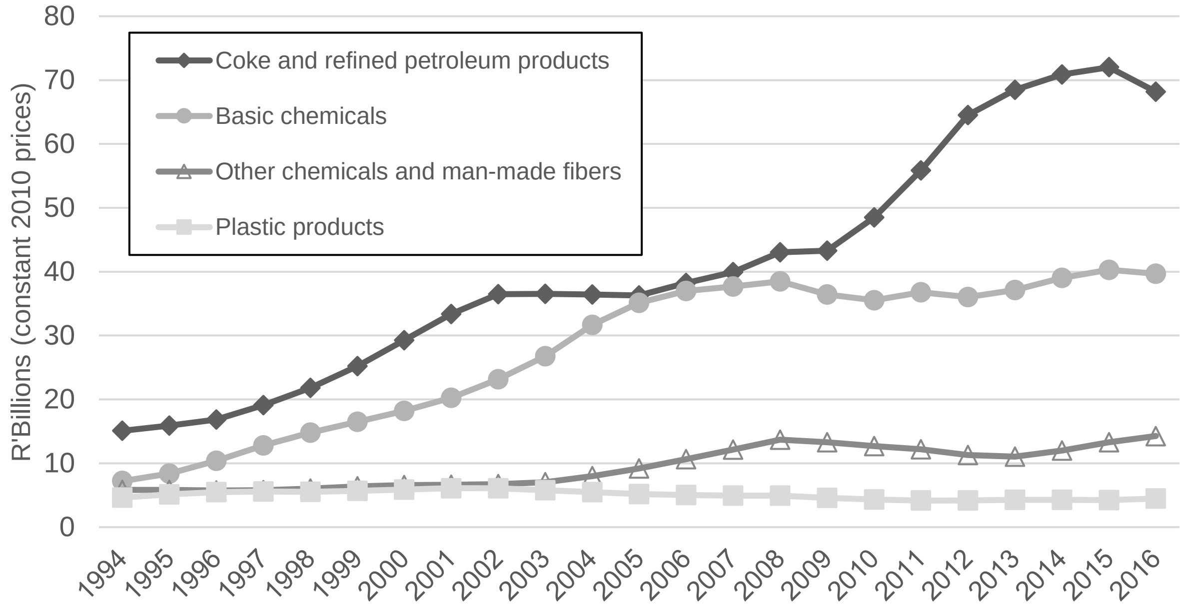
[25] One firm, Plastinternational, spoke about its desire to integrate 3D-printing with its CAD software as part of a full-service package vision that it hopes to offer its customers.
[26] Neither Plastinternational nor Calibre Plastics had investigated the adoption of such software given their small scale and types of products they produced, which from their perspective makes the adoption of such software unnecessary.
[27] For example, the MasterCAM software costs Calibre Plastics approximately R180 000 per annum. Additionally, 3D printers can range from R8 000 to over R70 000.
[28] Interview with Andrew Meikle, plant manager at the Port Elizabeth branch of Rehau.
[29] https://www.plm.automation.siemens.com/global/en/products/manufacturing-operations-center/
[30] To further this point, the cost of proprietary software packages that can link multiple machines from one supplier providing the firms the ability to centralise their data-driven operations and manage their production with real-time data and analytics can cost as much as R500 000

Investment Capabilities of South African Plastic Product Firms

The investment capability of a firm is defined above as the skills and information required to identify investment projects and purchase suitable technologies which contribute to a firm's level of technological capability (Bell, 1987; Lall, 1982; and Wei, 1995). While the strategy of the management team is important in identifying risks, opportunities, and goals for a given investment, it is abstract and hard to measure. A firm's investment capabilities can be discussed more specifically in terms of the firm's ability to purchase new machinery given the resources at its disposal. Resources, in this sense, represent the ability of the firm to purchase new technologies and the factors that may hinder their ability to purchase certain machinery and thus keep them tied to a specific level of technological capability.

Over the past 24 years, the downstream plastic products sector has reported substantially lower investment in production capacity compared to the upstream (Figure ##). While it is expected that the upstream industries will have substantially higher investment in fixed capital due to the capital-intensive nature of production, the downward trend of the plastics sector relative the others is alarming. It highlights the aging and stagnant levels of technological infrastructure within many plastic manufacturers. Average investment rates in the plastics sector have also been poor relative to overall manufacturing. On average over the period 2002-2014, investment rates were only 13% of value add for plastics, compared to manufacturing at 26%.

Figure 8: Changes in production capacity (machinery & equipment), 1994-2016



Source: Quantec data

A major hurdle for the expansion of the plastics industry are rising input costs (Beare et al, 2014).[31] This is because they directly affect a firm's profit margin and therefore its investment capability. This can be observed through the varying performance between the high value and low value products. Engineering plastics tend to be of higher value and have performed much better than the low value products such as the domestic ware but come at a greater cost. For firms in this sector, energy efficiency plays an important determining factor in the decision

[31] This was confirmed by the interviews.

about whether to invest in new technologies. Newer technologies are typically assumed to be more efficient in terms of their energy consumption. The cost of electricity to run a power-intensive[32] operation such as plastic product manufacturing is a contentious issue and a common complaint among the firms interviewed.[33]

The age of the technological infrastructure also strongly influences the energy consumption of the firm.[34] Older machines also pose an issue for firms as they require more maintenance.[35] Investing in machinery with the latest technology can reduce the energy consumption of a firm.[36] The high costs of the latest technologies hinder firms in their attempts to grow their scale and take advantage of the reported electricity-savings through the implementation of newer, more-efficient machinery.[37] This cost sensitivity of many firms means that firms in the sector likely weigh-up the demand for high precision products versus capability of their current infrastructure.

The capabilities view of the firm emphasises the fact that capabilities do not develop merely through the purchase of technologies (Teece, 2017). Rather, they are the result of value creation activities such as search, learning, research and development and operational capabilities. Thus, a multi-faceted understanding of a firm is key to understanding how firms can grow their technological capabilities. As such the next two subsections examine the operational and learning capabilities of the firms.

Operational Capabilities of South African Plastic Product Firms

The roles played by management and people within an organisation, along with their requisite skills, lies at the heart of the performance of any enterprise (Augier & Teece, 2009). Operational capabilities are the “secret ingredient” in explaining the creation, development, and maintenance of competitive advantage (Wu, et al., 2010). The traits of operational capabilities are also distinct to this capability set. Thus, the focused development and acquisition of these traits has the ability to create barriers to imitation, which makes them a potential source of competitive advantage.

In a lot of instances, smaller firms often lack the operational capabilities, understood as the skills needed to operate, maintain, repair and adapt technologies in order to increase production and efficiency (Kumar et al, 1999). For instance, the firms that have their own tool rooms even if just for maintenance of tools were performing better than those that did not. Though firms can outsource tool maintenance, there are efficiency gains from having internal tool maintenance including the aforementioned faster turn-around times. In terms of tool making, the plastic industry has seen a marked decline in the number of toolmakers resulting

[32] The sector is highly energy-intensive, as almost all conversion techniques involve heat generation and transfer, together with cooling cycles (Who Owns Whom, 2018).

[33] Rehau’s factory operates on a 24-hour cycle for 6 days a week resulting in a monthly electricity spend of approximately R1.8 million.

[34] The average age of the machinery at Calibre Plastics is 10 years. Rehau’s machinery’s average age is 6 years.

[35] This becomes more problematic as the machinery gets older because of greater inefficiencies which uses more electricity.

[36] Calibre Plastics has investigated the possible introduction of servo-motors into its operations due to its advertised energy efficiencies. However, the firm believes it is doubtful that servo-motors will produce the efficiencies that are purported and hence the company has decided to not pursue this route.

[37] The cost of ENGEL machines, as one noteworthy example, can range from $180 000 to as much as $500 000 (Monaco, et al., 2019).

in a severe shortage. The few toolmakers that do remain and are experienced enough to deliver quality products are able to charge a high premium for their services and have long waiting periods.[38] The waiting periods are so long that it is often faster to import the tools. Larger firms are able to internalise these processes allowing them to reap substantial cost savings which affords them the ability to price their products competitively.

Firms can purchase moulds from international companies that offer this service. However, due to the distance and time to go through iterations of changes and edits, many firms will continue to struggle to compete with firms that have internalised these services. An investment in a skilled toolmaker presents a real possibility for realising capability gains and reduced lead times for new customers who might require customised moulds. It further highlights the need for a firm to invest in operational capabilities as much as new technology as operational capabilities are a foundational aspect of the successful adoption and growth of their technological capability.

The above discussion on the importance of skills for a firm's operational capabilities as well as the apparent lack of necessarily skilled labour represents a major problem for the development of a firm's technological capabilities. Firm's reported issues regarding the proper skilling and training of workers from various colleges and training institutions. This disconnect between firm's skills requirements and the level of education currently being taught at these institutions hinders the firms' ability to develop sufficient operational capabilities.[39] However, it is not merely sufficient for a firm to possess the resources and skills needed operate advanced technologies so as to realise growth in its technological capabilities. A firm must also be able to combine both its investment and operational capabilities is such a way so as to realise the third supporting capability. That is the ability to continually learn through their experiences.

Dynamic Learning Capabilities of South African Plastic Product Firms

Dynamic capabilities were originally defined as those that enable the adaptation to external environment characterised by rapid or discontinuous change (Teece, et al., 1997). More simply, dynamic capabilities can be thought of as those capabilities that enable a firm to alter how it currently earns its income. While there are some overlapping aspects with both operational and dynamic capabilities, they differ in their purposes and intended outcomes (Helfat & Winter, 2011). Therefore, we view dynamic capabilities as being a firm's capacity shape its market in ways that lead to the creation and capture of value (Teece, 2010).

More specifically, the process of dynamic learning should be viewed as an on-going set of activities which represent a firm's dynamic capabilities (Teece, 2007). The process is divided up into three parts. Firstly, a firm continuously needs to be engaged in a process of identification and assessment of potential opportunities. This is thought of as *sensing*. Secondly, the firm must mobilise its resources to address the identified opportunity so that it can capture its value. This is known as *seizing*. Thirdly, a firm is required to continually renew its existing capabilities, known as *transforming*. Additionally, dynamic capabilities may also require a requisite assortment of operational capabilities that, when combined correctly, enable the discovery new technological capabilities.

The channels through which dynamic learning capabilities become apparent depend on each firm's individual desire to innovate and seek out niche markets. Through a combination of

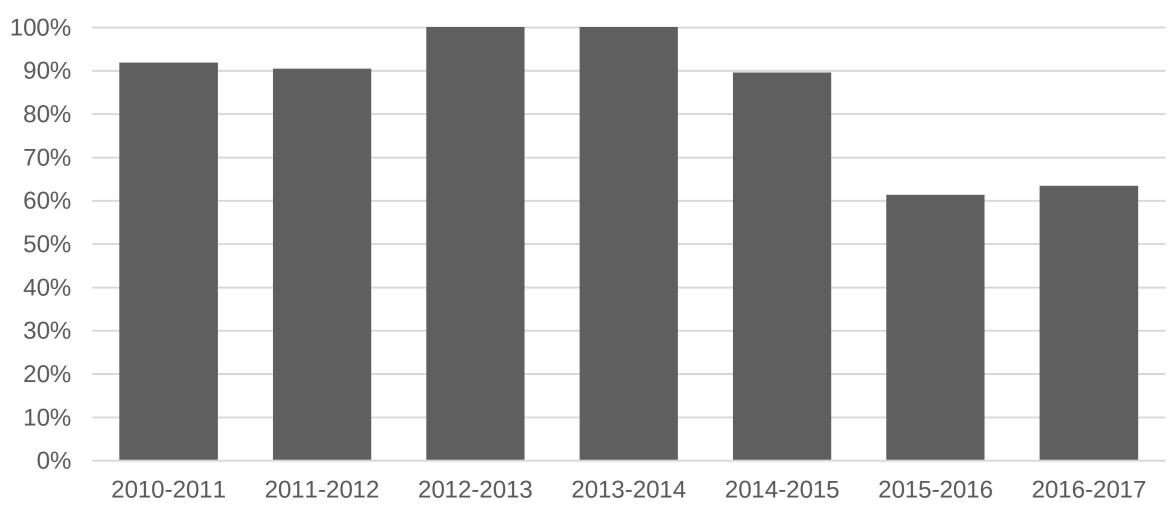
[38] Interview with Rupert Develing from Plastinternational, 31 May 2019.
[39] This is more thoroughly discussed in the next sections.

sensing, seizing, and transforming, firms can utilise their dynamic capabilities to realise niche market benefits. However, it can be argued that the ways in which an individual firm chooses to make use of its dynamic capabilities is heavily dependent on how well established its operational capabilities are. For example, Plastinternational's management team has over past 20 years, perfected their proprietary product line called *EzeeFlow™*. The *EzeeFlow™* range are the only plastic ball valves in South Africa that meet SANS 16135 specifications.[40] How this product came into development was through the firm's research and development as well as the identification of and seizing on a gap in the market. This ability to seek out gaps and opportunities is strongly linked to a firm's operational capability and the management team's commitment to transform its production in order to catalyse on niche markets.

There exists a beneficial relationship between a firm's dynamic capabilities and its ability and willingness to conduct research and development in order to boost its performance (Babelytė-Labanauskė & Nedzinskas, 2017). However, it may not be that a firm that exhibits the ability to dynamically alter its capabilities will automatically engage in behaviour and tasks that enable innovation and research and development. South African firm's need to ensure that they can organise and channel the correct amount of resources in the correct way into successful innovation. This is because South African firms also tend to be less concerned the quality of their R&D opting for short-term solutions to problems rather than fully investing enough time and resources into building strong R&D capabilities like many European firms (Garisch, 2016).

Furthermore, expenditure on R&D by the South African petroleum, chemicals, rubber and plastics sector is strongly influenced by the presence of SASOL. The below figure shows how little R&D expenditure is originating from more downstream industries in this sector. It echoes the experiences of South African plastic product manufacturers in that there is little to no money spent on innovative technologies and upgrades to their existing technological infrastructure.

Figure 9: Proportion of R&D Expenditure in the Petroleum, Chemicals, Rubber and Plastics sector by SASOL, 2011-2017



Source: SASOL annual reports and HSRC Annual Reports

40 Interview with Rupert Develing from Plastinternational, 31 May 2019.

Notes: For 2012-2013 and 2013-2014, SASOL's reported R&D expenditure was over the reported figures for the entire petroleum, chemicals, rubber and plastics sector (126% and 123%, respectively). This may be in part due to differences in the financial year-ends of both SASOL and the HSRC and the way in which both organisations report these figures.

One way downstream plastic product manufacturers can realise dynamic capabilities and R&D capacity is through an acquisition or joint venture with an innovative firm. Many plastics producers in South Africa possess similar capabilities unless they are part of a larger MNC. Hence, South African plastics manufacturers may seek out partnerships, less to boost their technological capabilities, and more to help each other in terms of scale.[41] Similarly, South African firms struggle with conducting innovative research. For example, Rehau, because of its standing as an international firm, houses its R&D and material science departments in Switzerland. This is due to there being greater engineering skills in Europe compared to South Africa.

Likewise, factors external to the firm may just as strongly affect its desire to innovate. If a firm operates within an industry whose margins are constantly squeezed by competitive forces, the need for growing its capabilities is much greater. Therefore, it becomes imperative for firms and associations to partner with institutions on product and materials development. However, the South African plastics industry appears to be unwilling to invest in innovative, forward-thinking research rather focusing its time and resources on practical solutions that are achievable in the shortest time possible. In contrast, plastic industries in Europe tend to be more inclined to create and sustain cultures where collaborative knowledge generation networks that support the strong and continuous growth of R&D that keeps these industries at the forefront of technological capabilities (Garisch, 2016).

The development of collaborative knowledge generation networks can mitigate the risks of research and development projects. Such partnerships are not difficult to identify. For instance, the City of Johannesburg is uniquely placed to foster the growth of such a network due to it housing a large number of engineering plastics firms. Furthermore, this cluster of firms is closely located to top research-focused universities (CCRED, 2016).[42] This makes it easier to facilitate a robust working relationship and will allow for easy flows of information between firms and universities. Evidence shows that knowledge partnerships with firms and institutions are key to the success of many European industries. Following the European model, the South African plastics products sector can combat its skills and research deficit through the creation of centres of excellence that are dedicated to R&D, learning, and skills development.

Continuous learning, and development of dynamic capabilities on the part of firms is crucially connected to the strength of the operational capabilities discussed above as well as the business ecosystem that surrounds it. Such learning is important for the development of technological capabilities of plastics firms in South Africa. The next section will investigate critical insights in how business enterprises work and what role public policy plays in shaping and assisting the enterprises' development within the framework of the broader business ecosystem.

[41] This was noted in the interview with Calibre Plastics whose factory is located within close proximity to three competitors. Calibre Plastics and the other firms share workload on large orders where one firm is unable to complete the order in the given timeframe.
[42] These are the University of Johannesburg and the University of the Witwatersrand.

4.2.2 Role of institutions and the broader business ecosystem

Firm-level innovations and the technological changes do not take place in isolation but rather through an array of interdependent processes and structures both internally and externally driven (Kaziboni, et al., 2018). This interdependence is critical in production and technological upgrading because the adoption of new technologies is dependent on complementary changes in a firm's environment. Institutions play a vital role in nurturing and developing firms through the provision of support and training, both technical and managerial (Engerman & Sokoloff, 2008). Institutional support is often conceived as being a combination of roles which include government, industry associations and other stakeholders. Together these form a network of public and private stakeholders (the broader business ecosystem), which enables the environment under which firm growth and development can occur (Monaco, et al., 2018).

In this section, the focus is on the role of institutions and the broader business ecosystem in facilitating technological change and development of production capabilities in the plastic industry. The existence of these various stakeholders and networks ground firms within an ecosystem of interdependent technology decisions (Adner, 2006). This formation of an ecosystem emphasises the need for firms to move beyond the traditional industry silos and form into networks focused on the creation of new opportunities for innovation and technological capability growth (Kelly, 2015). The concept of ecosystems is premised on the influence that various firms have on each other, namely in the way in which they compete and collaborate, share resources and information, and co-evolve (Adner, 2006). A distinctive characteristic of an ecosystem is that it has the ability to achieve goals which are beyond the scope and capabilities of any individual actor or group of broadly similar actors (Kelly, 2015).

One of the approaches embedded in the ecosystems framework are business ecosystems (Moore, 1996). The business ecosystems approach is concerned with interdependencies across public and private players and the activities, value networks, supply chains and technology systems that exist within it (Adner, 2017). The use of the business ecosystems framework is fundamentally for our understanding of the success of leading organizations. It allows us to view the strategies, business models, leadership, core capabilities, value creation and capture systems, and organizational models of each firm in terms of its role within the broader business ecosystem. We utilise this thinking and apply it to the questions of how individual firms can facilitate technological change and development of production capabilities in the plastic industry given the existence and role of the business ecosystem.

To facilitate technological change and development of production capabilities in the plastic industry we focus on three key factors that support technological upgrading and the development of technological capabilities. These are access to capital, the skills to work with the new technologies, and the existence of supportive innovation systems. These three factors are discussed below drawing from the policy documents of government, plastic associations, universities, research institutions, and development financiers and is supplemented with data from interviews conducted with firms in the industry.

Access to Capital

Businesses and firms require capital to fund the acquisition of the latest technologies that are able to build upon the firm's technological capabilities and improve its competitiveness. This is in line with the assertions by Fagerberg et al, (2010) that the process of upgrading capabilities requires an upgrading of existing capabilities and this can only be achieved if the necessary capital is available. However, they appears to be a lack of general financing options (internal and external) available to firms which presents a stumbling block for the growth of their capabilities.[43] The South African government has recognised the role that the proper access to capital can play in stimulating industrial upgrading and competitiveness.

Through the Industrial Policy Action Plan (IPAP), the government has developed incentive programmes drawing on public and private-sector sources of funding, to support the growth and diversification of the manufacturing sector. The objective of this funding is aimed at facilitating the adoption of technological infrastructure appropriate for the challenges of 4IR. The targeted support in the acquisition of the latest technologies can improve a firm's efficiency and scale. Yet, as mentioned above many firms are not at the size where such revolutionary investments make financial sense. However, the current landscape of the plastics industry in South Africa still necessitates the need for greater targeted access to capital as a means to the general expansion and upgrading of the technological infrastructure of many firms in line with global standards and best practices.

The Industrial Development Corporation (IDC), which is the major source of dedicated industrial financing in the IPAP incentive programme, disbursed R9.1 billion[44] (with an estimated R3 billion [45] directed to the plastic industry) in the 2016-2017 financial year. However, there are issues with such government support initiatives and institutions. Chief among them is the bureaucratic application processes, delays in granting of the financial support, and the general lack of awareness of the various schemes available to the firms.[46] These issues highlight the key role of industry associations in ensuring that firms are aware of such initiatives and perhaps providing a dedicated team of personnel directly responsible for assisting firms in their applications from start to completion.

Furthermore, regulatory restrictions and red tape have a more detrimental effect on small firms in their quest to access government support in comparison to larger firms who have the support structures and investment capabilities. Therefore, the roles of government and industry institutions as well as the broader business ecosystem should be to remove restrictions that hinder firms' access to capital for the acquisition of technological capabilities. The unsatisfactory progress with many of the IPAP interventions[47] to date highlights the coordination challenges and fragmentation of the state and its various governmental departments.

Skills to work with the new technologies

The second requirement from a business ecosystem to support technological upgrading are having the necessary the skills to operate new technologies. Until now, the general lack of

[43] See above section on investment capabilities.
[44] Industrial Policy Action Plan 2016/17 Annual Report
[45] Industrial Development Corporation 2017 Annual report.
[46] Plastinternational participated in the DTI's discretionary grant programme in 2012 which allowed them to purchase 4 machines and recoup 30% of the total cost. They also applied to be a part of the MCEP initiative but were not granted funds due to shortfalls in the funding.
[47] A list of IPAP interventions in the plastic industry is inserted in the appendices

skills to meet the demands of technological upgrading represents a critical stumbling block to the competitiveness of the plastics industry. At a national level, there exists a noticeable skills gap as old-school artisanal skills exit the economy with no new group of suitably-equipped artisans are entering the labour market. This may be due in part to the fact that artisanal work has lost its appeal among the many youths. Through the IPAP, government with other institutions such as Plastics SA, provincial economics departments and academic institutions have envisaged the development of a testing and innovation cluster so as to develop the much-needed skills to match the requirements of the industry.

Plastics associations have a key role to play in this regard. For example, Plastics SA offers a wide range of services which include: leadership skills, business skills, sales and marketing, industrial relations, health and safety for firms in the plastic sector.[48] In line with its mandate, Plastics SA has proposed an initiative termed the “Plastics Industry Innovation and Skills Cluster” whereby three components are to be focused on. The first being skills development to address the deficit of skills facing the plastics industry and to develop artisan-level skills (CCRED, 2016). This is in response to the decline in the skill-level of the average worker in the plastics industry. Secondly, there is a strong focus on research and development which is recognised as a key reason for the continued success of European industry. Lastly, is testing. This is key given the aforementioned short-sightedness of many South African plastics manufacturers in dealing with structural issues plaguing their firms and the industry at large.

International experiences reveal that countries with successful plastic industries have managed to grow them with the assistance of associations that are at the forefront in spearheading skills development aligned with the latest technologies. For instance, the Plastic Institute of Thailand is responsible for supporting the long-term skills development of Thailand's plastics industry through the sharing of information and workshops reflecting on experiences with the applications of 4IR technologies as well as their adoption of the smart factory model into their enterprises (Monaco, et. al 2019). Such initiatives are vital in supporting technological upgrading are the skills to work with the new technologies.[49]

Supportive innovation system

A supportive innovation system encapsulates the third requirement from a business ecosystem to support technological upgrading and capabilities development. The innovation systems approach is grounded on the idea that national systems of innovation are open systems that contribute to developing capabilities and local competitiveness (Bell, et al., 2018). Evidence from Europe identifies the existence of industry-wide research and development culture in support of product innovation. This is lacking in the South African context. This lack of a systematic research and development-based approach has been attributed for eroding sustainable and competitive product innovation in South Africa.[50]

As mentioned above, in many Europe countries collaborations between higher education and research institutes are the lifeblood of an innovative plastics industry. They achieve this through the establishment of collaborative knowledge generation networks. These

[48] Plastics SA represents the plastics industry in South Africa, including polymer producers, converters and recyclers
[49] However, Plastics SA asserts that issues relating to technological upgrading are not a priority at the moment in South Africa thereby incapacitating most of the progress on the Innovation and Skills Cluster. Because of this the initiative has been side-lined as Plastics SA focuses its efforts on waste reduction.
[50] MerSeta report 2016

partnerships also assist in dealing with the challenges around demand and supply of the labour force. The higher education and research institutes help educate and skill the next generation of the labour force to meet the needs of the industry and bridge the gap in the technological upgrading process. This can be through the adoption, research, testing and training in the latest machinery and materials science. The establishment of an innovation system will go a long way in assisting firms in the development of technological capabilities.

In South Africa, public institutions are both followers and leaders in terms of additive manufacturing and material science (Kaziboni, et al., 2018). There are also limited facilities to test new technologies in South Africa. Firms typically wait for technologies to be tested in Europe first and then adopt.[51] Despite this, South Africa is considered to be a late adopter of additive manufacturing technology, both the public and private sectors have built a viable additive manufacturing market in the country. One focused on collaboration and continuous innovation.[52]

Between 2014 and 2018, the country's public institutions invested approximately R358 million in 3D printing technology research and development.[53] The Vaal University of Technology in Gauteng, the Central University of Technology in the Free State, and the Rapid Product Development Laboratory in Stellenbosch all have additive manufacturing facilities that are open to firms for prototyping and production services. However, the take up of these services by industry has been slow and there is a need to review the reasons behind this.[54] The typical university governance structure tends to be bureaucratic which does not support the flexible arrangements required for various partnerships with industry (Kaziboni, et al., 2018).

With regards to material science, the Council for Scientific and Industrial Research (CSIR) has extensive research and industrial capabilities. These range from polymer formulation and additives, to testing facilities, bio-plastics development and encapsulation. There is also research on fibres and composites, additive manufacturing materials and techniques, governance on waste and recycling capacity development, and enterprise development. The support for these initiative stems from the efforts of Department of Science and Technology (DST). The focus going forward should be on marketing these services to industry and consideration should be given for discounting to small and medium forms that be not be able to afford the full cost of the services offered.

The success of the initiatives of the DST to contribute to the development an innovation system for the plastics industry is commendable. However, there appears to be a general lack of understanding of where the development of such a system should come from. It is usually understood that innovation systems are interactive and occur in organised systems and broader societal arrangements (Bell, et al., 2018). However, the above-mentioned fragmentation of the South African state continues to hinder the successful development of such a system with governments departments seemingly pulling in different directions resulting in a divergence in policy focus.

[51] Interview with Diemaster, 17 September 2018.
[52] https://3dprint.com/147991/south-africa-3d-printing/
[53] https://3dprint.com/147991/south-africa-3d-printing/
[54] Interview with VUT, 24 October 2018

5 Challenges faced by South African convertors and policy recommendations

Internationally, the adoption of automation and digitalizing plastic production systems has been estimated to create production productivity gains equivalent to between 6.3% and 9.8% of annual revenues.[55] In South Africa, this would translate to between R4,79 billion and R7,45 billion based on 2017 total convertor revenues.[56] However, due to slow uptake of adoption of the technological advances South Africa is yet to realise these gains. Most South African plastic convertors continue to use old machines averaging at approximately 18 years in age and this makes it difficult for them to be integrated with the latest technological advancement such as automation.[57] The poor investment in up-to-date machines is due to a combination of factors. First the machines are relatively expensive and the industry is mostly made up of small and medium enterprises with very few large firms. The recent machines can cost up to R7 million rand per unit.[58] The Industrial Development Corporation (IDC) launched a special scheme to assist the sector to upgrade machinery and equipment in 2019. The funding scheme is to the value of R500 million to invested in the sector over a 5-year period. The scheme will provide debt and equity-type finance at reduced return requirements, to support the sector's re-industrialisation and adjustment. The debt component of the scheme attracts the prime interest rates for most firms and prime minus 1% for firms owned by black industrialists as well as women and youth-owned enterprises. The equity instruments is based on a real after tax, internal rate of return of 6%. The scheme is better that typical IDC debt which is typically charged at prime plus approximately 3% (Bosiu and Goga, 2019).

Second, the local industry is typically characterised by low margins making it difficult for firms to accumulate sufficient capital to reinvest in the business.[59] This goes back to the issues raised earlier about the high cost of polymers. This is something that needs to be addressed urgently. The IDC's scheme alone may not be able to turn around the performance of the industry and as such complementary measures are required.

Third, generally the production volumes are relatively low which does not allow firms to benefit from economies of scale enjoyed by firms in Thailand or China for example. Firms also noted the fluctuation of the exchange rate and political uncertainty as undermining investment decisions.

In terms of upgrading to a complete smart factory system, Greentech Machines has only sold two TIG systems in South Africa and these have not yet been fully installed. Of the smart machines sold by Greentech into the South African conversion industry 60% to 70% have been to the automotive industry and the rest to packaging, medical, electronics and technical moulding.[60]

The estimated productivity and efficiency gains from adopting industry 4.0 technologies means that if South African firms do not invest in upgrading their technologies there is a real risk that the industry will further lose competitiveness. The South African plastics industry still has some

[55] Siemens. 2017. SFS-Whitepaper The Digitalization Productivity Bonus Plastics. [Online]
[56] Calculations based on Plastics SA estimates of convertor turnover at R76 billion. See Plastics SA 2016/17 Annual Review.
[57] Interview with Grentech machines. Also see Beare *et al* (2014) for state of machinery in the plastic industry.
[58] Interview with Greentech
[59] Beare et al, 2014.
[60] Interview with Greentech Machines

way to catch up with regards to technological changes in the industry. The biggest technological disruption in the industry so far has been the digitalization of the factory including integration of systems through the supply chain and condition monitoring and predictive maintenance. A strategy to support adoption in this industry has to start with capital upgrading of machinery and equipment. Though there are concerns about the environmental impact of plastics, demand for plastic products are estimated to grow and in the automotive industry plastic is replacing other materials and supporting light weighting and compliance with carbon emissions. The technologies supporting the fourth industrial revolution are enable future proofing investment in the industry. Increasingly, Tier 1 manufacturers are expecting Industry 4.0 technology to be filtering down throughout the tiers of their supply chains to support ever leaner manufacturing processes. Failing to match their pace may result in top-tier manufacturers looking elsewhere for future contracts.[61]

These changes will lead to a recompositing of the skills mix that is required by not just plastic firms but also manufacturing more generally. Firms and institutions have reported the need for more and better quality engineers. Digitalization of the production process has had varying impact on skills requirements. In some instances, digitilisation, integration and machine learning requires that the skills level required from a machine operator is lower as all measuring and analytics is taken over by the system. In other instances, the upgrading of systems required higher skills to be able to engage with and set the machinery.

Creating a culture of collaboration through clustering and benchmarking. Adoption of the technologies alone are not going to automatically result in the productivity and efficiency increases described above. The company culture is also important in ensuring that the new technologies are fully utilised to realise the maximum gain and that firms are using and responding to data, moving from a reactive to a proactive stance. This can be spurred through clusters and benchmarking of firms. The benchmarking can be required as a condition for firms that have secured finance for adoption of technology from government including agencies. So far we have observed that the firms that are part of MNCs and are benchmarked against other firms in the group and those segments that are part of global value chains where tier 1 firms require suppliers to adopt technologies are those that are adopting the

Review of training, skills development and re-skilling of employees. The skills set required for industry 4.0 is changing. Interviewed firms and institutions emphasized the need for process and mechatronic engineers and the overhaul of supply chain management curricula. The complaints are that the process engineers that are graduating from South African institution are not comparable to their international counterparts and there is a shortage of mechatronic engineers. Industry 4.0 has also significantly changed the supply chain management within industry and the curricula needs to be updated to reflect these changes. Training and reskilling of employees will need to focus on improving interpretation, modelling and decision making using big and small datasets.

Making public-private partnerships work in additive manufacturing and robotics. There is also a need to support the public and private partnerships in order to maximise the benefits from the public investment in technologies such as 3D printing. The public facilities such as VUT, CUT, TUT and others can be used for initial testing, prototyping and even mould manufacturing. This is crucial for small and medium firms that cannot necessarily afford this technology. Where firms are applying for finance of 3D printers then the development funding

[61] https://www.k3syspro.com/how-to-survive-industry-4-0-as-a-plastics-manufacturer/

institutions should encourage firms to use the public facilities for initial prototyping and testing, this could be funded as part of the project costs. This ensures that the machines and moulds that are procured are appropriate for firm needs. The VUT Science Park already offers virtual simulation to test tool design before manufacturing. An example of a successful public -private partnership is the DST's current flagship projects, Project Aeroswift, which is a collaborative effort between Aerosud ITC and the Council for Scientific and Industrial Research National Laser Centre. [62] Strategies need to be developed to have more effective partnerships with small and medium firms.

References

Abbott, P., Tarp, F. & Wu, C., 2017. Structural Transformation, Biased Technological Change and Employment in Vietnam. *The European Journal of Development Research*, 29(1): 54-72.

Amsden, A. H. (1997). Editorial: Bringing production back in—Understanding Government's economic role in late industrialization. World Development, 25(4), 469-480.

Autor, D., Levy, F. & Murnane, R., 2003. The skill content of recent technological change: An empirical exploration. *The Quarterly Journal of Economics*, 118(4): 1279-1333.

Barzotto, Corò, De Propris and Volpe (2015). GVC in Advanced Economies: Re-shoring and Re-industrialisation. *SASE 2015 Conference Paper*

Bell, J., Goga, S., Mondliwa, P. & Roberts, S., 2018. Structural Transformation in South Africa: Moving towards a smart, open economy for all. Available from https://www.competition.org.za/s/IDTT-Structural-Transformation-in-South-Africa-Moving-towards-a-smart-open-economy-for-all.pdf.

De Marchi, D., Di Maria, E. & Gereffi, G., 2017. Local clusters in global value chains: Linking actors and territories through manufacturing and innovation. London: Routledge.

Fagerberg, J. & Srholec, M., 2017. Capabilities, economic development, sustainability. *Cambridge Journal of Economics*, 41(3): 905-926.

Fagerberg, J., 2016. Innovation Policy: Rationales, Lessons and Challenges. *Journal of Economic Surveys*, 31(2): 497-512.

Fagerberg, J., Srholec, M. & Verspagen, B., 2010. Innovation and Economic Development. In: B. Hall & N. Rosenberg, eds. Handbook of the Economics of Innovation Vol. II. s.l.:North Holland, pp. 833-872.

Foresight, 2013. The Future of Manufacturing: A new era of opportunity and challenge for the UK Summary Report, London: The Government Office for Science.

Götz, M. & Jankowska, B., (2017). Clusters and Industry 4.0–do they fit together?. *European Planning Studies*, 25(9): 1633-1653.

Lall, S., 2004. Reinventing Industrial Strategy: The Role of Government Policy in Building Industrial Competitiveness. G-24 Discussion Paper Series.

[62] https://3dprint.com/147991/south-africa-3d-printing/

McMillan, M. & Headey, D., 2014. Understanding Structural Transformation in Africa. *World Development*, Volume 63, pp. 1-10.

Morrison, A., Pietrobelli, C. & Rabelloti, R. (2008) Global value chains and technological innovation in developing countries. A framework to study industrial innovation in developing countries.

Neffke, F., Matté, H., Ron, B. & Henning, M., 2018. Agents of structural change: the role of firms and entrepreneurs in regional diversification. Economic Geography, 94(1), pp. 23-48.

OECD, 2017. The Next Production Revolution. A Report for the G20.

Rip, A. & Kemp, R., 1998. Technological change. Human choice and climate change. 2(2), pp. 327-399.

WEF. (2017). Accelerating Workforce Reskilling for the Fourth Industrial Revolution. An Agenda for Leaders to Shape the Future of Education, Gender and Work. White Paper.

Augier, M. & Teece, D., 2009. Dynamic Capabilities and the Role of Managers in Business Strategy and Economic Performance. *Organization Science,* 20(2), pp. 410-421.

Babelytė-Labanauskė, K. & Nedzinskas, Š., 2017. Dynamic capabilities and their impact on research organizations' R&D and innovation performance. *Journal of Modelling in Management.*

CCRED, 2016. Industry nodes and cluster development in the City of Joburg. Background report on the plastics cluster.

Garisch, C., 2016. A study of innovatio culture and capability in the South African plastics industry. *MerSETA Plastics Chamber Research.*

Helfat, C. & Winter, S., 2011. Untangling dynamic and operational capabilities: strategy for the (n)ever-changing world. *Strategic Management Journal,* 32(11), pp. 1243-1250.

Monaco, L., Bell, J. & Nyamwena, J., 2019. Understanding Technological Competitiveness and Supply Chain Deepening in Plastic Auto Components in Thailand: Possible Lessons for South Africa. *CCRED Working Paper 2019/01.*

Teece, D., 2007. Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance. *Strategic Management Journal,* 28(13), pp. 1319-1350.

Teece, D., 2010. Technological innovation and the theory of the firm: the role of enterprise-level knowledge, complementarities, and (dynamic) capabilities. In: *Handbooks in Economics, Wolume 1.* s.l.:Elsevier, pp. 679-730.

Teece, D., 2017. Towards a capability theory of (innovating) firms: implications for management and policy. *Cambridge Journal of Economics,* Volume 41, pp. 693-720.

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

Wu, S., Melnyk, S. & Flynn, B., 2010. Operational capabilities: the secret ingredient. *Decision Sciences,* 41(4).