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TIPS RESEARCH REPORT FOR

DEPARTMENT OF TRADE AND INDUSTRY

FRAMING THE CONCEPTS THAT UNDERPIN DISCONTINUOUS TECHNOLOGICAL CHANGE, TECHNOLOGICAL CAPABILITY AND ABSORPTIVE CAPACITY

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ABOUT THIS PUBLICATION

This paper*, Framing the concepts that underpin discontinuous technological change, technological capability and absorptive capacity,* was commissioned by the Future Industrial Production Technologies Chief Directorate of the Department of Trade and Industry (the dti). This unit is focused on preparing South African industry for the fourth industrial revolution.

It is the first paper in a series, and takes the form of a literature study on the topic of technological change, innovation and building technological capabilities.

Other papers in the series are the *World Economic Forum and the fourth industrial revolution in South Africa; Mapping the meso space that enables technological change, productivity improvement and innovation in the manufacturing sector;* and *Technological change and sustainable mobility: An overview of global trends and South African developments.*

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ABBREVIATIONS

AfCFTA	African Continental Free Trade Area
APDP	Automotive Production and Development Programme
BERD	Business Expenditure on R&D
CSIR	Council for Scientific and Industrial Research
DST	Department of Science and Technology
dti (the)	Department of Trade and Industry
DUI	Doing, Using and Interacting
EU	European Union
GERD	Gross Expenditure on R&D
GDP	Gross Domestic Product
HSRC	Human Sciences Research Council
ICT	Information and Communication Technologies
IPAP	Industrial Policy Action Plan
R&D	Research and development
STI	Science, Technology and Innovation
SQAM	Standards, Quality Assurance and Metrology
MCEP	Manufacturing Competitiveness Enhancement Programme
MIDP	Motor Industry Development Programme
MOOCs	Massive Open Online Courses
NIPF	National Industrial Policy Framework
OEM	Original Equipment Manufacturer
PGMs	Platinum Group Metals
USPTO	United States Patent Office

EXECUTIVE SUMMARY

This literature study is the first paper in a series to enable the dti to prepare for future production technologies and the expected technological change brought about by the fourth industrial revolution.

The fourth industrial revolution is characterised by projections of convergence of several technological domains, an accelerating pace of change, and an underlying theme of digitalisation, interconnectivity and discontinuous change. It seems as if connectivity and digitalisation is reaching all domains of our existence. South African enterprises of all kinds have to become better at identifying new ideas, concepts and technologies, adapting these ideas to the local context, and innovating using new technologies as platforms. In other words, our enterprises have to become better at innovating at the product, process and business model levels.

The capability to confront, adapt, develop and master new technologies is referred to as technological capability. This capability goes beyond being able to identify and use new technologies and includes the ability to deliberately create and modify a range of economic and technological institutions. Technological capability encapsulates the distributed ability of a country, region or industry to learn a new technical language, to integrate relevant new ideas into current practices (innovation), or to explore how new ideas can be applied to solving local problems or exploiting local opportunities (innovation).

The ability to discover and absorb new ideas, enable learning, and the adaptation of technology are enabled by a network of public organisations referred to as meso organisations. These could include organisations involved in education, knowledge transfer, research; but could also include technical infrastructure, cluster and industry promotion programmes, development finance and other knowledge-intensive or intermediary services. The functions these meso organisations offer to firms usually come in the form of basic and advanced public goods. The dynamism of these meso organisations and their ability to anticipate and adapt to technological change is crucial in improving the dynamism of the ecosystem wherein firms operate and compete.

Despite increased public funds injected into innovation, as well as a series of policies designed to encourage innovation, South Africa's innovation activities appears to be constrained. Several research papers have questioned South Africa's ability to adapt and respond to technological change and especially discontinuous technological change.

This literature study lays the foundation for the dti to prepare South Africa for Future Production Technologies and rapid technological change.

BACKGROUND

The dti established the Future Industrial Production and Technologies Chief Directorate in 2017. This unit is focused on preparing South African industry for the fourth industrial revolution. The unit will work closely with other units in the dti and departments in the economic cluster. The Chief Directorate is expected to work closely with the Department of Science and Technology (DST) (Innovation and research and development/R&D) and the Department of Communications (big data, security and information and communication technologies (ICT) infrastructure). The final outcome is to develop an integrated strategic response, while at the same time mobilising stakeholders (public and private) to become more sensitive to global technological shifts and the implications for future industrial activity and employment.

This is the first paper in a series written for the dti and in particular the Future Industrial Production and Technologies Chief Directorate. This paper takes the form of a literature study on the topic of technological change, innovation and building technological capabilities. It investigates the role of meso institutions in strengthening the absorptive capacity, innovative ability and resilience of the economy. The intent of this paper is to inform the dti and its stakeholders on how technological change can be monitored, how South African industries are adapting to, and developing, new technological opportunities, and the role the dti can play in promoting technological change.

A second paper will focus on the fourth industrial revolution and the particular concept promoted by the World Economic Forum, international consultancies, and increasingly governments and multinational firms.

A third paper will assess how the South African economy is responding to change, how investment patterns are changing, and how knowledge intensity and value add is changing. The paper will be an extension of chapter six of this publication.

The fourth paper will take the fifth chapter of this publication further. It will focus on the role, adaptability and performance of the network of market-supporting and shaping formal organisations and institutions. Where possible, gaps in the institutional landscape will be identified.

A fifth paper will focus on the transport sector as a key enabler for the economy. The transport economy not only moves goods and raw materials, it enables connectivity between places.

1 INTRODUCTION

At the heart of the discussion about industrial revolutions and future production technologies is the topic of how societies adapt and develop the use of new technologies. To understand how societies confront or cope with technological change, it is necessary to unpack what is meant by technology, how technology is changing, new ideas are absorbed, and how the appropriate institutions and public goods that reduce the costs of learning and adaptation are developed. There is a rich body of literature on such changes, as well as how technology is disseminated, industries change and how innovation affects products, processes and business models.

The intent of this paper is to provide the dti with an overview of technological change to enable it to assist both internal and external stakeholders to better assess the potential future impact, and the demands and capacities that are required to cope with or even thrive due to technological change. The academic disciplines that are relevant to understand change in technology draw on evolutionary economic theories like those proposed by Richard Nelson and Sidney Winter, Brian Arthur, and the study of innovation systems.

This chapter provides a brief overview of the logic followed in this literature study. Chapter 2 makes a distinction between a narrow and broad definition of technology. It then shifts to how technology changes and the stylised cyclical patterns that can be observed. The next subsection describes discontinuities and disruptions. The final subsection of this chapter is focused on the evolution of technologies.

Chapter three introduces innovation. It clarifies the different types of innovation, and unpacks the difference between innovation at the level of components and innovation at the level of architectures.

In the fourth chapter the focus shifts to a more systemic view of technological change and innovation systems. First, the concept of technological capability is described. This is followed by a brief overview of the innovation systems approach and how it is related to technological capability development. The next section focuses specifically on sectoral innovation and technological systems, while the final subsection in this chapter is focused on strengthening the absorptive capacity.

Chapter five looks at the role of a range of public organisations that provide basic and advanced functions to enable enterprises to identify new technology and knowledge, and to assist them to adapt to these changes. The importance of the adaptiveness and responsiveness of meso organisations is explored.

In Chapter six the focus shifts to the South African economy. The research and knowledge intensity of the economy is assessed, with key economic trends of the past 10 years highlighted. Key statistics that provides a high-level view of innovation inputs, innovation outputs and investment are identified and analysed.

2 TECHNOLOGY, TECHNOLOGICAL CHANGE AND DISCONTINUITIES

2.1 Broadening the understanding of the meaning of technology

The meaning of technology can be understood in many different ways. In everyday English it could mean a gadget or artefact, or know-how, or a broader group of ways of doing things.

Arthur (2009:28) provides three different definitions of technology:

- The most basic definition is that technology (in a singular sense) is a means to fulfil a human purpose. For some technologies this purpose may be explicit, for others it may be vague. As a means, a technology may be a method, process or device. A technology does something, it executes a purpose. It could be simple (a roller bearing) or complicated (a wavelength division multiplexer). It could be material, like an engine; or nonmaterial, a digital compression algorithm.
- A second definition is plural, technology as an assemblage of practices and components. This covers technologies such as electronics or biotechnology that are collections or toolboxes of individual technologies and practices. It can also be called bodies of technology.
- A third definition is technology as the entire collection of devices and engineering practices available to a culture.

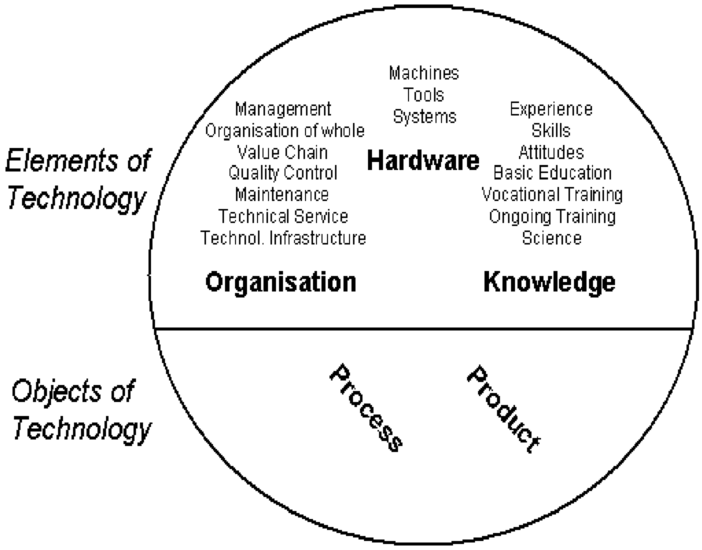
These three definitions each point to a technology in a different sense, a different category, from the others. Each category comes into being differently and evolves differently. Changes at the first level are relatively easy and fast, and becoming progressively more difficult with the second and third definitions provided above. The third definition is a slower process that could take decades to adjust, yet in the moment it could feel as if everything is changing very fast and all at once. Examples are, for instance, how international air travel currently operates, or how we use a variety of technologies to communicate with family, friends and business associates that are geographically distant.

While colloquially, technology is associated with artefacts and perhaps some training or documentation, the definition by Arthur (2009) highlights the importance of a broader understanding in which technology is seen as an action – about harnessing natural phenomena, arranging processes to produce something or achieve a specific purpose.

In economic development there have been long-standing discussions about a broader definition, especially in the context of international technology transfer, technology adaptation in developing countries and technological catching up. Meyer-Stamer (1997:7-9) highlighted four components of technology (illustrated in Figure 1):

(1) Technical hardware, i.e. a specific configuration of machines and equipment used to produce a good or to provide a service.
(2) Know-how, i.e. scientific and technical knowledge, formal qualifications and tacit knowledge.
(3) Organisation, i.e. managerial methods used to link hardware and know-how.
(4) The product, i.e. the good or service as an outcome of the production process.

Figure 1: A broader definition of technology



Source: Meyer-Stamer (1997:7-9)

The three elements of technology (Organisation, Hardware, Knowledge) can be independent of the objects (the process or the product). For instance, a particular arrangement of the elements could produce a great variety of products. The object is on one hand the product, but on the other hand it is the process that creates the product itself.

The advantage of the broad definition is that it helps to avoid barren discussions in that it prevents, for instance, any equating of technical artefacts with technology. This broader definition explains why technology cannot just be "transferred" in a package form. Successful transfer depends also on the recipient context, culture and a range of other supporting factors. Furthermore, the absorptive capacity of countries, regions within countries and between different firms differs vastly.

2.2 Technological change

This section briefly discusses technological change, technological change cycles, and discontinuity and disruption.

Most technological change is incremental, that is, each innovation constitutes a relatively small step built on the base of established practice (Nelson and Winter, 1982). Even though each step may be small, the cumulative economic consequences of change over many iterations may be huge. These changes could replicate through an economy like falling dominoes in a series of small disruptions.

These incremental changes often favour incumbents because of their established organisational and technological capabilities. Incumbents can scan the technological horizon, and pick elements that fit into their current business arrangements, or adjust their strategies and structures to exploit the benefits of new technologies.

However, this inertia also creates a lock-in and path dependence. Even if a new technology or concept could offer great benefits to an incumbent, the change, restructuring and rethinking of business models could simply mean that incumbents ignore certain developments, or do not even recognise the need for change. Because of its potential to render existing capabilities obsolete, radical change in technology is one of the greatest threats to incumbents whose competitive positions were built in a particular way.

One of the stylised facts of innovation is that radically new technologies are often pioneered by firms new to the industry they transform. Often they have had an opportunity in a different industry or technological context to develop their idea to a point where it surpasses the performance-cost curve of existing technologies in other sectors. This is because new innovations typically require a more organic form of management (in other words a different business model), in which technical or scientific expertise engages closely with other parts of the business. With incumbents, companies reach efficiency by establishing systems, procedures and to some degree stable silos. It implies that what may be seen to be disruptive by some (incumbents), could actually be an incremental change for new entrants (attackers).

However, the attacker does not always have the advantage. There are many examples when incumbents, after being confronted by a new innovation, figure out a way to integrate some of the functionality of the new technology into their organisation; thus combining new technology with existing technology and organisational structures. If incumbents are able to adapt this way then the attacker or disruptor might not gain a sufficient foothold, while the incumbents are able to protect their market or even gain a further advantage. Furthermore, attackers often struggle to scale their business models fast enough due to a lack of funding, management experience, global networks or many other factors.

The interesting aspect is that there is a certain cyclical pattern that can be observed about how new technologies are developed. The next section explains technological change cycles in more detail.

2.3 Technological change cycles

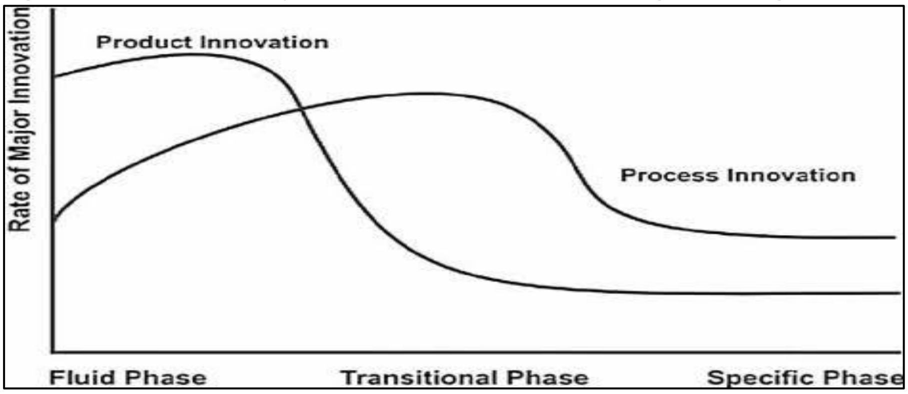
During the 1980s several scholars[1] recognised that technological change follows a cyclical pattern and several models were put forward to explain the phenomena. These models are still in use today and have been found to be active at different levels of technological change. The broad consensus was that a technological change cycle:

a) Starts with a technological discontinuity or disruption, followed by a period of unstructured and often chaotic innovation when a new idea or concept is made possible (based on preceding developments). This disruption results in a fluid or turbulent development phase during which many ideas are developed, tried and promoted as the next best thing,
b) That is followed by an era of ferment from which a dominant design emerges; and
c) This is followed by an era of incremental change during which the dominant design is elaborated.

This can be illustrated with the widely recognised Abernathy and Utterback (1978) model with its three phases of change that are illustrated in Figure 2. The three phases are a fluid phase, a transitional phase, and a specific phase, and is similar to the cyclical pattern described in the bullet list above. Other scholars used slightly different labels, but the characteristics in the different phases are all more or less the same.

[1] The work of Tushman and Anderson (1986), Abernathy and Utterback (1978) are still frequently cited today.

Figure 2: The Abernathy-Utterback model of technological change



Source: Abernathy and Utterback (1978)

The rate of innovation is highest during the fluid phase, during which a great deal of experimentation with product features and operational characteristics takes place between different competitors[2]. Because of all the changes in the product composition and characteristics, process innovation typically lags. Buyers and users are often confused or overwhelmed during this phase fearing that the benefits are overstated and that the costs of adaptation are uncertain. Only the brave and the innovative engage in finding, adapting and integrating new ideas and concepts.

In the transitional phase, the rate of product innovation slows down and the rate of process innovation increases. At this point, product variety gives way to standard designs that have either proven themselves in the market, or that are shaped by regulations, standards or legal constraints. The pace of innovation of how to produce the product increases. What was done earlier by highly skilled technicians may become automated or developed to a point when low-skilled operators can take over. Or lower-skills jobs are displaced from the production process to other functions like logistics, while the skills intensity on the production line is enhanced. At this point it is easier for bystanders and followers to engage in exploration. The early adopters are already over the horizon, while many early adopters have exited, sold out or moved on.

The final phase, the specific phase, is when the rate of major innovation dwindles for both product and process innovation. In this phase, the focus is on cost, volume, and capacity. Most innovations are very small incremental steps, improvements on what is already known and accepted. Latecomers can now engage with the technology, although it might already be too late.

The description of technological change provided above follows the generic three-step process of technology evolution: a process of variety creation, selection, and then amplification or retention.

- During the variety creation phase there are many competing designs and no dominant logic. Towards the end of this phase a few dominant designs may emerge, but there is still much competition between ideas. This is not only a technical selection process, there are important social, political and industrial adjustments taking place at the same time.
- During the selection phase, standards emerge for positively selected ideas, with a few designs dominating. It is a relatively stable process of incremental improvements in features, performance and results. This may be interrupted occasionally by leaps in performance as some designs are substituted by better technologies, or from breakthroughs often coming from other industries or contexts. In general, designs become simpler as a learning process

[2] Kuhn (1962) noted that in the early stages of research in a given field, the most that scholars typically can do is to report the phenomena they observe, without a unifying theory or framework to help them categorise or make sense of what they see. As a result, this stage of knowledge accumulation is characterised by confusion and contradiction. Theories are put forward but reports of deviating phenomena accumulate.

unfolds about how best to design, manufacture, distribute and use a particular technology around dominant designs. This period is characterised by growing interdependence as modules are developed, substituted and standardised. There is a growing exchange and increased competence within and between different communities of practitioners. Often there is industry consolidation during this phase. It is important to note the dominant designs are only visible in retrospect. They reduce variation, and in turn, uncertainty, but within the process it is hard to predict which designs will survive the next set of radical innovations. Once a design becomes an industry standard it becomes hard to dislodge.

- This leads to an amplification phase, in which the best ideas are not necessarily used as intended, but when technological changes spill over into areas not originally intended. This is a relatively stable process that can continue for long periods, until is it suddenly interrupted by a radically different idea, resulting in the process starting all over again.

Anderson and Tushman (1990) state that, from the perspective of the sociology of technology, technological change can be modelled as evolving through long periods of incremental change punctuated by revolutionary breakthroughs[3]. The innovation activities that take place that lead to these phenomena will be discussed in Chapter 3.

Arthur (2009:163) contends that change within technological domains is a slow process. He explains technology domains do not develop like individual technologies like a jet engine: focused, concentrated and rational. It is rather more like the development of legal codes: slow, organic and cumulative. With technology domains, what comes into being is not a new device or method, but a new vocabulary for expression, similar to a new language for creating and combining new functionalities.

A current example is the "Internet of things", where the connectivity of physical devices are spreading from the office and smartphone devices to interconnect household appliances, industrial applications and an endless list of technologies enabling data exchange, control and new functionalities . It could be argued that this is not a new technology, digital sensors have been around for a long time, our cars, smartphones and equipment have contained them for a long time. However, the language, standards, distributed nature of processing, and developments in big data visualisation have all contributed to this technology appearing to arise from obscurity into the limelight of the popular media. A similar argument could be made for artificial intelligence, drone technology and others.

2.4 Technological discontinuities or disruptions

The phrase "disruption" is often used to describe how both existing technologies and business models are challenged by new ideas. Disruption implies that somebody is being disrupted by somebody or something. Something that was unforeseen or unplanned for is occurring at a scale or velocity that is unexpected. It could mean that a company has decided to invest funds into developing a particular capacity, and then demand suddenly shifts to an area that they have not invested in, or demand shifts to a capacity that the company does not have a capability to deliver. Or despite their best efforts at trying to improve a particular technology, companies in another industry seem to be getting much better yields on investment, and suddenly their offering is in demand in the current market.

In this section, the discontinuities that can be observed at the level of technologies will be discussed. In Chapter 3, the innovative activities that result in these disruptions will be elaborated on further.

At rare and irregular intervals in every industry, innovations appear that depart dramatically from the norm of continuous incremental innovation that characterises product classes, and these can be

[3] This is often referred to as punctuated equilibrium by political scientists.

termed technological discontinuities (Anderson and Tushman, 1990). These discontinuities either affect underlying processes or the products themselves.

- Process discontinuities are fundamentally different ways of making a product that are reflected in order-of-magnitude improvements in the cost or quality of the product. An example is the Bessemer furnace in steel production.
- Product discontinuities are fundamentally different product forms that command a decisive cost, performance or quality advantage over prior product forms. An example is a steam engine vs. a diesel engine.

These discontinuities demand a fast response from existing players in many areas; they force a change in strategy, investment, priorities and execution. The reason why incumbents ignore the crudeness or incoherence of new innovations is because they have a current regime in place that is optimised and built around a particular paradigm[4].

Anderson and Tushman (1990) further characterised technological discontinuities as competence enhancing or competence destroying.

- A competence enhancing discontinuity builds on the know-how embodied in the technology that it replaces, meaning that current users of this technology are able to build on previous experience, qualifications and knowledge. An example is the turbofan advance in jet engines. A competence enhancing innovation can introduce a new technological order, with a vastly enhanced performance frontier building on the existing technical order rather than making it obsolete.
- A competence destroying discontinuity renders obsolete the expertise required to master the technology that it replaces. For example, the skills of mechanical watch manufacturers were rendered irrelevant by quartz watches.

It is important to note that what may be competence destroying for some, could be competence enhancing for others. It depends on the business model, and also the nature of the disruption and the scale of the disruption. Also, within technological hierarchies there could be areas where a new technology enhances capabilities, while destroying capabilities in another related area.

When a discontinuous technology is introduced it increases variation in a product class, and it introduces uncertainty for producers and consumers. It is crude and experimental when introduced, but it ushers in an era of experimentation as organisations struggle to absorb (or destroy) the innovative technology. This era is characterised by two distinct selection processes:

- Competition between technical regimes (old and new), and
- Competition within the new technical regime (different ways of achieving the same goal).

This period of substantial product-class variation, and in turn uncertainty, ends with the emergence of a dominant design.

Older technological orders seldom vanish quietly or quickly; competition between old and new technologies is fierce. New technologies are disparaged or undervalued when they are introduced because they frequently do not work well, are based on unproven assumptions, or are based on

[4] Christensen (2000):xii) argues that many of the examples of dominant firms that failed due to their inability to respond to disruption were often widely regarded as the most successful companies in the world. He argues that the reason these companies failed to adjust was because of their success and good management practices. They failed because they listened to their clients, invested aggressively in new technologies that would provide their customers more of what they wanted, and because they carefully studied market trends and systemically allocated investment capital to innovations that promised the best returns.

competence that is inconsistent with the established order or their effects are overinflated. This often results in the incumbent communities increasing their innovativeness and the efficiency of the existing technological order by taking key concepts from proven "new" concepts and integrating them into their existing practices. An example is where incumbent taxi operators start using smartphone apps based on the technologies introduced by Uber.

It is important to note that discontinuous technological advance does not always dominate older orders. Sometimes the new co-exists next to the old, although in time resources are increasingly shifted towards the new technology as it settles down and is proven and improved. Sometimes older technologies disappear, only to be revived a few years later, albeit at a smaller scale. This cycle can be seen in technical trades such as boilermaking, toolmaking and for instance diesel engine technologies.

This section raises the question of whether the fourth industrial revolution, or the technologies highlighted by the World Economic Forum[5], are destroying competencies or enhancing competencies. A key consideration for future analysis as part of this research project is whether the South African economy is able to promote the changes in business models, technological processes and supporting regulations and technological infrastructure to encourage exploration of these new domains. This will require a more systematic approach to identifying technological discontinuities (see Textbox 1).

Textbox 1: How to assess discontinuous technological change

A technological discontinuity is identified when an innovation:

a) Pushes forward the performance frontier along the parameter of interest by a significant amount, and
b) Does so by changing the product or process design, as opposed to merely enlarging the scale of the existing designs.

This can be done by tracking the state of the art of key performance metrics for each year of an industry's existence. For each advance it is necessary to check whether the improvement was produced by a new architecture or a version of the existing architecture. Only peaks that are associated with a new product or design are counted as discontinuities. The challenge is to identify the appropriate level of aggregation to track the performance change of key technologies, and perhaps also to decide which technologies and parameters to track.

For a contemporary innovation, one could measure competence enhancement and competence destruction by constructing an index, reflecting such factors as the amount of retraining required to master a new technology, the number of new skills a firm would have to acquire to exploit an innovation, or the degree to which models based on the old technology could be retrofitted with the new. One might also poll experts familiar with an industry's technology to see whether there is general agreement concerning the degree to which a new technology renders its predecessor obsolete.

Source: Anderson and Tushman (1990)

2.5 The evolution of technologies and industries

In the earlier research on technological evolution in the 1970-1995 period, attention was mainly paid to either a whole economy or a single sector or technological paradigm. It is broadly understood from this research that different industries and technologies evolve at different rates. This means that over time, some industries may be more important than others, or at least, some may be accelerating while

[5] The second paper in this series will elaborate on these technologies

others may be stagnant or declining. In recent research by Saviotti and Pyka (2013), the emergence of new technologies and industries (and the goods and services that they provide) is seen as offsetting the diminishing returns that are innate in the development of existing technologies. Nelson (2015) argues that this is a reason why absorption and further development of these technologies are necessary to maintain economic development.

In enabling technological evolution in countries, a whole range of actors play a part. Individuals and informal networks, to large and small firms all play a role. However, for the last century, most technological advancements have been supported by scientists, the academia and professional societies and a range of supporting meso organisations. In Europe, professional associations often play an important role in the deepening and dissemination of technological knowledge.

Nelson contends that scientific and technological research and teaching, especially the more applied fields, provide a base of knowledge that is accessible to all technically sophisticated individuals and firms working to advance technology in a field (Nelson, 2015). However, different fields also depend, to different extents, on scientific and formal research and technology support. Furthermore, different industries depend, to different extents, on government support and incentives. In some fields public support is crucial, and in other cases, provides little incentive or value. In many cases innovations preceded science, and continued development is only possible due to the iteration between researchers and enterprises. Nelson continues that the kinds of firms that do most of the innovating differ – in some fields this tends to be large, established firms while in others it is smaller firms or new start-ups (Nelson, 2015).

Nelson draws an important conclusion that is very relevant for this study, and that is that there is no single set of policies that are applicable to all technologies and industries. What will be effective in some fields will not be in others.

Nelson is also known for his writing on the importance of a wide range of social institutions, both formal (for example a cluster development organisation) and informal (the trust networks between members of the clusters). He refers to these social institutions as social technologies, and he argues that they co-evolve with physical technologies to enable economic development. These social institutions range from central banks to a diverse range of firms, but importantly include other forms of organisations such as scientific and technological societies, universities, government agencies and even capital markets. These institutions are the focus of the discipline of innovation systems.

Nelson emphasises that "that when a potentially new technology emerges, new institutions often are needed to develop it, and invest in and operate effectively the economic practices based on it".

Nelson acknowledges it is not an easy task, as it is hard to predict which emerging fields of promising new technologies are going to be important in driving economic progress in the future, and which will have a modest impact. The policies to create or reform institutions need to be adaptive and flexible. Arthur (2009:186) confirms the view of Nelson and argues that *"We cannot tell in advance which phenomena will be discovered and converted into the basis of new technologies. Nor can we predict which combinations will be created."*

2.6 Chapter conclusion

In its simplest form, technology is a means to fulfil a human purpose. It could also be seen in a plural sense – technology as an assemblage of practices and components. A broader definition of technology includes not only hardware and know-how, but also considers organisation around a technical capability and the product as well as the process applied. For policymakers it is important to not focus too narrowly on specified technologies or domains, but to remain focused on a broader definition. While technology application at, for instance, the level of 3D printing should be encouraged, the higher order focus should rather be on smart factories, rapid prototyping or new materials sciences. Enterprises, universities and individuals should be encouraged to engage with new technologies to learn the language and about the possibilities of each technological domain.

Most technological change is incremental and often favours incumbents due to established organisational capabilities. However, these organisational capabilities also make it harder for incumbents to adapt to technologies that demand a different organisational culture, capabilities or strategies. The result is that radically new technologies are often pioneered by firms either new to the market or industries that are able to organise themselves in new ways that are more suitable to the opportunities offered by new technologies. New entrants thus put pressure on incumbents to remain abreast of technological possibilities. Another way to promote technological exploration and spillovers is to encourage more cross-sectoral initiatives and networking. This can for instance be done by focusing on complex problems (like those around water management); by encouraging cross sectoral benchmarking or collaboration; or focusing on value chains rather than specific industries.

Technological change follows an evolutionary pattern. The process often starts with a technological change or a discontinuity. This is a period of contestation between different concepts, alternative arrangements and solutions. It is easy for buyers to be paralysed by all the alternatives. This phase is followed by a relatively stable period when a few dominant designs and standards emerge, while process technologies accelerate its development. While there may be occasional leaps in performance due to modular substitution or breakthroughs, this phase is mainly driven by incremental improvements. The final phase is an amplification phase, when the technology may spill over into other markets or applications not originally intended. During this phase, most innovations are process and scale related. It is characterised by industry consolidation and a focus on efficiency. Through all these phases, access to demonstration facilities, technology extension services, specialised technological consultancy and, for instance, carefully documented case studies of technology application are crucial. These measures all play a role in reducing search and evaluation costs, and reduce coordination costs as well as risks. At the moment, search costs in South Africa appear to be high, resulting in only larger and better-resourced companies being able to remain abreast of technological developments elsewhere.

Within technological discontinuities a distinction can be made between competence enhancing discontinuity that builds on the know-how embodied in the technology that it replaces, and competence destroying discontinuity that renders obsolete the expertise required to master the technology that it replaces. What may be competence destroying for some skillsets and professions may be competence enhancing for others. To deal with discontinuities, the ability to reskill or encourage skills upgrading, aimed at both individuals and organisations, are important. This involves a broad range of measures ranging from short courses, vocational training and university education.

The ability of societies to deal with technological change depends on the ability of societies to create or adjust formal and informal institutions where and when required. This is not an easy task, as it is hard to predict which emerging fields of new technologies are going to be important in driving economic progress in the future. A second element is the ability of professions, scientists, technologists, industries and the academia to collectively sense and adjust, based not only on new developments, but also to adjust based on how the absorption and dissemination or amplification of already existing technologies develop or change. In many new technological domains, South African public institutions are already building capacity. These facilities must be open to the public and business sector; they should be incentivised to take their technologies, applications and ideas to existing industry and potential enterprises.

3 INNOVATION

At the heart of the technological changes outlined in the preceding section are attempts by entrepreneurs, scientists, engineers and policymakers to be more innovative. This section will delve deeper into the meaning of innovation and the role it plays in technological change. While technology is focused on action, on exploiting or harnessing natural phenomena, innovation is focused on change. Something is different or better than before.

The so-called Oslo-manual of the OECD (2005:29) states that it is crucial to understand why firms innovate. The ultimate reason is to improve firm performance. A new product or process can differentiate a firm and give it a market advantage. Or it can gain a cost advantage. New processes can enhance a firm's ability to innovate. For instance, new organisational practices can improve knowledge exchange or the ability to respond fast to market changes. However, it must be understood that innovation requires change, resulting in discomfort, inefficiency, re-organisation and stress. It introduces variation. Not all innovations work in the marketplace, and a mistake can be costly to rectify. There are many reasons for companies and individuals not to innovate. Therefore attention must also be paid to the pressure or incentives that make it worthwhile for individuals, organisations and companies to take risks, try new ideas and explore different ideas.

Arthur (2009:164) identifies two themes of innovation efforts:

- One is the constant exploration or putting together of new solutions out of existing toolboxes of pieces and practices.
- The other is industries constantly combining their practices and processes (there are known knowledge modules) with functionalities drawn from newly arriving toolboxes – new domains. This is where the ability to recombine old with new, familiar with novel ideas into new business concepts, technologies, new contexts or traditional applications are important management and social capabilities.

Edler and Fagerberg (2016) argue that a broader perspective is needed on innovation. A narrow view is mainly about the intentional efforts to improve a product or process in an organisation, it is often seen as being novel. A broader perspective is understood as the introduction of new solutions in response to problems and challenges, or opportunities that arise in social and/or economic environments. The solutions could be generated internally, but in most cases involve a process of building on what exists, recombination, copying ideas from elsewhere and adapting to a specific context.

The next sections will clarify the difference between innovation and invention, how innovation occurs at different technological levels, and different modes of innovation.

3.1 Innovation versus invention

A widely accepted distinction between invention and innovation is provided by Fagerberg et al. (2005:4). According to Fagerberg et al, **invention is the first occurrence of an idea for a new product or process** (first in the world), **while innovation is the first attempt to carry it out in practice within a specific context** (by, for instance, introducing a machine from another country into a local manufacturing process). Thus invention and innovation may be closely linked, although in most cases they are separated in time (sometimes decades or centuries), place and organisation.

To turn an invention into an innovation, a firm typically needs to combine several different types of knowledge, capabilities, skills and resources from within the organisation and the external environment (Schumpeter, 1964/1911). The challenge for governments is to figure out how to ensure that entrepreneurs, innovators and decision-makers are encouraged to keep on searching for better combinations, or for ways to combine new ideas with existing (known) knowledge and technology modules.

The fact that innovation typically emerges within a complex system is often overlooked. For instance, as Schumpeter (1964/1911) explained, the innovator who invented the steam engine still had to wait for others to develop the different aspects of the rail system before it could be commercially viable. The steam engine was initially invented in a completely different context, again illustrating how inventions are dependent on the context in which they arise. This highlights that invention and innovation can sometimes be separated in time. In science-intensive fields like electronics and biotechnology it is much harder to distinguish the difference.

Innovation is often associated too narrowly with research and development activities that are carried out in the high-tech world (Kline and Rosenburg, 1986). While the innovation efforts to improve a specific aspect of a technology or solution may appear to be linear, and can be planned in detail in advance, most innovations are actually far more messy (non-linear) in how they are developed. Often, we think of innovations as a singular development, and the fact is that a whole series of interdependent developments, chance events, experiments, failures and dead-ends had to first be tried, improved, recombined and tested.

Innovation includes not only technologically new products and processes, but also improvements in areas such as logistics, distribution, management and marketing.

Even in so-called low-tech industries, there may be a lot of innovation going on, and the economic effects may be large[6]. Moreover, the term innovation may also be used for changes that are new to the local context, even if the contribution to the global knowledge frontier is negligible. In this broader perspective, innovation – the attempt to try out new or improved products, processes, or combinations of doing things – is an aspect of most, if not all, economic activities. Thus, innovation could include imitating what works elsewhere, or integrating an idea from another context into the local environment.

While many innovations can be linked to well-funded research programmes, funding is not a pre-condition for innovation. In fact, in many cases a lack of resources could stimulate people to innovate. Firms usually innovate because they believe there is a commercial benefit to the effort and costs involved in innovating. This commercial benefit could be measured in terms of return on investment or profits, but it could also be about cost saving, resource optimisation, solving a recurring problem or responding to the demands of a customer. Often increased competition, changes in market structure or market demand, changes in input prices and availability, or changes in technological performance also affect the incentive to innovate. In most cases, innovation requires taking, or at least managing, risks to overcome some form of uncertainty. As a result, firms with low capital or tied-up resources are less likely to innovate, but this also depends on the context, the industry and the required changes.

The willingness of an individual to tinker and explore better solutions is influenced in part by the organisational context of the innovator, but also by factors such as education, qualifications, meta-level factors such as culture, personal characteristics (such as patience, inquisitiveness or tolerance of failure) and the institutional environment (see the sub-section on technological capability) which is also a key feature of industrial policy. Other factors such as competitive pressure, problem pressure, or social and economic incentives also play a role. Locations with a more diverse economic and social make-up are more likely to be conducive to innovation, as actors interact with people with similar and different interests. The proximity of other actors and the density of interactions make imitation, cross-

[6] See for instance Von Tunzelmann and Acha (2005)

pollination of ideas, learning from others and the combination of different ideas into new products and services more viable (and less expensive). This feature could explain why urban areas are often hotbeds of innovation – there are more people with different ideas and perspectives that stimulate and often absorb new innovations. The spillover effects are higher and it is more likely that ideas developed within specific contexts are exposed to other contexts, leading to shorter cycles of mixing, adaptation, integration and learning.

3.2 Different types and modes of innovation

The work of Joseph Schumpeter[7] has greatly influenced theories of innovation. Schumpeter (1934) proposed a list of five types of innovations:

i) Introduction of new products.
ii) Introduction of new methods of production.
iii) Opening of new markets.
iv) Development of new sources of supply for raw materials or other inputs.
v) Creation of new market structures in an industry.

These five types of innovation are still used in econometric and academic research today. Many scholars make a distinction between product (i) and process (ii), marketing innovation combining types iii and v, and business model innovation.

The most easily identifiable form of innovation is innovation aimed at developing new or improved products and services. In technical products, this product development process may require deep knowledge of how to harness natural phenomena or use certain technology, while in other sectors like the food sector developing a new product may require a good understanding of consumer tastes and different ingredients. Not all new products require a complicated design and development process.

Process innovation is slightly more difficult and involves making improvements to existing products and services or designing completely new products and services, often in an incremental or ongoing way. Process innovation could be aimed at improving efficiency and reducing waste or costs, or it could be the introduction of new equipment and technologies into an existing process. While many smaller companies lack this process improvement ability in-house, even high-tech manufacturers depend on specialists external to the organisation. In places where these experts or specialists are not available, process improvement costs are much higher, and improvements are more difficult to implement. In many industries, product innovation is made possible by new process innovations, so manufacturers which integrate new equipment into their production facilities may be able to offer new products and services simply by upgrading their systems. An interesting phenomenon is that enterprises that are good at continuous process improvement are often able to introduce many more product innovations, as they typically have internal systems for product development, product distribution and knowledge accumulation.

The third kind of innovation is focused on business model innovation and organisational design. This kind of innovation is all about internal organisation, functional specification, combining different kinds of internal expertise, knowledge and technology domains and being able to adapt the strategic management to different in specific contexts. We include innovation in marketing strategies,

[7] Schumpeter combined insights from economics, sociology and history into a highly original approach to the study of long-run economic and social change, focusing in particular on the crucial role played by innovation and the factors influencing it

innovation in supply chain integration, and innovative approaches to co-opting or working with customers as well as improved management models under this heading. Enterprises that can manage innovatively tend to be better at process innovation, resulting in more options and the ability to improve products or services.

There are also different modes of innovation that are important to recognise. In some industries, the Science, Technology and Innovation (STI) mode is the norm, like in biotechnology or materials sciences. For this mode of innovation patents are an important way of protecting investment, thus the intellectual property rights regime is an important aspect. Inventions, new-to-the-world discoveries, are often the result of the STI mode, but this depends on the technological domain and the country context. In STI mode innovations, research collaborations between research centres, universities and firms are commonplace. Research management, research funding and documentation are important aspects of this mode of innovation.

In other industries, such as food production, the main form of innovation is through the Doing, Using and Interacting (DUI) mode, where producers learn (often with their key customers) how to improve product quality, labelling and food standards. This is more iterative than the STI mode. In the DUI mode, informal networks between different kinds of enterprises and institutions are important, and the process of improvement is incremental, based on learning and adjustment of what works. Tacit knowledge is exchanged via personal networks with lower levels of formality, while the STI approach is often more formal, contract based and focused on explicitly documented knowledge. In the DUI mode, proximity to demanding clients, well-defined or articulated problems, and experts with complimentary knowledge are important. There is often a regional or a locational focus of this mode of innovation.

3.3 Incremental, radical and disruptive innovation

In Section 2.3 technological change was discussed. In this section, the "how" behind these observable cycles is explained.

In business management literature a distinction is often made between incremental, radical and disruptive innovation[8]. Incremental innovation introduces relatively minor changes to an existing product, process or technology, while radical innovation is based on a different set of engineering, scientific and business principles and often opens up new markets and applications. While incremental improvements may be small, the cumulative effects of an ongoing series of incremental improvements could be huge.

Incremental innovation exploits the potential of an established design and often reinforces the dominance of established firms. It mainly originates from within the sub-sector or system, and the informed or connected firms are often aware of the changing trends[9]. While it hardly requires new science, incremental innovation draws on incredible skills, deductive reasoning and experience, and over time can have significant cumulative economic consequences. Most businesspeople hardly recognise incremental improvement as innovation, although when prompted, many are able to identify several incremental improvements to their products, processes and organisational arrangements.

[8] While this literature is increasingly popular since the publications of Clayton Christensen, it is not new. Schumpeter (1934) and Freeman and Soete (1997), among others, already wrote about this much earlier.

[9] Several trends, such as the increasingly important knowledge-intensive business service sector, or new ways of sharing and protecting knowledge, play an important role in providing firms with access to new or relevant information.

Radical innovations occur when new technologies are introduced into an existing market or technological domain. In the cycles introduced in Section 2.3, a radical innovation can start one of the change cycles (start a fluid phase), or it can be a blip in the performance of the technology during the amplification or selection phases.

Christensen (2000) argues that both incremental and radical innovations based on a specific technological paradigm often benefit incumbent firms, and describes them as sustainable innovations (for incumbent firms). Incumbents and markets can recognise the benefits of the radical innovation and quickly adapt to it, or integrate it into their operations.

Disruptive innovation is different in that it often favours the new entrants (called the attackers by Christensen), who often combine different product, process and marketing innovation with a different business model. Christensen et al. (2015) explains that disruptors often challenge incumbent firms with new business models, and attack incumbents by targeting marginal or even low-end markets[10]. Firms with resources and adaptive management systems are often able to exit these markets or to shift into new (often higher-value) market segments. While incumbents may be able to adapt their products and processes, it is often a matter of time before newer business models of the attackers outperform their traditional arrangements. There are examples of famous and powerful firms going under or losing market dominance because they were disrupted by a new technological paradigm introduced by actors from another sector. Recent research comparing the US Fortune 500 companies in 1955 and 2017 shows that only 60 firms were in both lists (Perry, 2017). It is already hard enough for firms to stay abreast of technological changes and innovations within their sector and in related industries, therefore many established firms are often blindsided by technologies developed in other sectors that may in future disrupt them[11].

3.4 Architectural vs. component-level innovation

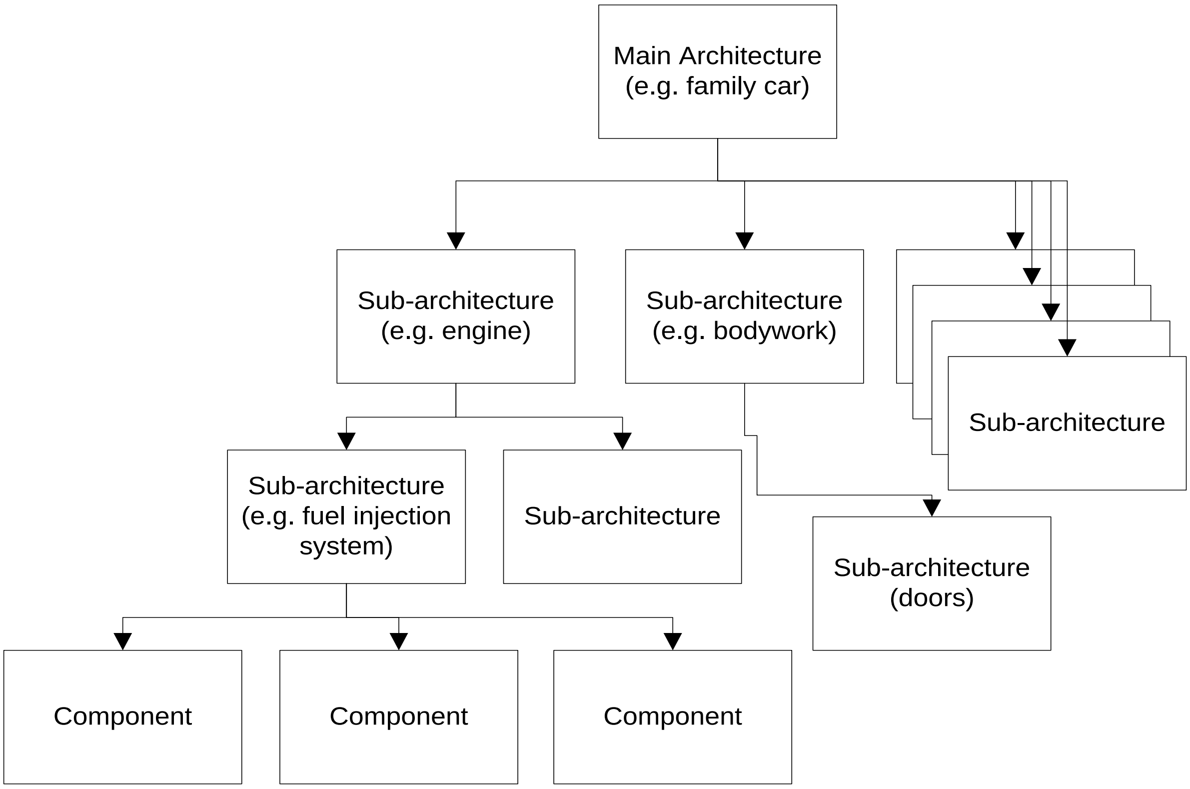
An important distinction can be made between architectural innovation and component-level innovation. The architecture defines the way different components or sub-systems are organised and how they interact with other components. Innovations at the component level, which is a physically distinct portion of the technology that embodies a separate design concept, mostly reduce costs of production, and often take place at high frequency with a wide range of choices available. While the organisations that innovate at the component level are more dependent on past experience as well as economies of scale, the organisations that determine the architecture are able to depend far more on their value addition, as well as the sunken investments of many other agents into the system. To change the architecture of a system requires many simultaneous changes to different sub-architecture and component levels, which may be beneficial to some agents in the system, but not to others (thus vested interests often create a path dependency). A change to the architecture could even disrupt industry structure, and it changes the way the markets judge whether a specific architecture is suitable for the function or tasks it fulfils. A combination of path dependency and architectural change can be used to describe why many industries (or architectures) have disappeared.

[10] Christensen, Raynor and McDonald (2015) argue that from a disruptive theory perspective Uber is not seen as disruptive, as many taxis have been using apps for a long time, and Uber did not really enter the market by starting in underserved markets. However, due to the violent protests by traditional taxi owners, Uber is often described as being disruptive.

[11] An ironic example of a company that failed to recognise one of its own innovations as disruptive is Kodak. Management was so set on its film-based business and technology model that it chose to ignore its own market research that showed the disruptive potential of digital technology that one of their engineers developed in 1975. Not only did digital technology disrupt Kodak, it created many completely new industries, markets and applications.

Figure 3 illustrates the architecture of a family car made up of several sub-architectures (bodywork, brakes, electronics and engine).

Figure 3: An example of architecture and components



Source: Cunningham (2012:16)

However, architectures such as the vehicle example in Figure 3 change slowly over time and can certainly be influenced by improvements at component level. Interestingly, the architecture of the vehicle also forms part of a wider architecture of road networks and urban designs, again reinforcing another higher level of path dependency. Some examples of architectures and components are: desktop computers (architecture) and an internal graphics card (component) or a jet airliner (architecture) and in-air entertainment systems (components).

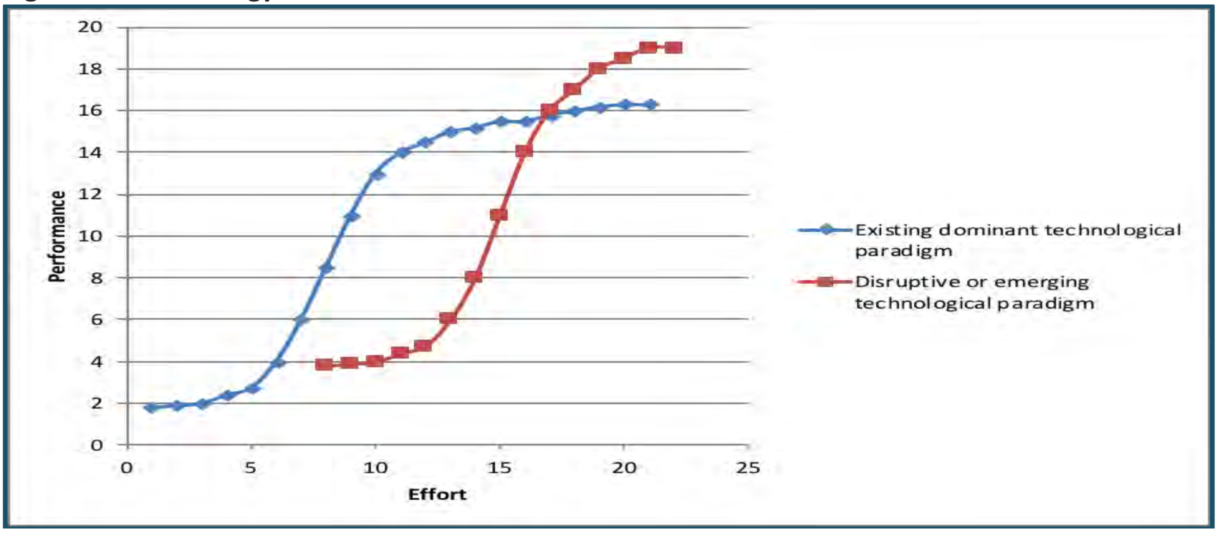
3.5 Technology S-curves

A widely publicised model is the S-curve model that enables the evolution of the performance of a technology (Foster, 1986a; Foster, 1986b). In management of technology textbooks, this model is used to make predictions about the evolution of the rate of technological change, to detect possible technological disruptions, or to determine the limits of a particular technology.

In the S-curve model[12], the Y-Axis tracks performance of a specific technology, while the X-Axis shows effort measured in R&D investment and resources aimed at technology development (see Figure 4).

[12] It is called an S-curve because when the results are graphically illustrated the curve that is usually obtained is a sinusoidal line that resembles an S.

Figure 4: A technology S-curve



Source: Author, based on work by Foster and Christensen

In the beginning of the development cycle of a specific technology, it takes a lot of effort to get performance increases out of a technology (blue line in Figure 4). This phase is often characterised by many different competitors with many different approaches to solving a given technological problem. This is often followed by an exponential improvement curve where the effort pays off with large increases in performance. Typically, improvements to the performance of the technology at this point in time are driven by several incumbent competitors, with many companies if their technologies are not chosen. After a while, the performance increases for every unit of investment (effort) starts to taper and return on investment diminishes. This is where incumbent firms are most vulnerable, as they try to squeeze as much profit from their existing technologies without looking for new investment opportunities even though they are almost completely dominating the market. New entrants find it very difficult to challenge the incumbents in the existing market place, because the incumbents have established a brand reputation, distribution networks and supporting systems.

Clayton Christensen (2000) explains that incumbent firms are often overconfident about the value of their existing technologies and tend to ignore potential new technological approaches. New entrants that are using a different technology aimed at a different market segment might be entering a new steep S-curve (the red line in Figure 4).

The new technology is usually at a lower level of performance than the original technology, and targeting a small, not-so-profitable niche that the incumbent firms are not willing to fight for (as they are benefitting from the scale of their current customer base). The niche market provides the new technology space to innovate in ways to increase in performance, and at some point, the graphs may intersect. This is where whole industries or technologies can be disrupted, as existing customers switch to a new technology that is in an upward performance curve. Christensen and Raynor (2003) explain that incumbents are very often "relieved" to exit small, low-margin markets, and so they constantly upgrade towards higher-margin or higher-volume target markets. This leaves small niche markets for new entrants where demands are not being met. These niche buyers and the new entrants often work together through several development iterations together, until the performance curve of the new technology crosses the incumbent technology in the broader market.

Christensen argues that whether a technology is disruptive or not depends less on how radical it is, but more on its specific effect on the S-curve. If a new development improves performance of an existing technology, then the incumbents are preserved and tend to benefit most as this improvement often suits its current scale of operations. If a technology creates a new S-curve, then it may disrupt existing technology at some point, leading to a disruptive change in industry structure. This implies that radical or incremental performance improvements in most cases benefits incumbents, while disruptive innovation challenges industry structures. In an interesting twist, Christensen argues that incumbents are not ignorant of new technologies and underserved markets. He argues that they are the victims of their own success in making decisions that leverages existing knowledge, networks, markets and capabilities. Ironically, customers may actually communicate that they prefer incremental improvements on existing technologies rather than adjusting to disruptive technology. It is not only the innovator that faces risk and uncertainty, buyers also try to avoid making decisions about technologies that are only emerging, or where performance, results and requirements are vague or uncertain. Decision-making in research and development may also be biased towards the most likely-to-succeed ideas that directs resources away from tinkering or experimenting with fundamentally different ideas.

Existing companies may be able to spot an emerging technology or group of technologies with a potential to disrupt their current market. However, it may still be very difficult to decide when to switch more resources to completely new technologies that may also require different business structures, culture, market and supplier relations (thus switching resources from the blue line to the red line in Figure 4). The performance of the technology is born from the strategy of firms and how they allocate resources to product, process and business model innovation. One way that governments can reduce the costs of incumbents and new innovators to confront, investigate and test new technologies is through technology demonstration and applied technology research, where companies can visit, use or test technologies hosted by public universities. Because companies know that their competitors might be investigating the feasibility of trying a new technology, they themselves are more likely to invest in new skills, in trying the new technology or exploring how this new technology could result in new markets, business models and capabilities.

Gathering all the information that is necessary to construct an S-curve requires time and can be costly. It is especially difficult to figure out which performance criteria and measures of effort to use to construct the graph. However, when a portfolio of technologies is tracked this way it shows not only inflection points, but when certain technologies may outperform existing dominant technologies. A key question that must be answered in constructing this model is whether to track performance change at the level of components (modules), sub-systems or architectures. Furthermore, even if the performance lines cross, incumbents may not switch if their sunk investments are too high, or the learning cost of the new technology is too high. That is why newer companies are needed in the economy, as they might have lower sunk investments and more to gain from higher performance. Over time, resources shift from the old technology to the new, but only if the new technology is accepted and is disseminated sufficiently.

A critique of the S-curve model is that while the graph makes sense, it is often hard to construct and project into the future. It often makes sense ex-post to explain why a given technology outperformed a previous dominant technology. Also, a weakness of the narrow focus on technological performance disconnects the technology from the broader technological and social context, such as the organisation capacity and supporting networks and infrastructure that is required to make a given technology work.

3.6 Chapter conclusion

This chapter looked at innovation and its role in technological change. A distinction was made between invention and innovation. To turn an invention into an innovation, a firm typically needs to combine several different types of knowledge, capabilities, skills and resources from within the organisation and the external environment. Innovations increase profits, reduces costs and creates new markets.

Innovation is often associated too narrowly with research and development activities that are carried out in the high-tech world. The importance of problem-solving and copying ideas from other contexts and adapting them into a local context is often overlooked. Funding is often not a pre-requisite, and in some cases a lack of resources could even stimulate innovation. The importance of innovations in logistics, marketing, supplier development and internal arrangements are often overlooked when a too narrow view of innovation is held. That is one of the key reasons for the dti to increase its involvement with other government departments (like DST and the Department of Higher Education and Training) as well as the private sector.

The willingness of an individual to tinker and explore better solutions is influenced in part by the organisational context of the innovator, but also by factors such as education, qualifications, meta-level factors such as culture, personal characteristics (such as patience, inquisitiveness or tolerance of failure) and the institutional environment. Innovation is a risky behaviour, and companies are more likely to innovate if they are under pressure to be more competitive.

Incremental innovation introduces relatively minor changes to an existing product, process or technology, while radical innovation is based on a different set of engineering, scientific and business principles and often opens up new markets and applications. Radical innovations occur when new technologies are introduced into an existing market or technological domain. This has two implications. First, most innovation is incremental and made up of small improvements at the levels of products/services, inputs, processes/systems and business models. It is not all about products. Second, incumbents are often too busy to keep track of technological developments beyond their industry. They are good at blocking out ideas that could distract them. This is where local institutions that promote technology play an important role in instigating innovation, tinkering and exploration, as well as lowering the costs for new entrants.

An important distinction can be made between architectural innovation and component-level innovation. The architecture defines the way different components or sub-systems are organised and how they interact with other components. To make a change to the architecture of a system requires many simultaneous changes to different sub-architecture and component levels, which may be beneficial to some agents in the system, but not to others (thus vested interests often create a path dependency). The implication is that companies that are part of global value chains are often embedded in broader architectures. These companies must be encouraged to not only remain abreast of new changes, but to continue investing in new capabilities in their supply chains, supporting institutions and at the level of policies and regulations. They can play an important role in helping South Africa to figure out which public good capabilities are missing in the local landscape, both at the level of architectures and components.

Most innovations at component level are incremental, and here factors external to the firm could nullify innovative improvements within the firm. For instance, doubling the performance of a component at the same cost could be of little value if transport costs, shipping delays or compliance costs are not also striving to become more efficient both in costs and efficiency.

It is important to also consider innovation beyond companies. For instance, finding ways to promote cross-sectoral collaboration could also encourage innovation, knowledge transfer and spillovers. As already mentioned, innovation is also not only a characteristic essential to the private sector, the public sector itself should innovate. In countries like Germany there is a long tradition of the public and private sectors innovating together around strategies of how to improve the uptake and further development of digital technologies in the private sector, civil society and the public sector.

4 TECHNOLOGICAL CAPABILITIES AND INNOVATION SYSTEMS

The previous chapters unpacked technological change and innovation. These are phenomena which can be assessed at the level of technologies, individuals, firms and production networks or industries. The importance of innovation within the public sector, and between the private sector and the public sector, were also explored.

This chapter will consider the technological capability in the society, and how this capability can be developed through an innovation systems perspective. It is about understanding the factors beyond the micro layer that affect the ability of firms to experiment with, and apply, new knowledge in order to be more innovative. This typically involves strengthening institutional arrangements and fostering social technologies like trust, collaboration, competition, and so on.

Arthur contends that an economy does not adopt a new body of technologies, it encounters it or is confronted by it (2009:146). The economy reacts to the new body's presence, and in doing so changes its activities, its industries, its organisational arrangements – its structures. Some structures, like incumbent firms and existing institutions might choose to fight or ignore new capabilities. New entrants, or adaptive firms and institutions might embrace these new ideas and may gain a performance advantage despite not having the scale or market penetration of incumbents. Some incumbents and even public funded institutions might adopt new language and labels but stay the same at the core.

This chapter will unpack the structures that affect how a society encounters and responds to new technologies and innovations. The first sub-section will introduce the concept of technological capability and absorptive capacity. The second sub-section will introduce the concept of an innovation systems perspective. This approach highlights the importance of the systemic patterns of interactions between the various components of inventions, research, technical change, learning and innovation. It is related to technological capability, but focuses more on the relationships between actors and the dynamics of exchange than on the institutions themselves. The third sub-section is focused on sectoral patterns of innovation. It builds on Section 4.2, but highlights important sectoral differences in knowledge intensity and how learning takes place.

4.1 Building technological capability

In a seminal work, Lall (1992) emphasised three aspects of what he called "national technological capability":

- The ability to mobilise the necessary (financial) resources and use them efficiently;
- Skills, including not only general education but also specialised managerial and technical competence; and
- "National technological effort", which he associated with measures such as R&D, patents and technical personnel.

Lall further made a distinction between technological capabilities and their economic effects which, he noted, also depend on the incentives that economic agents face whether coming from political decision-making (governance) or embedded in more long-lasting institutions (the legal framework, for example).

Technological capability can be described as *"the ability to make effective use of technological knowledge in efforts to assimilate, use, adapt and change existing technologies"* (Kim, 1997:4). According to this description, technology as the know-how required to develop and apply certain products refers not only to the transfer of know-how, but how knowledge contributes to economic learning in a given social context, country or sector (Fagerberg, 2008). Fagerberg and Srholec (2017) argue that it is not just knowledge of science, technology and knowledge modules that makes up technological capability, but also the ability to combine different types of knowledge related to, for example, finance, logistics, products, markets, production and so forth.

Nelson (2004:365-366) confirms Kim's description and stresses that it is not only about copying what others have done, but about a deliberate process of developing and modifying the appropriate social technologies[13] and institutional arrangements. This process often requires learning from the leaders, and modifying and combining insights to better suit the requirements of developing countries and local contexts.

Nelson contends that it is much easier to copy physical technologies than to master social technologies, which raises two problems for countries wanting to catch up. The first, which is to make physical technology work effectively, is a real challenge for developing countries as it requires a wide range of social technologies. He says that it is easier, for example, to import a machine than to organise a firm and its management structure or to acquire specific inputs or do marketing. The second problem that he raises is the nation's broad institutional infrastructure, the operation of particular institutions such as educational and financial systems, and its system of public research and advanced training (Nelson, 2004).

Fagerberg and Srholec (2015:22) build on these arguments of Kim and Nelson and explain that *"while technological capabilities to a large extent are attributes of firms, social capabilities are characteristics of the social environment that firms share, and that influence firm's operations in various ways, from being a source of much needed resources, such as skills, to for example providing an institutional and legal framework for firms' activities".* They continue *"that although politicians may influence the development of technological capability, and many examples – not the least from the emergence of the Asian Tigers as technological and economic powerhouses in the world economy – testify to that, their say is probably even larger when it comes to social capabilities".*

4.2 Improving absorptive capacity

A distinction can be made between technological capability and absorptive capacity, even if these terms are often used interchangeably.

UNCTAD (2014:23) defines absorptive capacity as *"The ability to recognize the potential value of new or novel knowledge and technology, and to transfer and assimilate it with the objective of bringing to market a product or a service. It determines if and to what extent a firm, an industry or, indeed, an economy, can use existing and new knowledge to compete."* The concept of absorptive capacity was first introduced by Cohen and Levinthal (1990) who argued that:

- Firms invest in basic research less for particular results than to be able to provide themselves with the general background knowledge to enable them to rapidly apply scientific and technological knowledge through their own innovations, or to respond quickly when competitors come up with a major advance. **Thus firms do research to increase their knowledge base and learning which enables them to innovate when they need to.**

[13] Nelson stresses that these social technologies are not conventional technologies, but rather concern complex processes of how a wide range of people and organisations are organised and governed. Behind the scenes are processes to recruit, retain and even release different kinds of workers. This is all supported by another layer of institutions that supply education and other services, and so on.

- The relationship between the absorptive capacity of firms and the broader technological capability present in the environment causes firms to be highly sensitive to the context within which they operate. **This larger context not only provides inspirational ideas, but the implementation of the ideas depends on resources from this larger context, such as technical experts or specialists, professional, management and vocational skills, and even standards and financial or regulatory systems.**

Cohen and Levinthal (1990) contend that the absorptive capacity of firms is more likely to be developed and maintained as a by-product of routine activity when the knowledge domain the firm wishes to exploit is closely related to its current knowledge base. This is different when a firm wishes to acquire and use knowledge that is more distant from its ongoing activity. The firm must then dedicate effort and resources to create absorptive capacity. It is hard to imagine how this can be done without reaching out to networks of institutions, skilled and professional employees, and networks of suppliers that are all striving to increase their relevant knowledge. Zahra and George (2002) explain that absorptive capacity has two sub-sets of potential and realised absorptive capacities at the level of firms.

- Potential capacity comprises knowledge acquisition and assimilation capabilities, and includes the ability to strategically manage change.
- Realised capacity centres on knowledge transformation and exploitation.

Zahra and George argue that absorptive capacity is a dynamic capability that influences the nature and sustainability of a firm's competitive advantage (2002).

4.3 Strengthening absorptive capacity by building technological capability

While the preceding arguments of absorptive capacity are mainly about individuals and organisations, increasingly scholars argue that it is a systemic capability that can also be measured, developed and induced beyond the level of firms.

Hidalgo (2015) explains that with the increasing sophistication of technology, the ability of organisations to have all the relevant knowledge in-house diminishes. Therefore, knowledge is being increasingly distributed among larger numbers of actors, spread over organisational and even territorial boundaries, who need to work together dynamically to produce and transact. Knowledge tends to flow more easily where there is a certain density of diverse actors. A whole range of actors, publicly funded organisations, key suppliers, and demanding local and international buyers, all contribute to making this technological capability possible (see Section chapter 4.1). It is also important to note that knowledge does not only flow through formal structures during business hours, but that knowledge also flows through social networks and events. This is one explanation of why innovation is increasingly an urban phenomenon that is greatly enhanced by the diversity of the urban economy.

Hillebrand et al. (1994) argue that technological capability is built on four pillars:

- The skill of the producers to imitate and innovate at product, process and business model levels. This is largely dependent on pressure to compete as well as pressure to collaborate with each other.
- The economic, political, administrative and legal framework conditions determine whether there are incentives to develop technological capability. In the past, it was often not recognised that these incentives were lacking in many developing countries.

- Direct support by technology-oriented state institutions or specific types of knowledge-intensive service companies depends on the existing level of development, the competition situation and the characteristics of a technology branch in the given country. These organisations disseminate technical and expert knowledge between different actors, knowledge domains and industries, and play a crucial role in the use and application of tacit and explicit knowledge.
- Indirect support by the public and private educational systems – in addition to a sound basic education, it is important that technical training of a suitable quantity and quality is available at secondary school level and also in the universities. The private sector often plays a role in short-term training aimed at particular technology applications. Overall the education sector must be able to identify and respond to changes in the application, development and use of technology in society.

The close interaction between these four pillars creates technological capability. Thus technological capability differs between countries and even within countries because the context and the dynamics of interaction differ. A single firm may, in the short-to-medium term, manage to get a sophisticated product into the market, however, to sustain its position it will sooner or later need to tap into the education system, the knowledge networks of intermediaries and technology experts, or into supplier networks. It is not enough to have a handful of companies that are able to innovate, explore new technological applications, or combine different fields of specialisation in one enterprise successfully.

In Chapter 2 it is argued that technology proceeds out of deep understandings of natural (increasingly technological) phenomena, and these become embedded as a deep set of shared "knowings" that resides in people and establishes itself locally – and that grows over time (Arthur, 2009:162). This is one possible explanation why countries that lead in scientific inquiry lead also in technology development and application. Although this may seem contrary to the argument that innovation is not linear, the opposite is true. Knowledge is iterative, it builds on what exists before much like innovation; it grows through re-combination, application, reflection and adaptation of existing knowledge modules. Individuals and groups that have mastered difficult concepts in the past (through for instance their academic qualifications) are often more able to muster the discipline to master new difficult topics and concepts.

The ability of a country to excel in knowledge and technology-intensive domains (like scientific research, but also philosophy and other knowledge domains) also fosters capability in exploiting synergies between different fields of specialisation, developing different kinds of complementary infrastructure, and being able to balance longer-term and shorter-term development projects. It thus requires the co-evolution of physical technologies and social technologies. It depends on the ability to play with abstract ideas and concepts, and to mentally simulate how the application of a technology, regulation or the creation of new institutional forms can play out in the short and the longer term.

The implication is that if a country wants to participate in developing, adapting or leveraging new technology, or wants to closely follow or catch up to advanced technology, it needs to do more than invest in industrial parks, clusters of similar firms, or vaguely foster innovation at the level of firms and institutions. It needs to intentionally build its basic science without any stated purpose or commercial objective. It needs to decouple the outputs of research and academic pursuits with the process, with the latter being more important. Encouraging the growth of different scientific fields could be seen as creating building blocks that can be drawn on by society to create new combinations. By purposefully investing in the development of emerging technology domains, what comes into being is not a new device or method, but new vocabularies for expression – new languages for programming new functionalities into the society or context. At the same time, investments must be made into reducing the risks and costs of trying new ideas, building trust, and finding novel ways of cooperation and collaboration. This should include paying attention to social security (in case of failure), making it easier for people to start or close business, and making it easier for people with unique skills from abroad to enter into the local labour or business market.

Drawing again from Hillebrand et al. (1994), this technological capability gives the ability to scrutinise and grasp what technology components are available, to assess and select a technology, to utilise it, to adapt and improve it, and, finally, to develop technologies independently. Technological capability encapsulates the distributed ability of a country, region or industry to learn a new technical language, to integrate relevant new ideas into current practices (innovation), or to explore how new ideas can be applied to solving local problems or exploiting local opportunities (innovation). Technological capability is a key pre-requisite to the capacity for self-help. However, not all firms are able to tap into this internal asset, mainly because many are managed in a way that does not allow them to reflect on their own patterns of behaviour or the trends affecting their performance (Zahra and George, 2002). When the day-to-day emphasis is on survival or routines, a tendency to underinvest in purposeful innovation activities may occur. This behaviour not only undermines the development of the internal knowledge base, but will also lead to underdevelopment of external networks that could lead to exchange or transactions with other knowledge sources. The ability of companies to be managed strategically again highlights abstract capabilities that often derive from non-technical fields such as business studies, resource availability and so on.

A last argument must be made about the role of knowledge accumulation and adaptation. Central to the concept of absorptive capacity is knowledge and the ability of individuals, teams and networks to gain more knowledge, often through an iterative process. Cunningham (2012) states that this knowledge may be acquired in two different ways:

1. In a solitary way where knowledge is gained through **experimentation** (as an individual or as part of a team) without much communication or interaction with other external actors, or through a process of **deductive reasoning.** Or it may involve a combination of tinkering and deduction (often referred to as deductive tinkering).
2. By **purposeful interaction with other external agents** involving personal or non-personal communication with other people, specialists and knowledge sources.

The first point is mainly about absorptive capacity of the organisation or individuals. However, the second is a combination of absorptive capacity of the team, and the broader environment in which the organisation can reach out to other experts beyond its own boundaries. Cunningham goes on to say that a large part of the knowledge a firm needs is available internally, namely the knowledge of its engineers, managers, technicians and other employees. Their knowledge is partially acquired externally through previous formal training, and partially through a cumulative process of learning-by-doing. This internal knowledge, which is available at any given time, is the main innovation resource of a firm. It is often highly tacit, which explains why firms of a particular type cluster together in regions despite the huge advances in information technology, global communications and search engines. To again emphasise, this ability to leverage knowledge to be innovative is an essential characteristic of a healthy workplace, with knowledge emerging within a specific context. There is also evidence to suggest that the more diverse an organisation or region is in demographics, expertise and areas of specialisation, the more innovative opportunities exist. However, this would require a strong leadership team that can draw in the different voices, opinions and types of expertise, and healthy working relations between different interest groups. These are social technologies that must be developed in the private, public and civil sectors.

Learning from others is only possible if the costs of interaction with peers and other organisations are low enough or if the density of networks makes this possible. Malerba (2005:387) states that *"knowledge is highly idiosyncratic at the firm level, does not diffuse automatically and freely among firms, and has to be absorbed by firms through their differential abilities accumulated over time".*

This accumulation of knowledge often emerges through an iterative cycle combining deduction, experimentation, application, reflection, learning and adaptation between people working on the same problems or opportunities. Hence knowledge often flows easier within technological domains and industries than between them, and the speed of absorption also depends on the density of interaction between different stakeholders, supplier networks and markets.

The implication is that in economic development the focus should be on those firms, organisations and sectors that are able to innovate and absorb new ideas, and find ways to accelerate their learning journey.

As these more "learning capable" firms and organisations master new capabilities it becomes easier for industries and groups that grow at a slower pace to absorb and learn from their experience. This technology and knowledge transfer from leading to lagging sectors or domains often take place through the mobility of individuals, through the emergence of an ecology of supporting industries, institutions and service providers, and through the adaptation of formal and informal education programmes. It can also be encouraged through cross-sectoral problem-solving, collaboration and networking. While this could be a natural process in some instances, in most cases it requires an active innovation systems promotion strategy to ensure that institutions or channels for transfer, absorption or dissemination are built, and that the costs or risks of adaptation are reduced for the rest of the economy. This must be done so that future entrants and lagging industries can upgrade and step up and be more innovative and efficient than the incumbents.

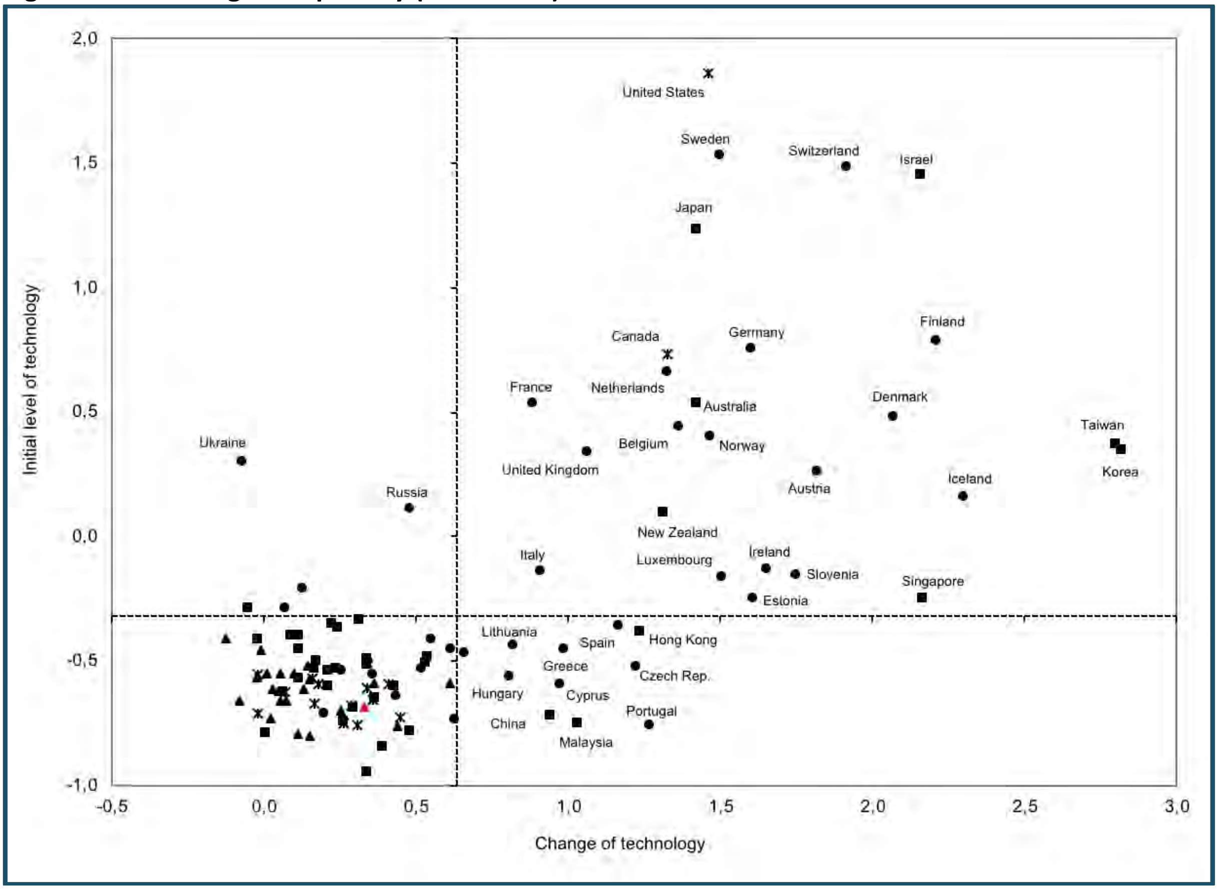
4.4 Assessing technological capability

Fagerberg and Srholec (2017; 2009) have developed a methodology to assess the technological capability at a high level with a particular focus on developing countries. In the case of technological capability, the indicators taken into account in their model include the quality of a country's research system (as reflected in scientific publications), invention and innovation (as measured by patent applications and R&D expenditure), and development of the ICT infrastructure (proxied by Internet users). With social capability, the authors were able to include two broad dimensions, the first of which is the skill level of the population (as reflected in primary, secondary and tertiary attainment and literacy). A second dimension refers to the quality of the governance in a country. Indicators considered in this case include measures of how effective the government is, the extent to which corruption is a problem and, finally, whether law and order prevails[14].

Fagerberg and Srholec plotted their analysis in Figure 5, with the position of South Africa marked in red in the bottom left quadrant.

[14] The authors conducted a factor analysis that resulted in the identification of three different capabilities, labelled Technology, Education and Governance, respectively. Technology is highly correlated with R&D, patenting, scientific publication and the proliferation of the Internet but also, to a lesser extent, with tertiary and secondary attainment. Education loads particularly highly on the two most basic education indicators, literacy and primary attainment, but also on secondary and tertiary attainment. Finally, Governance is highly correlated with government effectiveness, (lack of) corruption and the prevalence of law and order

Figure 5: Technological capability (1995-2013)



Source: Adapted from Fagerberg and Srholec (2017)

The graph plots the development of a country's technological capability over the period 1995-2013 against its initial level in 1995. In this way four quadrants appear. Up to the left, in the quadrant labelled "losing momentum", are countries with a high but stagnating (or declining) technological capability. Very few countries appear in this category. In contrast, the countries in the top right quadrant combine a high initial capability level with an above-average capability increase. Hence, these are countries that are "moving ahead" technologically. Korea, Taiwan, Israel and Finland are examples of countries that particularly excel, but many other developed countries also belong to this category. Another group of countries with above-average performance can be found down to the right. These countries, a mixed crowd of Asian (China, for instance) and European countries (from the Southern and Eastern part of the continent), are "catching up" technologically from a relatively low initial level. Finally, in the quadrant down to the left we find countries that are "falling behind" technologically, i.e. countries that combine a low initial level with below-average performance. Many countries in Africa, Latin America and Asia belong to this category. South Africa falls in this area. Fagerberg and Srholec (2017) conclude that technological and social capabilities cannot be untied, they are closely related. Firms not only draw on technological capabilities to innovate and adapt, they also draw on the social environment, local resources, the legal frameworks and so on.

As a side note, Fagerberg and Srholec (2017:916) have also found that in many countries with a medium to low level of development, the major contribution tends to come from diffusion of ICTs. This is particularly notable for the "catch-up" and "transition" groups. This is typically achieved through for instance technology demonstration, education and making technology available to firms through, and for instance technology extension. Investments in key ICT infrastructure and education is critical to enable this. Fagerberg and Srholec (2017:916) further find that at a higher level of development, growing "innovation capabilities" as reflected by increases in science, R&D and patenting are of much larger significance, as about three-quarters of their high increase come from such sources. While much of South Africa's science, technology and innovation focus is aimed at these kinds of activities, it would appear that more emphasis should be placed on diffusing technologies and encouraging uptake through experimentation and extension. For instance, if "the internet of things" becomes more widespread, South Africa should invest in technology promotion, demonstration and education at all levels to ensure that companies, individuals and communities are not left behind.

Arthur (2009:163) concludes that *"Building a capacity for advanced technology is not like planning production in a socialist economy, but more like growing a rock garden. Planting watering and weeding are more appropriate than five-year plans".* This art of "building rock gardens" is known in the academia and policy field as strengthening innovation systems. This will be discussed in the next sub-section.

4.5 Strengthening the innovation ecosystem

The preceding sub-section laid a foundation of how technological capability and absorptive capacity in countries can be developed. This section will explain how to strengthen the health and dynamic of a country or an industries technological capability through the innovation systems logic.

The innovation system approach searched for ways to better understand the feedback and learning loops in which knowledge and innovation are created in societies. Early scholars concluded that there are not only market failures in the expenditure of R&D, but also system failures in which knowledge is not transferred or does not lead to learning loops that are based on market demands.

While support for R&D-based Science, Technology and Innovation (STI) policies was one issue, overcoming system failures essentially required a better understanding of how demand-driven and product-related knowledge is created in specific contexts, how learning emerges, and what complex interactions between science, institutions, businesses and policies lead to the most effective way to develop new products and new processes that responds both to local demands and global opportunities. It is thus about building and strengthening the technological capability and the dynamic in a country, region or an industry.

Christopher Freeman was one of the early scholars who laid strong foundations for the study of innovation systems. Freeman (1987:1) defined an innovation system as *"the network of institutions in the public and private sectors whose activities and interactions initiate, import and diffuse new technologies".* Lundvall (1992:10) argued that the structure of production and the institutional set-up are the two most important dimensions that jointly define an innovation system. While the mandate to steer the national innovation system in South Africa rests with DST, many of the structural issues, economic incentives, trade opportunities and elements of the technological capability rests with other departments including the dti. It means that the close collaboration between the dti and DST is essential and should be intensified.

Most research into innovation systems draws on evolutionary and complexity theories, building on the seminal work by Nelson and Winter (1982) and others, in which economic growth and technological change are seen as endogenous to the system (Nelson, 2015; Romer and Link, 2008; Nelson and Winter, 2002). **The emphasis is mainly on the dynamics, process and transformation of knowledge and learning into desired outputs within an adaptive and complex economic system**.

The innovation system approach spells out quite explicitly the importance of the systemic patterns of interactions between the various components of inventions, research, technical change, learning and innovation (Freeman and Soete, 2009; Soete, Verspagen and Ter Weel, 2009). Thus the interplay between knowledge application and absorption, and different kinds of innovation and learning by doing as an interactive process is more important. UNCTAD (2014:23) contends that *"An innovation system is the key to capturing tacit knowledge because it is developed over time through practice and interactions in environments specific to a particular technology. The effectiveness of a national innovation system will, therefore, be largely defined by how it incentivises and supports such learning interactions."*

Although most of the research and literature on innovation systems have similar origins, there are small yet important differences between the various schools of thought. In general, three slightly different perspectives on innovation systems are described in the literature, namely[15]:

- The national innovation systems perspective – brings to the forefront the central role of the state as a coordinating agent of public resources.
- Local or regional (sub national) innovation systems – the key characteristic of a local or regional innovation system is that it mainly focuses on a specific geographic space and on the specific knowledge spillovers that occur around certain firms, industries or institutions unique to that space.
- Sectoral innovation systems – according to (Malerba, 2005), the emphasis of sectoral innovation systems is on a group of firms that develop and manufacture the products for a specific sector and that generate and utilise the technologies of that sector. The boundary of the system is drawn around a technological paradigm that is formed by a knowledge base, specific technologies and inputs, the different actors and networks that are systemically interacting, and the institutions supporting a specific industry.

Of these three approaches, the national innovation systems logic is dominant in South Africa since the creation of the Science and Technology Whitepaper in the late 1990s. In the period 2005-2011 there was an initiative in the DST to support sectoral innovation systems through establishing a range of technology stations hosted at universities. This programme was supported by the German Development Cooperation (GIZ). These technology stations offered technology extension services to industries. Although the Technology Stations Programme still exists, it does not identify so strongly with the sectoral innovation systems approach anymore as it is mainly measured on demographic, product and firm-level indicators.

In a recent handbook that deals with innovation systems in development, to which many of the leading scholars of innovation systems contributed, the editors proposed a revised definition of innovation systems that encapsulates more than 20 years of development of the field: *"The national innovation system is an open, evolving and complex system that encompasses relationships within and between organisations, institutions and socio-economic structures, which determine the rate and direction of innovation and competence building emanating from the process of science-based and experience-based learning"* (Lundvall, Joseph, Chaminade and Vang, 2009).

In many countries, the responsibility for innovation policy increasingly spans several ministries and government levels, and frequently involves non-state actors (Edler and Fagerberg, 2016:16). Innovation policy is seen as an important cross-cutting approach to solving social, environmental and local issues on topics such as climate change, water scarcity, unemployment, rapid urbanisation, quality of life and technological convergence.

In a paper commissioned by the GIZ, Kraemer-Mbula (2011:4) describes innovation systems as the landscape in which capabilities inside a country or a territory can emerge. This definition emphasises

[15] For a more detailed comparison see Cunningham (2012)

the importance of the development of tacit knowledge and the informal ways in which it emerges. She emphasises that it is the context that matters, as does the "ecology of organisations" and the interaction patterns between public and private actors. Thus the innovation system approach does not only look for the existence of institutions and policies and R&D expenditure, because this does not tell whether knowledge and applied knowledge for, and with, the private sector is developed in a creative and innovative way. Instead, it analyses the type and learning-oriented quality of interlinkages between certain business clusters, associations, non-government organisations, unions, universities, R&D institutions and political and policy structures.

Accordingly, promoting innovation systems requires much more differentiated policies; a highly sophisticated understanding of policy interactions and network-driven requirements by ministries, support institutions; a much deeper understanding of market demands; and related joint technology-push and demand-pull cooperation relations between private and public sector representatives.

The implication is the innovation system which emerges in a specific context is never static and is always in a continuous process of change. Nonetheless, the ecology of organisations and policies is still shaped by past decisions (it is path dependent) and a wide range of environmental factors. For firms, the different innovation systems around the firm are invisible, and any particular firm can be part of several different kinds of innovation system simultaneously without even being aware of these systems.

With innovation policy, the innovation system approach is not primarily about the creation of new ideas, or a linear approach to science resulting in development and then innovation or commercialisation (the domain of traditional science and technology policy). Edler and Fagerberg (2016) argue that increasingly innovation policy is about trying to exploit such ideas in practice in order to enhance competitiveness and respond to problems or challenges that arise within a given context. They emphasise that it is this "problem-solving" nature of innovation that potentially makes innovation a relevant force for dealing with important social and economic issues that politicians care about. Innovation policy is therefore particularly relevant when politicians are able to clearly define problems that they want innovation to respond to. An effective innovation policy is one that provides direction to a firm's innovation efforts, and that is credible and not subject to frequent, unpredictable changes. This policy direction creates incentives, it reduces risks, it raises interest and it mobilises resources. Understood in this way, innovation policy may be a powerful tool for transforming our economy in fundamental ways.

Innovation systems can be addressed at the national, sectoral and regional levels. In each of these there are a slightly different set of stakeholders, priorities and issues that must be addressed. Much of the preceding text has dealt with a national perspective. The next section will focus on a sectoral innovation perspective as it aligns with the dti's industrial policy framework.

Sectoral innovation systems researchers distinguish between high R&D-intensive sectors (such as electronics or drugs) and low R&D-intensive sectors (such as textiles or shoes)[16]. These systems change over time as the different elements co-evolve. Furthermore, sectoral innovation systems could transcend and connect different local, national or international borders. However, not all sectors are equally innovative. Some sectors are net innovators of key technologies (computers and instruments) while others are net users of new innovations (textiles and agriculture).

[16] See Cunningham (2012)

A key difference between different sectors lies in the sources of innovation and the appropriability mechanisms. Pavitt (1984) proposed four types of sectoral patterns of innovation activities that are still relevant today (see Table 1).

Table 1: Four types of sectoral innovation patterns

Type of industry	Main sectors	Main features			
		Source of process technology	**Balance between process and product innovation**	**Relative size of innovating firms**	**Appropriability or diffusion of technology**
Supplier-dominated	Agriculture, housing, private services, traditional industries	Suppliers	Process	Small	Diffusion of new technologies and learning take place by learning-by-doing
Scale-intensive	Bulk goods (steel, glass), assembly lines	In-house R&D, equipment suppliers	Process	Large	Appropriability is obtained through secrecy and patents
Specialised suppliers	Machinery, instruments	In-house R&D, customers	Product	Small	Appropriability comes mainly from the localised and interactive nature of knowledge
Science-based	Electronics, chemicals, software, engineering	In-house, suppliers	Mixed	Large	Science is a source of innovation, and appropriability means are of various types ranging from patents to lead times and learning curves

Source: Cunningham (2012), adapted from Pavitt (1984) and Malerba (2005)

The dti would have to approach different sectors in different ways based on Table 1. It would be valuable to map the different public programmes and incentives into these categories.

4.6 Chapter conclusion

Technological capability can be described as *"the ability to make effective use of technological knowledge in efforts to assimilate, use, adapt and change existing technologies"* (Kim, 1997:4). It is not just about using and mastering technology, but about creating and innovating in relevant social technologies. Ways to reduce the costs of trying, learning about and applying new technologies must be found. However, there is a risk that this may only be attractive to techno enthusiasts and pioneers. Therefore, a key way to encourage capability development is to use complex problems as a means to draw in different sectors, areas of specialisation, types of companies and their supporting institutions.

A different but related concept is absorptive capacity, which is the ability of individuals, organisations and societies to recognise the value of new knowledge and technology, and to then transfer and assimilate it. Absorptive capacity can be strengthened by building technological capability. Technological capability is built on four pillars. The first is the skill of the producers to imitate and innovate at product, process and business model levels. The second is the framework conditions that shape the incentives to innovate. The third pillar consists of the technological institutions that disseminate technical and expert knowledge between actors, knowledge domains and industries. In South Africa these institutions are not so visible beyond the Council for Scientific and Industrial Research (CSIR) and the universities. There is not a map of institutions or regular assessment of South Africa's technological capability on a regional, sectoral or domain level. In many cases, access to higher technology institutions have high entry barriers as there is not much of a focus on technology demonstration, knowledge dissemination and public education. The final pillar is the responsiveness of the public and private education system to technological change. The education funding crises of the last few years have diverted attention and resources away from building technological infrastructure at public education institutions. Furthermore, these centres are often incentivised to either participate in commissioned research, or to sell services to companies that can afford to pay. Finding alternative ways to fund technological extension, and providing problem-solving support, product testing, etcetera, are underfunded and not seen as a priority.

The close interaction between these four pillars creates technological capability. This close interaction depends on network governance and collaboration between the public sector, the private sector and civil society. While some would argue that the development of technological capability is a natural process, from the research it appears that this only really happens if networks, collaboration, joint problem-solving, and inclusive search and discovery processes are undertaken regularly and at different levels.

5 HOW MESO INSTITUTIONS ENABLE SELF-DISCOVERY, INCREASING LEARNING AND RESILIENCE

Diversity (or variety) of options is a prerequisite for evolution to work. In natural evolution, variety is created by random mutations in DNA, while variety in the economy is created through an ongoing process of self-discovery at different levels, involving different segments of the society (Hausmann and Rodrik, 2003). Rodrik (2000) states that this process can be called a meta-institution. He argues that if it is democratic and participatory, this kind of arrangement typically results in higher-quality growth. This discovery process draws heavily on the ability of groups of organised people in business, government and civil society to conduct a process of combining existing ideas with new ideas in novel designs. It involves both reflecting on the status quo, and imagining alternative arrangements. Nelson (2003:20) stresses that *"some of our most difficult problems involve discovering, inventing and developing the social technologies needed to make new physical technologies effective"*. The more distributed this kind of search is, the better the variety created and the stronger the resilience of the system becomes.

Businesses that are able to generate or recognise modules that work better and that can be repeated elsewhere by drawing on their past experiences have a huge advantage over businesses that are not able to do so (Dosi and Nelson, 2010; Beinhocker, 2006; Nelson and Winter, 1982). Schumpeter already argued some time ago that innovation consists of *"the carrying out of new combinations"*, with many of these combinations depending on past knowledge or understanding of physical, social or economic properties (Schumpeter, 1934:65-66). Dosi and Nelson (2010:103) argue that the ability of firms to learn, adapt and innovate is generally highly heterogeneous, idiosyncratic and unevenly spread.

Not all the knowledge needed to conduct ongoing discovery processes is available within a single individual or organisation. Hence social infrastructure, technology, education and business networks are important in connecting organisations into broader networks of knowledge (Hidalgo, 2015). The factors within firms and beyond firms can be collectively described as the technological capability (see Section 4.1), and the dynamic of how these factor influence each other in an ongoing process of learning, dissemination and adaptation is typically referred to as the innovation system (see Section 4.5).

5.1 The social technologies that enable evolution, learning and adjustment

With the dissemination of new knowledge and technologies to firms, a few factors typically inhibit this process. One is the fixed cost of the new technology itself. This could both be the cost of finding the right solution, or the cost of acquiring the technology. All other investments required to optimise or leverage a new technology could also make the investment outside of reach. A second aspect relates to the social costs and complementary institutional or physical infrastructure needed to fully utilise a new technology. For instance, a driverless car could still be affordable, but all the changes needed in road rules and in driver behaviour might make the acquisition of a driverless vehicle senseless. These other changes and co-investments are the focus of structural change.

Hausmann, Rodrik and Sabel (2008) argue that structural change must overcome three main types of failure that hamper economic development:

a) **Self-discovery externalities**: Learning between different "agents" about which new products can be produced profitably in an economy, and how.
b) **Coordination externalities**: New local economic activities are often required simultaneously by different investors upstream, downstream and in parallel or in related industries. For

instance, to promote a circular value logic would require stakeholders that may not even be aware of each other's existence or interests to develop new concepts along a new value chain that does not yet exist.

c) **Missing public inputs**: Private production typically requires highly specific public inputs – legislation, accreditation, R&D, transport and other infrastructure specific to an industry – of which government institutions often have little up-front knowledge.

For the evolutionary process to work, it is essential that entrepreneurs and a wide range of social actors have an interest and the incentive to discover individually and together more of what is possible. This applies both to organisations or workplaces, but also between different stakeholders and segments of the society. Central to the process of self-discovery is the generation and use of information and knowledge. Some of the elements of this knowledge could be public goods when they are non-rival or non-excludable. These public goods are mostly provided by a range of publicly funded organisations that are responding to temporary and permanent market failures. Their presence typically encourages problem solving, learning, upgrading and collaboration towards improved competitiveness and economic development.

5.2 The role of a dynamic meso organisations

A range of organisations, often publicly funded, play the role of enabling discovery, reducing costs of exploration and transforming codified knowledge into regulations, standards, organisations and development programmes. When these organisations emerge, new entrants are likely to be at less of a disadvantage than incumbents – they still have less experience but they can draw from the latest knowledge (Nelson, 1995). For example, universities play an important role in lowering the costs of gaining access to new knowledge, codified knowledge and research.

Investigations of successful economies show that dynamic locations and countries have an institutional structure in place that allows both private and public actors to organise rapid and effective learning and decision-making processes, and to provide a specific business support environment in accordance with continuously emerging and changing requirements (Esser, Hillebrand, Messner and Meyer-Stamer, 1996).

The meso level is especially important for strengthening the competitiveness of a territory and/or a specific sub-sector that has often been underestimated or is underperforming. In many developing economies, the meso level is very thin or even non-existent.

Neither the market alone nor a centrally led development state can structure the economic environment and effectively strengthen locational factors. Meso organisations such as local development agencies, extension centres, technical institutions, development banks, or knowledge facilities play an important role in the process of promoting local economic development. They engage in information provision, coordination and knowledge creation. If they are working well, it means they understand the business sector's needs as well as strategic policy requirements. This gives them the ability, on the one hand, to feed information and support requirements back from the business world to the designers of targeted policies. On the other hand, they deliver targeted support programmes to overcome market underperformance in line with the wider policy environment. Thus the dynamics, diversity and adaptability of these organisations are crucial in improving the competitiveness of a territory. This is particularly true in a time when globalisation has increased the mobility of goods, people and ideas, and tacit knowledge and local learning are becoming more and more important in creating a dynamic locational advantage.

5.3 Functions performed by meso organisations

For certain services to be delivered, it is necessary to create a dedicated organisation or add a mandate to an existing one. Such services are often not provided naturally by the market, either because their function is to provide public goods or because trust in an institution needs to be established first. For all these reasons, individual businesses are disincentivised to invest in these services (see Table 2).

Table 2: Examples of services offered by meso organisations

	Technology	Education and training	Finance	Infrastructure	Foreign trade	Entrepreneurship	Business membership associations
Basic functions	Measure-ment, standards, norms, quality assurance	Secondary and higher education in basic disciplines	Credit, Investment capital	Basic infra-structure: roads, water, electricity, telephony	Basic foreign trade transactions	Awareness-raising on potential of entrepreneurship	Elementary services Ad hoc lobby
Advanced functions	Technology transfer	Vocational training in specialised disciplines	Develop-ment banking Micro-finance Collateral banking	Reliable, efficient, high-quality infrastructure	Export financing Export credit insurance	Entrepreneurship training, business skills training Business Development Service market facilitation	Specialised services Business networking
Specialised functions	Specialised R&D	Highly specialised, high-quality training courses	Specialised, innovative financing Venture capital	Specialised, innovative infrastructure	Advice and support for market research, design, packaging, etc.	Business incubation, business acceleration	Compre-hensive services Active role in locational policy

Source: (Meyer-Stamer, 2005)

While the examples of typical activities in Table 2 are directed towards firms, meso organisations also play an important role in advocating for policy change and shaping public sector strategies at the policy level, based on their insight into the incentives and behaviours of enterprises. Very often these organisations must balance the requirements of the micro-level actors with the priorities of policymakers or funders.

To find opportunities for improvement, or to address binding constraints, meso organisations must typically work with other stakeholders, conduct all kinds of diagnostic processes, and formulate improvement processes over the short, medium and longer term. An example is a standards body that assists enterprises to meet international and national standards.

5.4 The adaptiveness and responsiveness of meso organisations

Meso organisations need to be innovative because their management style and creative use of resources infuses the system with dynamism, optimism and new ideas. But meso organisations not only need to be creative and innovative to be good examples to local enterprises, they also need to adapt and update their services to new requirements and changes in the environment. They need to innovate, not only in the way they design and offer their services to the businesses in a region, but also in the way they enable these businesses to become more innovative and competitive in a dynamic global market place.

Meso organisations are in a unique position to anticipate future trends and adapt to them early on. From their vantage point, when they can move between different market actors, they are able to detect small shifts in the way things are done, identify pioneers who overcome boundaries in innovative ways, or detect new capabilities in the system. In addition, they need to continuously screen what happens beyond the region and how the national and international trends could influence their region – and what this means for their offering.

When meso organisations become better able to detect change in others and adapt to these changes, the dynamic of the whole system improves. Meso organisations are important for disseminating knowledge about new opportunities, changes in conditions or innovations, while at the same time they need to be able to adapt their offerings to changing demands. In this way, they lower the barriers to upgrading and increase the pressure on enterprises to use new capabilities and resources to become more competitive.

It is not enough, however, for meso organisations to detect small changes after they have happened. These organisations also need to anticipate future pathways and scenarios, and to guide and support enterprises in their process of discovery of what is possible within their context. This means that the offerings of meso organisations cannot only be shaped by what incumbent firms are willing to try or demand, but must constantly assess what the new entry requirements are, and what capabilities, resources and sources of knowledge may be needed to enable enterprises to adjust or for new business to be established in a dynamic, competitive environment.

Various future search methods that can help meso organisations prepare for the future include scenario development and technology road mapping. At the same time, meso organisations that stay in touch or closely follow mavericks and innovators will also be exposed to what is possible despite the conditions or obstacles in a marketplace. To prepare for an unpredictable future means that the meso organisations must purposefully create a variety of options based on what they anticipate even when demand for these new ideas is currently low or non-existent. This involves identifying the pioneers who are willing to try, and to experiment with or invest in new possibilities.

Meso organisations do not do this in isolation. They need to network with other organisations and enterprises that are also striving to increase their competitiveness or the competitiveness of the region. It may be necessary for the meso organisation to assist other management teams in their network so that they themselves become more sensitive to change.

At least three kinds of shifts that meso organisations must constantly reflect on and respond to are:

- **Continuous shifts in national and global policies that may have a direct or indirect effect on the economic system**. Are enterprises aware of these shifts, and are they prepared? Do they make certain kinds of markets, technologies or strategies more or less attractive? Are new skills, capabilities or services going to be needed? Related to this shift is the ability of the meso organisation to communicate expected or detected trends back to the relevant policymakers and funders, while at the same time communicating these political shifts to enterprises.
- **Shifts at the micro level where enterprises are created, formed and compete.** This requires that meso organisations detect changes in how their services are used, and that they are sensitive to changes in performance at the level of enterprises.
- **Shifts in the meso level itself**. Over time, the number and diversity of meso organisations tend to increase. This provides more opportunities for specialisation and the development of

depth, but it could also mean that enterprises are more easily confused or overwhelmed by the options they face. The changes in the meso level could also offer opportunities for collaboration between different organisations to address related issues or to harness synergies.

To assist meso organisations to become more adaptable requires leadership within these organisations to frequently reflect jointly with others on the small and large shifts they detect in their context and beyond. To become more sensitive and responsive to such shifts might require changes in governance structures of meso organisations, but it might also imply a more diversified base of expertise, as people from different disciplines tend to interpret situations differently.

5.5 Chapter conclusion

This chapter highlights the role of meso organisations and how their dynamism is crucial to enable learning, adaptation and development of firms and economies. However, the map or landscape of these meso organisations and programmes in South Africa is not known. Many organisations and programmes exist, but they are often measured on micro indicators rather than on the economic, social and technological health of the regions they work in, the sectors they serve, or the persistent patterns of underperformance and structural issues they were mean to address.

The functions these meso organisations offer to firms usually come in the form of basic and advanced public goods. Meso organisations have to constantly adjust and shift their focus as the economy and technology changes. We do not know the health and adaptability of our institutions. Nor are most of our publicly funded organisations measured on their long-term effectiveness in upgrading, modernising and improving the technological capability of the country and key industries. Most of our evaluations are done directly at the level of firms, while the overall health of innovation systems or ecologies are not measured.

This chapter highlighted the importance of strengthening social technologies that exist within but more importantly between firms, and also between different segments of the society. Processes to encourage or incentive joint search and discovery processes between different groups should be encouraged. Where possible, ways to encourage collaboration, dialogue and joint solution development between the private and public sectors should also be incentivised.

It is important to find ways to identify missing public goods, ineffective meso organisations and areas in which coordination costs are undermining investment and development. While the sector desks of the dti could play an important role in identifying current and potential meso organisations and public goods within sub-sectors, cross-sectoral or transversal projects could also play a key role in dialogue, shared sense-making, and the development of compelling collaborative development projects.

6 OVERVIEW OF SOUTH AFRICA'S SOCIOTECHNICAL CAPABILITY

This Chapter[17] will provide a high-level overview of South Africa's socio-technological capability. It draws connections between innovation in South Africa and South Africa's industrial performance. In particular, it shows how poor performance in innovation in the business sector has constrained South African manufacturing growth and exports.

As noted in Nyakabawo (2015) there is a broad understanding that R&D and innovation are important for business performance (at a firm level) and economic development (at a national or industrial sector level). Different types of R&D in different sectors and industries will have different impacts through different transmission mechanisms in different market dynamics. R&D/innovation can impact different aspects of business performance and different aspects of economic development. The scale and nature of the link depends on: the characteristics of the industry, the size of the firms, and the competitiveness of the market in which they operate.

To get a clearer picture, when pertinent and possible, South Africa is compared with Brazil. Brazil is a good comparator. Over the last two decades, manufacturing in Brazil has recorded very similar growth rate to that of South Africa – a positive but low growth rate. In both countries, the growth rate for manufacturing has been below the growth rate for the economy as a whole, resulting in a declining share of manufacturing in gross domestic product (GDP).

6.1 High-level economic overview

South Africa's economy has undergone noticeable structural changes since the 1970s with the tertiary sector (which includes services) expanding and production in the primary sector (agriculture, manufacturing and mining) declining. The change in the structure has been in line with global trends, though in the past five years the economic structure has remained relatively the same with the tertiary sector dominating economic activity.

The fastest growing sectors between 1994 and 2014 were telecommunications, financial services and retail. The share of mining and quarrying in the GDP grew from 7% in 1994 to 10% of GDP by 2012, primarily due to booming global commodity prices (while mining output decreased slightly over the period). This subsequently fell to 7.5% in 2014 due to declining commodity prices. The manufacturing sector is particularly worrying, having decreased its share in GDP from more than 20% in 1994 to around 13% in 2013 with related decreases in proportionate employment in manufacturing.

Since 1994, manufacturing firms have been successful in enhancing their international competitiveness as evidenced in the marked increase in exports. However, the contribution of the manufacturing sector to growth and employment creation has been disappointing. The National Industrial Policy Framework (NIPF) and successive Industrial Policy Action Plans (IPAPs) have consistently stressed the manufacturing sector's vital role in supporting dynamic employment and growth in the economy. It has also emphasised the need to frame and drive industrial policy with a particular focus on high value-adding sectors that embody a combination of relatively high employment and growth multipliers.

IPAP has targeted a range of industries for rapid development, especially by working with industry and labour to support investment, technology uptake, upgrading and competitiveness improvements, and importantly – job creation. IPAP sectoral priorities are clustered around two main themes: first, sectors that have traditionally had strong growth multipliers (automotives, metals fabrication, capital and rail equipment, plastics, pharmaceuticals and chemicals); sectors with strong employment

[17] TIPS commissioned Prof David Kaplan to contribute to this chapter.

multipliers (agro-processing, forestry, timber, paper, pulp and furniture); stressed sectors (clothing, textiles, leather and footwear); and sectors offering paths to skills upgrading (business processing services and crafts). The second cluster focuses on sectors deemed crucial for long-term resource sustainability (oil and gas, renewable energy, and green transport); sectors that can leverage domestic comparative advantage (mineral resources); and high-tech, ICT, advanced materials and niche manufacturing.

The NIPF had two strategic programmes around Innovation and Industrial Upgrading (Tsedu, 2015). The NIPF stressed upgraded industrial capabilities such as investments in machinery, upgraded skills and improved logistics capabilities as key resources that assist firm competitiveness. Key programmes included the Manufacturing Competitiveness Enhancement Programme (MCEP), Technological Infrastructure and Technical Infrastructure for a sound Standards, Quality Assurance and Metrology (SQAM) system. In 2009, the dti completed the revised guidelines for incetives such as the Enterprise Investment Programme and Automotive Investment Scheme and developed the Section 12i Tax Allowance Regulations with National Treasury. MCEP provides enhanced manufacturing support to encourage upgraded production facilities that sustain employment and maximise value addition.

The other NIPF strategic programme related to innovation and R&D, inately through providing greater support for innovation and technology so as to reach the R&D expenditure target to 1,5% of GDP as spelled out in the Medium Term Strategic Framework of 2014. Particular emphasis for the dti was on process and product development, and the commercialisation of technology. The need for coherence and collaboration with the DST was clearly identified. There remain some concerns especially around the alignment of departmental priorities.

However, in collaboration with DST, the dti continues to review incentives and instruments for science, technology and innovation, including formalising an R&D-led industrial development approach and R&D projects that scale-up industrial growth – ideally through partnerships between government, academia (including science councils) and industry (large, medium and small enterprises). Key programmes include the Technology Commercialisation Strategy and a process to harmonise innovation support programmes.

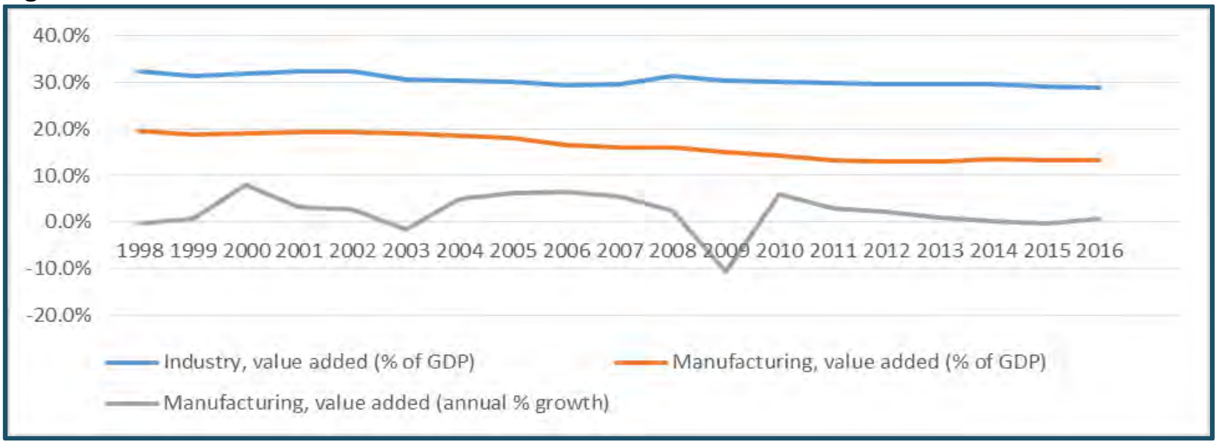
In Section 4.4 (Figure 5) it was shown that South Africa is falling further behind global peers in technological capability. It was argued that firms not only draw on technological capabilities to innovate and adapt, they also draw on the social environment, local resources, the legal frameworks and so on.

This chapter is a first attempt to create a local observatory of technological capability. This monitoring capability will be further developed during the remainder of this research project.

6.1.1 Value-addition trends

As evidenced by Figure 6, both industry and manufacturing value add as a proportion of GDP has been on a steady decline since the late 1990s. From a high of 20%, manufacturing value add had collapsed to just over 13% in 2016, having taken a substantial knock in 2009 as an impact of the global financial crisis.

Figure 6: Value-added trends



Source: Data from database: Development Indicators (World Bank, 2018)(Last Updated: 05/21/2018)

Table 3 outlines value-addition trends for the various manufacturing subsectors for the period between 1994 and 2016.

Five industries account for the bulk of employment and value addition within manufacturing – these are food (agro-processing); metal products; machinery and equipment; basic iron and steel; and motor vehicles. Together these sectors account for 44% of employment and around 48% of value add within manufacturing. These sectors, as alluded to above, are the highly capital-intensive sectors that drive employment and output.

Table 3: Manufacturing performance: selected sectors

	Total Employment			Value Added				
	Growth	Share of Total		Growth	Share of Total		Average Real Wage/Employee	Labour Productivity Index (2016)
	(1994-2016)	1994	2016	(1994-2016)	1994	2016	(1994-2016)	(1994=100)
Food	-0,7%	14,3%	15,6%	3,5%	11,7%	14,9%	R118 293,00	238,1
Coke and refined petroleum products	2,0%	0,9%	1,6%	6,0%	4,3%	9,0%	R173 589,00	221,3
Basic chemicals	-2%	1,9%	1,5%	2,8%	3,4%	3,8%	R262 365,00	292,2
Basic iron and steel	-2,8%	3,7%	2,6%	4,9%	3,8%	6,4%	R242 272,00	489,3
Basic non-ferrous metals	-2,4%	1,8%	1,4%	2,3%	3,2%	3,2%	R144 890,00	266,6
Metal products excluding machinery	-0,6%	8,3%	9,2%	1,9%	6,8%	6,3%	R110 823,00	167,2
Machinery and equipment	0,9%	5,3%	8,2%	2,9%	5,2%	5,8%	R126 259,00	151,1
Motor vehicles, parts and accessories	-1%	6,6%	6,8%	3,8%	4,3%	5,9%	R129 707,00	262,7
Other diversified manufacturing	-1,40%	57,2%	53,1%	1,1%	57,1%	44,7%	R103 222,00	
Total manufacturing	-1,10%	100%	100%	2.3%	100%	100%	R116 809,00	202,3

Source: Adapated from Bell et al, 2018

With agro-processing, it grew its proportion of employment from 14% to just under 16%, and the sector also grew its value-added contribution significantly from 11% to just below 15%. Though iron and steel account for a smaller component of employment (2,6%), its share in value added grew (nearly doubled) from 3,8% in 1994 to 6,4% in 2016. Metal products and machinery and equipment have been traditional mainstay sectors within manufacturing. Between them the sectors account for 17,4% of employment and 12% of value addition in manufacturing. Finally, in motor vehicles (or automotive) employment grew slightly from 6,6% to 6,8%. Value added from motor vehicles grew at an annual rate of just below 4%, growing from 4,3% in 1994 to 5,9% in 2016.

On the whole, the manufacturing sector has struggled over the past 20 years with overall employment falling by 1%. Positively value added averaged an annual growth rate of just over 2%.

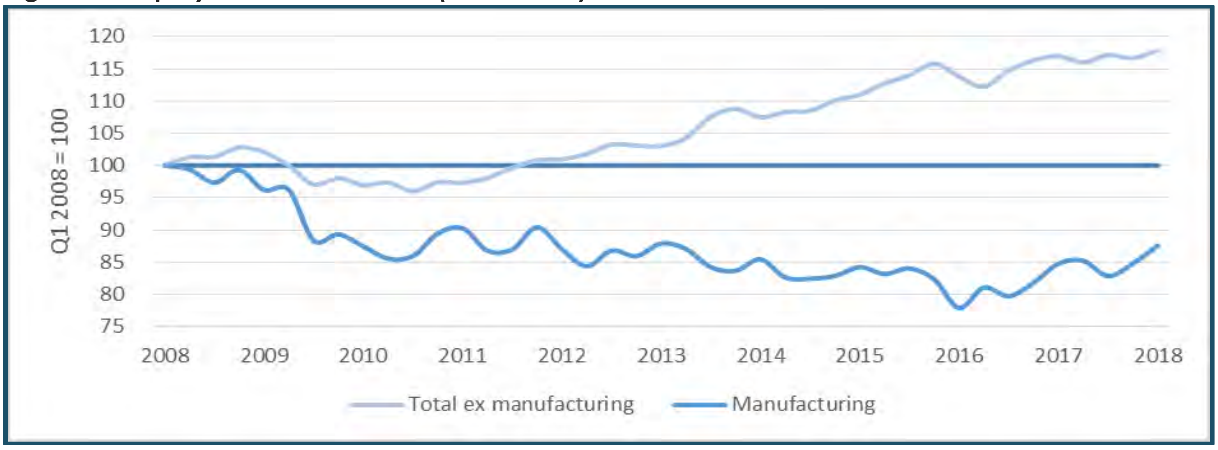
6.1.2 Employment and labour intensity

The manufacturing sector decline in GDP also saw related decreases in employment in the economy and disappointing contributions to growth and new employment creation. While overall employment recovered after 2008, manufacturing employment continued to decline from 2008 through 2014. As a result, its share in total employment dropped from 14% in 2008 to 12% in 2012 with the biggest job losses in manufacturing from 2008 to 2014 in commodity-based manufacturing i.e. metals, heavy chemicals and the wood/paper value chain (Makgetla, 2014).

Manufacturing production grew relatively strongly in the commodity boom of the 2000s, rising by 5% a year from 2003 to 2008. The fall in manufacturing employment followed a particularly sharp drop in output following the global financial crisis of 2008/9, which was followed by a slow recovery from 2009 onwards.

Despite positive signs from late in 2016, manufacturing employment has taken a slump recently. As shown in Figure 7, manufacturing employment was down 15% (equivalent to 308 000 jobs) compared to the same period in 2008. Manufacturing employment continued to recover after hitting a low point in the first quarter of 2016, as Figure 7 shows. In the two years to the first quarter of 2018 it climbed by 138 000 jobs, partially reversing the loss of 470 000 jobs between 2010 and 2016.

Figure 7: Employment trends index (2008 = 100)



Source: TIPS (2018)

In 2001, the biggest manufacturing subsector was clothing and textiles, accounting for approximately 23% of employment. However, it is also the subsector which experienced the highest rate of job losses over the period – around 15% up until 2014, mainly due to foreign competition and imports. However, Metals and Food and Beverages experienced employment growth between 2001 and 2014. The Metals subsector increased its share of manufacturing employment from 20% to 22%, while the Food and Beverages sector marginally increased its share of employment from 17% to 18% and the

Petroleum and Chemicals subsector also showed some strong employment growth, increasing its share of employment from 11% to 12% of manufacturing employment (Bhorat and Rooney, 2017).

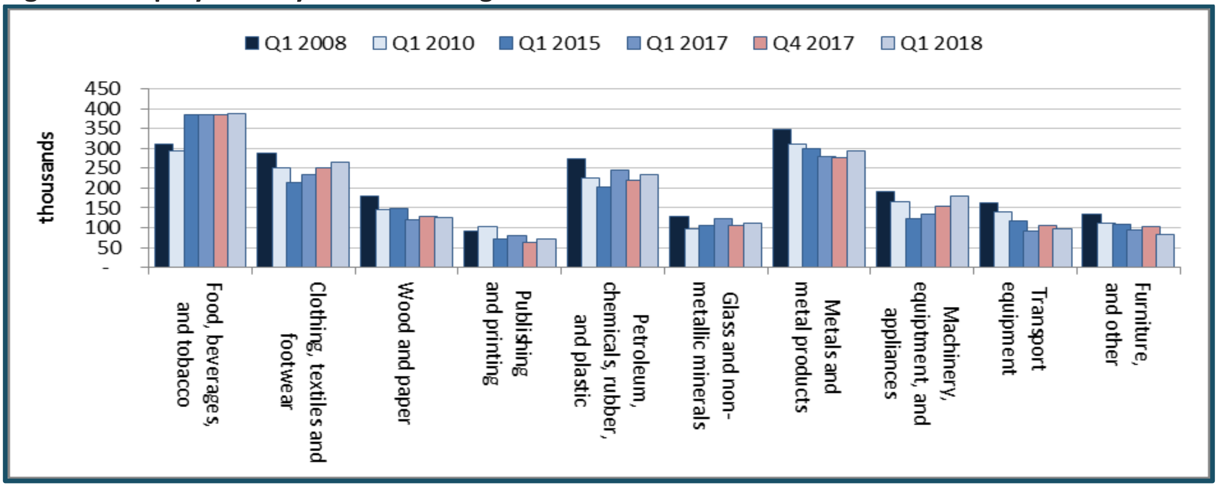
In the year to the first quarter of 2018, the bulk of new employment emerged in machinery and equipment and clothing, textiles and footwear. Together, these industries generated almost 80 000 net new jobs in the year to March 2018, continuing a three-year recovery. Metals and metal products saw a small uptick after years of shrinking employment, while furniture remained in a long-term decline. The other manufacturing industries were essentially stable.

TIPS (2018) shows that recent job losses primarily stemmed from the labour-intensive portions of manufacturing including clothing, textiles and footwear (down 13 000 as compared to 2008 levels); wood and paper (down 40 000 jobs); rubber and plastics (down 40 000); metals and metal products (down 65 000 jobs), machinery, equipment, and appliances (down 60 000 jobs) and transport equipment (down 59 000 jobs). Still, the data indicate that virtually all job creation primarily occurred in two industries – food and beverages, and chemicals.

Exports of manufactured goods are an additional source of aggregate demand for producing firms and manufactured goods constitute around 50% of South Africa's merchandise export basket, up from 41.2% in 1994. The main manufactured export product categories are machinery and equipment, motor vehicles (including components for auto assembly), refined petroleum products and other chemicals.

The African continent has become the leading external market for South Africa's manufactured exports, dominated by non-electrical machinery, processed food, chemical products as well as motor vehicles, parts and accessories. While the European Union's export basket is dominated by motor vehicles, parts and accessories, which accounted for approximately 32% of the EU imports and platinum group metals (PGMs) at 12%. However, only 3.9% of South Africa's manufactured exports were destined for China in 2017. These comprised mostly of base metals, paper and paper products, as well as processed food. The export basket to the US is dominated by PGM exports and motor vehicles, parts and accessories which accounted for a 21.2% (the dti, 2018).

Figure 8: Employment by manufacturing subsector

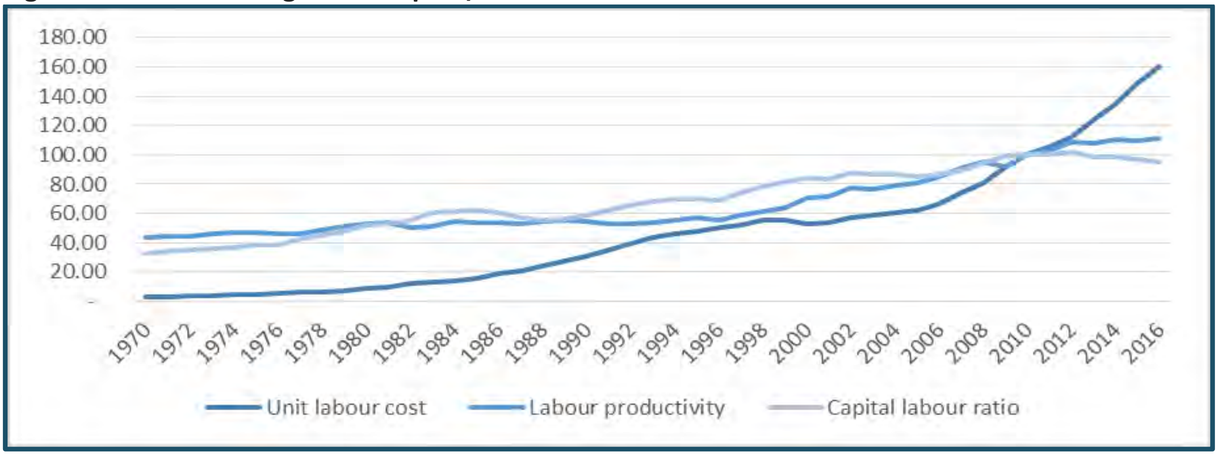


Source: TIPS (2018)

Capital to Labour Ratios are a good indicator of changes and trends in labour use and the utilisation of capital. Figure 8 outlines the trend in capital/labour ratios for the South African manufacturing sector (as a whole).

As can be seen, the capital/labour ratio has been on a steady increase since the early 1970s, with a noticeably steeper increase between the early 1990s and early into the 2000s. However, this ratio has been stable (if not in decline) from 2008 onwards. Co-incidentally, unit labour costs have experienced a significant jump, first in the 1980s with increased unionisation and labour organisation and again from 2010, presumably due to higher wage increase pressures at the same time there were notable increases in labour productivity.

Figure 9: Manufacturing sector capital/labour ratio trends



Source: TIPS, 2018

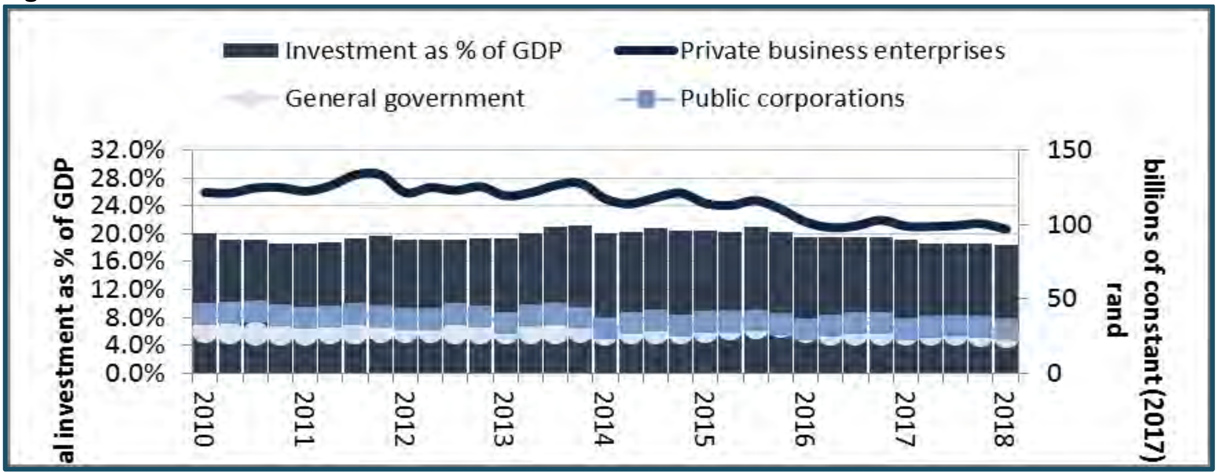
What can be noticed is that all manufacturing sectors experienced rising capital intensity from the 1990s onwards. However, the capital to labour ratio has stabilised across the board from 2010 onwards. The main drivers of the stagnation can be traced to the large capital-intensive sectors, with significant reductions in the capital to labour ratios of specifically the food and beverages, wood, non-metallic minerals, and the metals and machinery subsectors.

6.1.3 Foreign Direct Investment and investment trends

Total investment in the economy grew a significant 4% during 2017, remaining at around 20% of GDP at R158 billion (see Figure 10).

Investment from public corporations grew an impressive 10% in that year, highlighting the significance of State Owned Enterprises as key investment drivers for the year. Investment growth from general government and private enterprises were more muted at 3% quarter-on-quarter growth. Positively, private enterprise investment growth is positive for the first time since late 2016, signalling some positive sentiment.

Figure 10: Investment trends



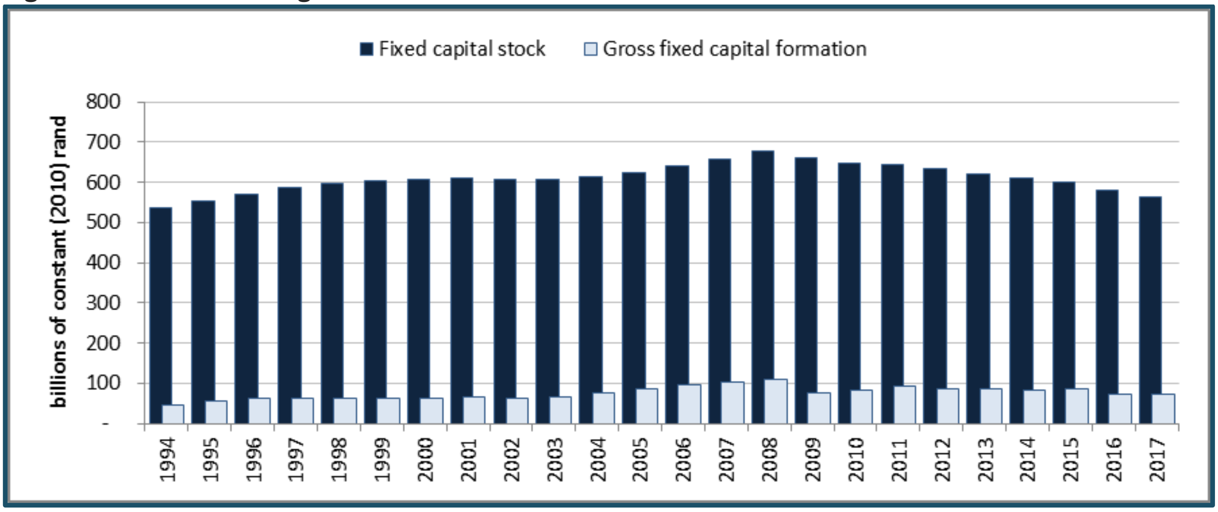
Source: TIPS (2018)

6.2 Innovation inputs in the business sector

Two key input measures of resources are devoted to innovation in the business sector. The first is expenditures on innovation: Business Expenditure on R&D (BERD). The second is the number of personnel engaged in research.

Manufacturing fixed capital stock peaked at R678 billion in 2008, just as the financial crisis was beginning to unravel. This subsequently decreased by more than R100 billion to R568 billion in 2017, signalling significant disvestment and sell-offs. New investment (Gross Fixed Capital Formation) also fell from a peak of R110 billion in 2008 to R74 billion in 2017, with sustained decreases from 2011 onwards.

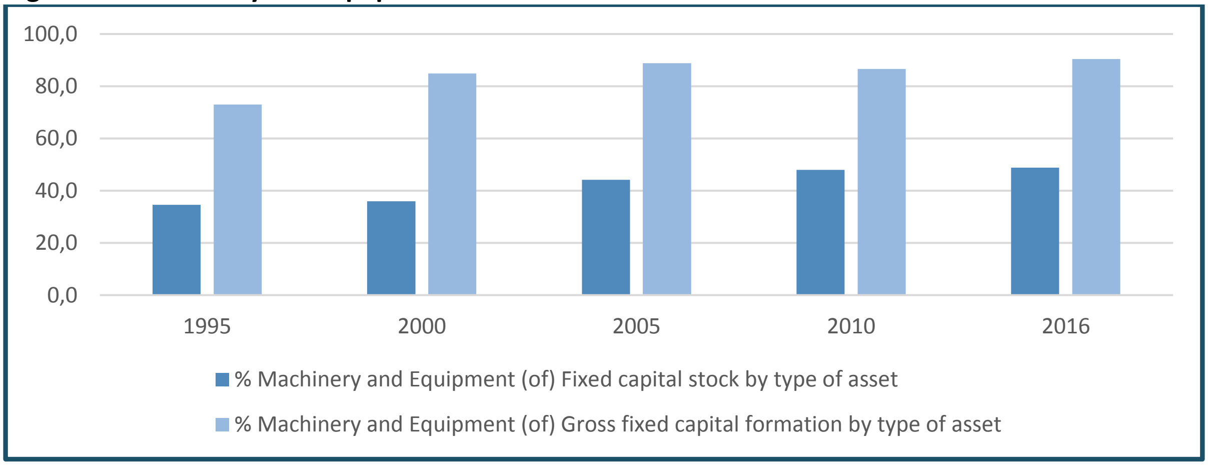
Figure 11: Manufacturing investments



Source: TIPS (2018)

Machinery and equipment has been and remains an integral part of the manufacturing sector, as evidenced by the investment trends in Figure 12. Machinery and equipment grew as a proportion of fixed capital stock from 35% in 1995 to just under 50% in 2016.

Figure 12: Machinery and equipment investment trend

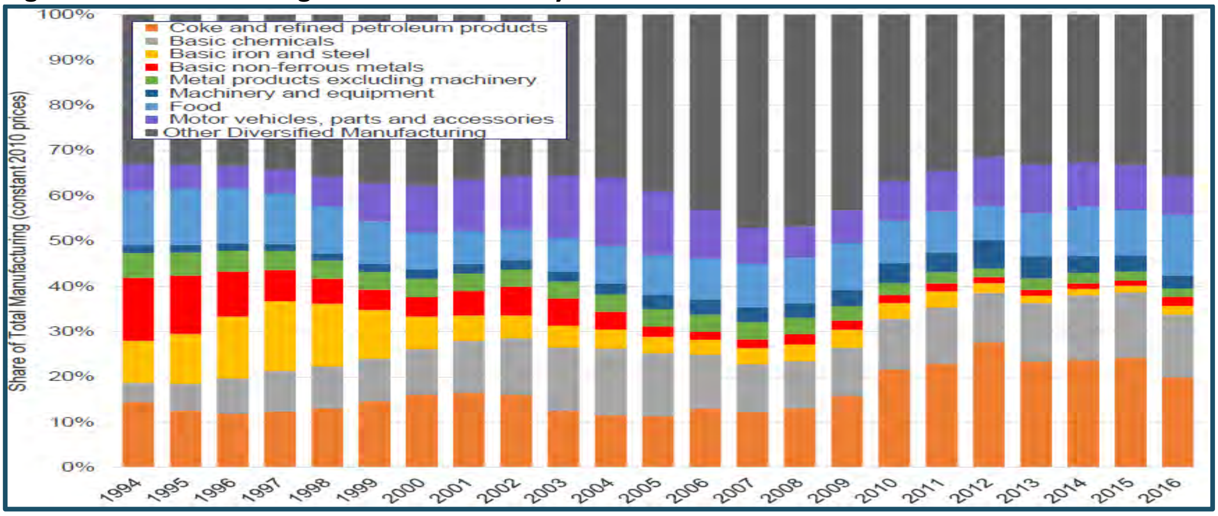


Source: Compiled from Quantec Data, 2018

Machinery and equipment is an increasingly dominant part of new manufacturing investments. Machinery and equipment has increased from 73% of GFCF in 1995, to an all-time peak of 90% in 2016, highlighting increased investment in technology, machines and equipment.

Bell, Goga, Mandliwa and Roberts (2018) stressed the lack of diversification in manufacturing investment, highlighting a continued inclination towards capital-intensive industries such as coke, petroleum and basic chemicals. Although iron and steel, and non-ferrous metals were a significant driver of investment in the 1990s, this has since fallen to minute levels when compared with 1994. Food and beverages (agro-processing) has remained a constant and significant contributor to manufacturing investments over the last two decades (see Figure 13).

Figure 13: Manufacturing investment share by subsector



Source: Bell et al. (2018)

Increasingly, the automotive sector has been a key sectoral driver of investment, highlighting the (potential) impact of successive industrial policy initiatives aimed at the automotive sector, including the Motor Industry Development Programme (MIDP) and more recently, the Automotive Production and Development Programme (APDP). However, the sector is dominated by foreign-owned firms, meaning that most of the R&D is intellectual property of the original equipment manufacturers (OEMs) and with limited local innovation due mainly to assembly activities, limiting innovation opportunities for local firms.

6.2.1 Research expenditures

Table 4 is nominal and Table 5 is real expenditures on the part of business on research.

Table 4: South Africa R&D expenditure by sector

YEAR	GERD	GOVT	SCIENCE COUNCILS	HIGHER EDUCATION.	BUSINESS	NOT-FOR-PROFIT
	R'000	R'000	R'000	R'000	R'000	R'000
2006/7	16 520 584	1 021 355	2 774 718	3 298 808	9 243 165	212 538
2007/8	18 624 013	1 154 399	2 886 094	3 621 862	10 738 456	223 202
2008/9	21 041 046	1 139 676	3 137 343	4 191 366	123 232 012	240 649
2009/10	20 954 677	1 067 302	3 458 074	5 101 224	11 139 237	188 840
2010/11	20 253 805	1 011 340	3 956 023	5 424 602	10 059 010	162 830
2011/12	22 209 192	1 235 669	3 729 680	6 609 216	10 464 022	170 605
2012/13	23 871 219	1 437 509	4 025 998	7 333 153	10 570 726	503 833
2013/14	25 660	1 697 151	43 045 567	7 292 853	11 782 848	583 165
2014/15	29 344 977	1 893 010	5 004 669	8 377 575	13 290 951	778 772
2015/16	32 336 679	2 013 021	5 740 897	98 766 223	13 814 995	891 142

Source: HSRC, R&D Surveys (HSRC, 2017)

Table 5: R&D Expenditure by sector, constant Rands (2010)

YEAR	GERD	GOVT	SCIENCE COUNCILS	HIGHER EDUCATION	BUSINESS	NOT-FOR-PROFIT
	R'000	R'000	R'000	R'000	R'000	R'000
2006/7	22 735 580	1 383 329	3 717 463	4 467 926	12 518 999	287 863
2007/8	23 173 765	1 436 413	3 591 152	4 506 664	13 361 806	277 729
2008/9	24 056 670	1 303 016	358 990	4 792 077	14 099 448	275 139
2009/10	22 285 524	1 135 087	3 677 699	5 425 206	11 846 698	200 833
2010/11	20 235 805	1 011 340	3 596 023	5 424 602	10 059 010	162 830
2011/12	20 847 398	1 159 902	3 500 988	6 203 961	9 822 403	160 144
2012/13	21 283 165	1 281 658	3 589 510	6 538 112	9 424 676	449 209
2013/14	21 553 925	1 425 544	3 615 667	6 125 725	9 897 153	489 837
2013/14	23 303 998	1 503 314	3 974 404	6 652 961	10 554 866	618 453
2014/15	24 458 370	1 522 581	4 342 220	7 470 343	10 449 195	647 030
2015/16	n/a	n/a	n/a	n/a	n/a	n/a

Source: HSRC, R&D Surveys (HSRC, 2017)

Overall spending on R&D, Gross Expenditure on R&D (GERD) has increased significantly since the financial crisis but in real terms GERD is slightly lower than before the financial crisis. The increase in nominal GERD is primarily the result of significant growth in R&D in higher education and to a lesser extent in government and in the science councils.

By contrast, while BERD increased in nominal terms in the past decade, in real terms, BERD in 2015/16 is 22% lower than in the period before the financial crisis (2006/7-2008/9)

6.2.2 Number of personnel engaged in research

A second measure of inputs into innovation is the number of R&D personnel engaged (**Table 6**). Overall, there has been a significant increase in total R&D personnel. However, in 2015/16, the number of R&D personnel employed in the business sector is still, albeit marginally, below that in the period before the financial crisis (2006/7 – 2008/9).

Table 6: R&D Personnel full-time equivalents by sector

YEAR	TOTAL R&D PERSONNEL (FTE[18])	GOVT	SCIENCE COUNCILS	HIGHER EDUCATION	BUSINESS	NOT-FOR-PROFIT
2006/7	30 984	2 068	4 956	11 002	1 259	362
2007/8	31 354	1 950	5 058	11 503	12 461	379
2008/9	30 801	2 074	4 699	11 169	12 492	364
2009/10	30 891	1 904	4 782	11 870	12 024	309
2010/11	29 486	2 178	4 312	12 477	10 205	313
2011/12	30 978	2 405	3 803	14 563	9 849	312
2012/13	35 050	2 597	4 784	15 614	11 322	768
2013/14	37 956	2 245	5 164	17 777	118 774	891
2014/15	38 465	2 181	4 180	17 994	12 927	1 231
2015/16	41 054	2 062	4 361	20 812	12 457	1 367

Source: HSRC, R&D Surveys (HSRC, 2017)

[18] Full-time equivalent

6.3 Innovation outputs

There are a number of measures of business innovation output. We consider four. None of these output indicators in and of themselves is definitive. But, taken together, they provide a fair picture. This is especially so when the indicators point in the same direction – as they do in South Africa.

6.3.1 Patents

The number and share of patents at the United States Patent Office (USPTO) is generally used as a proxy for patent output and for comparative purposes. What is significant is less the number and share of patents and more the direction of change.

South Africa's patent numbers filed per annum were static 1996-2006 (**Table 7**). Since 2006, there has been a significant increase in South African patents. However, there is a trend for countries to patent more and the rate of growth of South African patents is significantly lower than patents for non-US countries. As a result, there has been a long-term decline in the share of South African patenting in the USPTO. By contrast, Brazil which initially registered far fewer patents than South Africa, now registers almost twice as many. Brazil's share of non-US patents has experienced an increasing trend.

Table 7: Number and share of non-US patents at the US Patent Office, South Africa and Brazil

	1996	2006	2015
South Africa No. of Patents	111	109	166
South Africa share of Foreign Patents	0,22	0,13	0,10
Brazil No. of Patents	63	121	323
Brazil Share of Non-US Patents	0,13	0,14	0,21

Source: USPTO

6.3.2 Technology receipts and payments

South Africa's receipts from foreigner technology payments have risen slowly. Indeed, there has been almost no growth in real terms (Table 8).

By comparison, Brazil, which in 1995 had lower receipts than South Africa, now has receipts that are six times higher. Receipts from foreigners expressed as a percentage of payments to foreigners for intellectual property has declined significantly for South Africa. By contrast, for Brazil, the percentage has risen significantly.

Table 8: Technology receipts and payments, South Africa and Brazil in $ million

	1995			2005	2016
SOUTH AFRICA					
Receipts	45			46	109
Payments	293			1071	2012
Receipts/payments %	15			4	5
BRAZIL					
Receipts	32			102	651
Payments	529			1404	5141
Receipts/payments %	6			7	13

Source: World Bank Development Indicators (World Bank, 2018). Charges for the use of intellectual property.

6.3.3 High technology exports

The share of high technology exports in total manufactured exports in South Africa is very low. Initially static, over the past decade there has been some decline (**Table 9**). By contrast, Brazil, whose share of high technology exports in total manufactured exports was initially lower than South Africa, is now considerably higher, albeit that the share has declined in the past decade.

Table 9: High-technology exports as a percentage of manufactured exports, South Africa and Brazil

	1992-95	2001-5	2016
South Africa	5,6	5,7	5,3
Brazil	4,6	14,4	13,4

Source: World Bank Development Indicators (World Bank, 2018)

While there has been growth in South African exports, raw material or lightly beneficiated raw materials made up almost 90% of all of South Africa's growth in 2007-2012 (World Bank, 2014:18). Table 9 shows that the share of high-technology exports as a share of total exports in South Africa is very low hovering at around 5% for the past decade.

Although some of the products identified by the World Bank as sophisticated are technologically advanced and entail significant innovation, it should be noted that many of the other sophisticated products relate to the automotive and auto component sector (Bell et al, 2018:12) – known for conducting limited product development or innovation, and is concentrated (geographically and brand wise), dominated by foreign firms and highly subsidised (and has been for a very long time through the MIDP and APDP).

6.3.4 New exporting firms and new exported products

New exporting firms and new export products are an important expression and outcome of innovation. Exporting new products and opening up new markets require significant product, production and marketing innovations.

Many firms in South Africa export but for the vast majority of firms, the value of exports is small and a minor part of their output. Such exports are a vent for surplus – selling off small quantities of what is already produced for the home market and which accordingly requires no significant innovation or adaptation. However, when firms become significant exporters, product and market adaptations are crucial – thus the entry of firms into significant exporting is indicative of innovation and technological advance. New products and new export markets are an important outcome and indication of effective innovation activity.

In South Africa, only a few firms have become significant exporters with entry rates below those of comparator countries.

> ***"…over the decade only around 100 of the nearly 7 000 exporters active in both 2002 and 2012 moved from the bottom 80 percent to the top 5 percent. South Africa has one of the lowest new firm entry rates into exporting among its peers (World Bank, 2014:21).***

By far the largest share of South Africa's export growth is accounted for by existing firms selling into existing markets and this share has been increasing. " …the so-called intensive margin, which reflects the expansion of existing products into already-established markets, has become an even larger contributor to export growth, its share rising from 79 percent in 2006–08 to 88 percent in 2010–12." (World Bank, 2014:22).

What is particularly concerning is that South Africa's top exporting firms, which are responsible for the overwhelming share of South African exports, are developing and selling fewer products into global markets.

The top one percent of firms has seen a sharp drop in the contribution of new products to their markets in recent years. Since 2010 the share of total exports (among the top one percent of exporters) coming from firms selling 10 or more products has fallen from 73 percent to just 64 percent. By contrast, smaller exporters are expanding in both products and markets. However, the high concentration in South Africa's export sector means that the net impact of increased dynamism at the bottom end of the market fades into insignificance against the super-exporters' retreat from experimentation. Declining dynamism is also evident in the size and reach of South Africa's export products. Over the past decade, a number of high-value products that were exported to multiple markets – in many cases 20 or more markets – disappeared from the export basket (World Bank, 2014:22).

6.4 Some counter tendencies

All innovation indicators, both input and output, point in the same direction. There is limited commitment to innovation on the part of the business sector – indeed, since the financial crisis, industry and business in general have committed less resources to innovation. Innovation outputs and innovation dependent manufacturing activities, notably exports, are consequently showing a tendency to stagnation or decline.

There are, however, some contraindications and progress in some areas. In this section, these contraindications and the areas where progress is evident are briefly considered.

6.4.1 Science publications

There has been a substantial increase in scientific publications and in citations. By all indices, South Africa's outputs of scientific publications have increased significantly both in quality and in quantity (Table 10). By contrast with technology outputs – international patents for example – South Africa's share of global scientific output has increased.

Table 10: South African scientific publications

	1996-2000	2001-2005	2011-2015
Number of Scientific Publications	25 453	28 624	75 270
% World Share of Publications	0,39	0,39	0,63
% Publications in Top 1%	0,66	1,04	1,42
% Publications in Top 10%	7,33	8,90	9,54
% International Collaborations	25,31	36,24	46,19
Number of Citations	415 877	552 682	454 176
% World Share of Citations	0,35	0,41	0,76
Impact Relative to the World	0,899	1,052	1,202

Sources: Derived from Clarivate Analytics "InCites 2.0" and National Research Foundation. Quoted in the Mail and Guardian (2017).

The rising trend of South African scientific publications is impressive, but it does raise an obvious question – why has this increasing science output not translated into a better performance in technology outputs?

6.4.2 Export sophistication

A number of measures suggest that South Africa's export basket has a high level of sophistication for its level of development, i.e. that South Africa exports a comparatively high number of technologically advanced products as compared to other countries with a similar GDP per capita (World Bank, 2014:25).

Some of the products identified as sophisticated are indeed technologically advanced and entail significant innovation and product development in South Africa – the outstanding example being mining and mining related machinery. However, on examination, many of the other sophisticated products relate to autos and auto component (Bell *et al.*, 2018:12). The autos and components sector performs very little product development or innovation; is dominated by foreign firms and is highly subsidised.

6.4.3 The continental Africa market

South Africa's exports to the rest of Africa have been increasing rapidly – particularly of manufactured products. The proposed African Continental Free Trade Area (AfCFTA) agreement has the potential to significantly further increase South Africa's trade in manufactures with Africa.

However, South African exporters to Africa are opportunistic – entering markets on an ad hoc basis with existent products as opposed to innovating and developing new products and processes. Regional markets are less competitive, and standards are lower, which necessitates less innovation and product adaptation.

6.4.4 Technology-based start-ups and new entrants

While it is difficult to document, and no systematic data are available, there is clear evidence of increasing activity on the part of technology-based start-ups in South Africa. Mainly centred on Cape Town and Johannesburg, there are clusters of technology-based activities that are developing rapidly. With a core technology in ICT, young South African trained graduates are developing new activities – some of which are coming to scale and some of which have attracted international investors. Mark Shuttleworth was just one example. Recently, a start-up in the area of Massive Open Online Courses (MOOCs) attracted a foreign investment of R1.4 billion. For a list of the most promising start-ups see the various reports by Disrupt Africa (Disrupt Africa, 2017).

However, despite some significant successes, the number of start-ups are still quite limited. In addition, and related, social transformation within this area is limited as there are few black entrepreneurs.

A broad eco-system to support start-ups is in place. The major constraint on further development appears to be the shortage of skills. Start-up entrepreneurs are well-trained – but the limited number of local students graduating with technical and/or business schools from high-quality universities, combined with a skills shortage and a considerable brain drain, severely limits the supply of entrepreneurs. Black graduates with the requisite skills are, for a number of reasons, particularly likely to be attracted to well-paying jobs in well-established companies rather than venturing into a risky start-up. Skill shortage appears to be the immediate, binding constraint on further start-up developments (Goldberg, Kuriakose, Kaplan, Tuomi, Daniels and Draper, 2010; Breitenbach, Kaplan and Wood, 2006). And the number of graduates is rising – but slowly.

6.5 Chapter conclusion

The National Development Plan (NDP, 2012) characterised South Africa as caught in a middle-income trap. South Africa is a middle-income country and, on the one hand, cannot compete in low-skilled industries because cost structures are already too high. On the other hand, the country lacks the skills to compete with advanced manufacturing countries such as Germany. South Africa therefore competes in the mid-skill manufacturing and service areas, and niche markets that do not require large economies of scale nor massive job creation. Since the NDP report, South African labour costs have risen further and more increases at the lower end, particularly with the introduction of the national minimum wage, can be expected. Rising wages will make it more difficult for South Africa to compete in low-end labour-intensive manufacturing activities and will add to the pressure for South African firms to enter into higher value-added activities which necessitate product and process development and innovation.

At the heart of South Africa's technological evolution are two central themes, that is industrial upgrading and the concept of catching up. Industrial upgrading is usually related to the process by which economic actors (nations, workers, producers) move up value chains by generating outputs that have more value-added invested in them because they are higher quality, are produced more efficiently, or require more complex skills (Gereffi, Humphrey and Sturgeon, 2005). Zhu and He (2016) simplify this further by plainly stating it as making better products, making them more efficiently, or moving into more skilled activities, issues inherently related to competitiveness. Zhu and He further outline the four ways in which upgrading can occur, that is process, product, functional, and chain upgrading.

However, as this report suggests, the picture, while not all gloom, is not looking encouraging for innovation and the movement into more sophisticated products. This chapter also highlights the need for more specific data and tracking mechanisms to be created that will give the dti a much better picture of the performance of industries.

The somewhat discouraging picture painted in this chapter exists despite significant and growing injections of public funds into innovation as well as a continuing series of policies designed to enhance innovation. If these findings are tied with the preceding chapter, then the underperformance of meso organisations becomes more apparent.

There is clearly a need for an analysis as to what is constraining innovation on the part of the business sector and the likely impact policy has had on mitigating those constraints.

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