Understanding Economic Complexity: An Application to the MER Sector

By Caitlin Allen Whitehead and Haroon Bhorat

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Abstract

This paper develops a relatively novel method for identifying opportunities for diversification in the South African Manufacturing, Engineering, and Related Services (MER) Sector. The central tenet of this analysis is the economic complexity framework, which states that countries are able to increase their complexity through the diversification of their economies toward increasingly complex products. By constructing a measure of economic complexity based on a dataset of traded MER sector products, it is shown that the most complex economies have shifted export activities toward highly complex, manufactured goods, specifically those in the MER sector. This manufacturing-led process of structural transformation centered around the MER sector is shown to be advantageous for both a country's level of economic development and its long-run prosperity. Using network analysis, a MER sector product space, along the lines of Hidalgo et al. (2007) is used to identify optimal complexity-enhancing diversification opportunities in the sector. South Africa is sparsely represented in this product space. However, there is a core of automotive, rubber, and metal products, representing current productive capabilities from which future diversification opportunities within the MER sector can emerge. These opportunities, termed frontier products, are largely situated adjacent to the automotive sector.

Keywords:
Economic complexity; manufacturing; industrial relatedness; product space; structural transformation; diversification

JEL codes: O13; O14; O25

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INTRODUCTION

It is well known that South Africa is stuck in a long-run economic growth trap, resulting in an ongoing policy debate on how to kick-start economic growth and development in the country. International evidence has shown that developing countries are able to generate sustained economic growth, thereby shifting to higher levels of national income, through following a path of rapid and intense industrialisation. This process is often referred to as one of growth-enhancing structural transformation, whereby productive resources shift from low- to high-productivity sectors (McMillan & Rodrik, 2011; Herrendorf, Rogerson & Valentinyi, 2013). In the case of recent industrialisers such as Japan, China, and South Korea, this shift has been from low-productivity agricultural activities to high-productivity manufacturing (McMillan & Rodrik, 2011). In these Asian economies, the manufacturing sector has remained central to the process of economic growth and structural transformation.

In contrast, the South African economy remains semi-industrialised. Between 1960 and 1970 the manufacturing sector experienced an expansion, which Nattrass (2014) attributed to a large rise in capital stock, accompanied by a positive growth in the manufacturing labour force. In the mid-1980s South Africa still had a relatively large manufacturing base. However, this was undone to an extent with the advent of trade liberalisation in the 1990s resulting in both a deterioration in employment and manufacturing output (Kaplinsky, 1995; Edwards, 2001; Fedderke & Szalontai, 2009; Erten, Leight & Tregenna, 2019). , South Africa exhibits characteristics of premature deindustrialisation, whereby a boom in the services sector has overtaken the growth experienced in the manufacturing sector (Rodrik, 2016).

In this paper, a relatively novel approach of understanding South Africa's structural transformation is taken, by viewing this premature deindustrialisation through the lens of economic complexity. The mechanism underlying economic complexity, as explained by Hidalgo and Hausmann (2009), states that countries are able to increase their complexity through the accumulation of capabilities. In doing so, countries are able to produce and diversify into increasingly sophisticated products. These are typically manufactured products. As such, a key manufacturing sector in the South African economy – the Manufacturing, Engineering, and Related Services sector – is examined.[1]

[1] The merSETA, established in terms of the skills development legislation of 1998, includes a variety of manufacturing activities as well as some service and retail activities (merSETA, 2019). In this report the non-manufacturing, service and retail activities are excluded as the analysis focuses on manufactured products and the data does not include reliable information on service activities.

The main objectives of this are threefold. Firstly, to apply the method of economic complexity to economic complexity of the MER sector. Secondly, to map the MER sector to the product space. Thirdly, to use network analytics to identify a set of frontier products, or growth opportunities, within the MER sector

Using the method outlined by Mealy and Teytelboym (2018), an index for economic complexity is developed for the MER sector, allowing for the tracking of economic complexity relative to manufacturing as a whole. MER sector products are then positioned in a network termed the product space which is created based on the export structure of the particular country under consideration (Hidalgo et al., 2007). This product space allows for the visualisation of the paths that a country can take to diversify its MER sector product exports. To conclude this analysis, a set of products – termed frontier products – are identified based on the paths for diversification represented by the product space. These products offer the best opportunities to enhance complexity given the country's current set of capabilities (Hausmann & Chauvin, 2015; Bhorat et al., 2019).[2]

1. STRUCTURAL TRANSFORMATION IN SOUTH AFRICA

Structural transformation describes the process of reallocating labour and other resources across agriculture, manufacturing, and services (Herrendorf, Rogerson & Valentinyi, 2013). As shown by McMillian, Rodrik and Verduzco-Gallo (2014), when resource flows are from low- to high-productivity sectors, structural transformation can be growth-enhancing. This has been the widely documented case of recently industrialised East Asian countries such as Japan, China, and Korea, where there has been an aggregate shift from low-productivity agricultural activities, toward high-productivity manufacturing (McMillan & Rodrik, 2011). This is a prime example of manufacturing-led structural change.

However, there can be structural change which is growth-reducing, as is the case in South Africa. Contrary to the East Asian model, South Africa is a semi-industrialised country which has started to undergo a process termed by Rodrik (2016) as premature deindustrialisation. This is a pattern of structural transformation whereby the manufacturing sector does not reach its full potential, with

[2] The term `MER sector products' refers to the products produced in the five MER sector chambers alone, which is not the same thing as the manufacturing sample of products as a whole. Therefore, when the `MER economy' is discussed, this refers to these five chambers of product categories.

labour and other resources shifting resources from low-productivity agriculture to relatively unproductive services instead.

Following the approach outlined in McMillian, Rodrik and Verduzco-Gallo (2014) the extent of aggregate structural transformation in South Africa between 1995 and 2019 is examined. Figure 1 shows the correlation between the natural log of relative productivity (vertical axis) and the change of employment by industry (horizontal). The bubbles are sized according to the sector's share of employment in 2019.

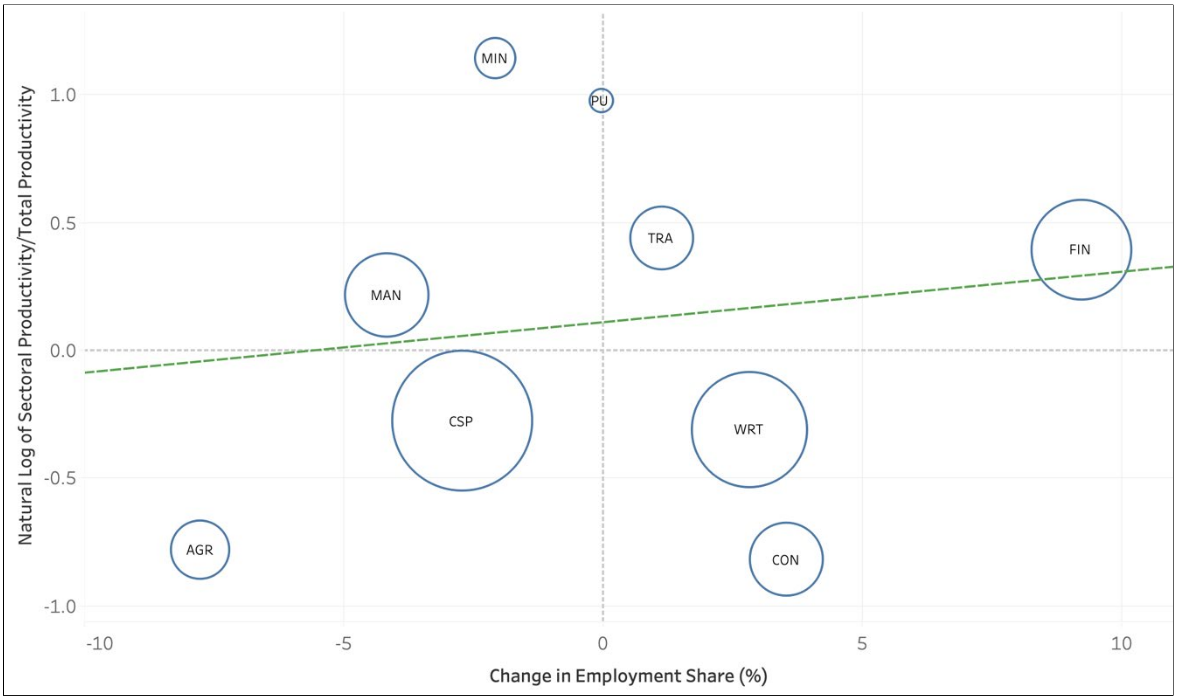
South Africa shows somewhat of a mixed picture. While there was a clear shrinkage in employment in the high-productivity manufacturing sector, this collapse was offset to an extent by an even larger reduction in employment in the agriculture sector, which exhibited the second lowest relative productivity.[3] However, the most rapidly growing industries were relatively unproductive non-tradable sectors such as wholesale and retail trade and construction. A notable exception was the increase in employment in tertiary services such as transport and communications, and finance which offset some of these negative effects.

The linear regression line in Figure 1 can be interpreted as follows: an upward sloping line means that productive resources were shifted away from low-productivity sectors, such as agriculture, toward higher productivity industries, like manufacturing. This is termed growth-inducing structural transformation. Conversely, a downward trend, or one that is not statistically significant, indicates that structural transformation has not been growth-enhancing.

In the South African case, the push-and-pull effects on the relationship between resource reallocation and productivity result in a slightly upward sloping regression line. However, though this slope is positive with an estimated coefficient of 0.02, this value is insignificant (p-value = 0.72), suggesting that there is no evidence of growth-led structural transformation.

[3] A large contributor to the decrease in employment in the South African agricultural sector is the introduction of a minimum wage (Bhorat, Kanbur & Stanwix, 2014). This a partly due to the shedding of part-time jobs (Bhorat, Kanbur & Stanwix, 2014).

Figure 1. Correlation between sectoral productivity and change in employment in South Africa, 1995 - 2019



Source: author's own calculations using DataFirst (2020) and Statistics South Africa (2020).
Notes: 1. Size of circle indicates employment share in 2019. 2. β=0.02 (t-stat=0.37; p-value=0.72).
2. AGR = Agriculture; MIN = Mining; MAN = Manufacturing; PU = Utilities; CON = Construction; WRT = Wholesale & Retail Trade; TRA = Transport Services; FIN = Financial Services; and CSP = Community, Social and Personal Services.

Manufacturing has become more capital-intensive and skill-intensive, resulting in an erosion of unskilled employment (Edwards, 2001). Based on the high proportion of workers in South Africa which fall into the low-skilled cohort, this shift has resulted in steadily rising unemployment.[4]

There is a shift of labour resources, as represented by the employment growth in Figure 1, to the high productivity financial services sector which is typically characterised by high proportions of skilled workers. However, this increase in labour is overstated in the sense that a large share of this employment growth is of Temporary Employment Service Workers who fall under the 'Business Services' industry category and not finance and insurance (Bhorat, Cassim & Yu, 2016). These workers include cleaners, support workers, and security guards – not the high-skilled workers one would expect to find in the financial services industry (Bhorat, Cassim & Yu, 2016). From the perspective of being labour absorbing of low-skilled workers, the issue is that the service sector is, firstly, not that big and, secondly, it cannot act as a large source of employment like manufacturing as countries industrialise.

4 Low-skilled workers are defined as elementary occupations using the Organising Framework for Occupations. This is the standard definition used in Statistics South Africa's labour force surveys. Examples of workers in this category include cleaners and helpers; labourers in mining, construction, manufacturing, and transport; and refuse workers.

Ultimately, the post-apartheid period has witnessed a manufacturing sector in South Africa which stalled, giving way to a process of premature deindustrialisation. As a consequence, growth in the economy has been driven and shaped by the services sector. It is not surprising then that today, South Africa can be classified as a services-based economy, as the latter constitutes 70 percent of GDP (Statistics South Africa, 2020).

2. UNDERSTANDING ECONOMIC COMPLEXITY

The concept of economic complexity, which is used to explain divergent patterns of economic development and growth, is relatively new in the economic literature. This novel theory is based on the central idea that countries which have accumulated more capabilities are able to produce a diverse range of sophisticated products, thereby pointing to their economic complexity. This section contains an overview of the economic complexity literature: Firstly, a conceptual understanding of economic complexity is provided. Secondly, the various approaches that have been used to measure economic complexity are detailed. Finally, it is shown how economic complexity explains cross-country variation in levels of economic development, and how this can aid in an understanding of the process of structural transformation.

2.1 CAPABILITIES AND COMPLEXITY

The theory of economic complexity postulates that countries which are able to accumulate vast stores of diverse capabilities enjoy higher levels of economic development and growth (Hidalgo & Hausmann, 2009; Hausmann & Hidalgo, 2011; Hausmann et al., 2014). Capabilities are more diverse and multidimensional when compared to standard factors of production such as labour, capital, and technology. For example, embedded within the production of high complexity ranked motor vehicles are capabilities in mechanical engineering; automation and robotics; production of plastic composites; development of tooling; as well as services such as logistics and supply chain management. The emphasis of this paper is the importance of skills as a subset of capabilities which are an important component in determining the success of building economic complexity, and in doing so, growing the economy.

The nature of growth-enhancing capabilities requires gains in knowhow to be in tacit rather than explicit abilities. While explicit knowledge can be obtained by reading or listening, tacit knowledge is timely and costly to transfer (Hausmann et al., 2014). As explicit knowledge is easily transferred it allows developing countries to potentially converge to industrialised country income levels. On the other hand, tacit knowledge allows well-resourced countries to achieve differential growth in capabilities.

The attainment of explicit knowledge is largely the product of a country's population developing specialised skills, with the amount of knowledge acquired by each person being referred to as a personbyte. The co-ordination these personbytes by way of institutions or markets creates a vast network of diverse capabilities (Hausmann et al., 2014).

As there is no straightforward way to quantify the capabilities that a country has, these capabilities have to be inferred indirectly. One approach to doing this is backward-engineering a measure of a country's available capabilities based on the portfolio of goods that it is able to export competitively. Hausmann et al. (2014) postulate that if a country is able to export a given product competitively, it can be inferred that the country has the capabilities required to do so.[5] Further, products requiring a large amount of specialised knowledge to produce can only be produced in those few countries which have the requisite capabilities.

It follows that countries which possess a wide range of capabilities are able to export a greater diversity of goods competitively. These countries are deemed to be complex (Hidalgo & Hausmann, 2009; Hausmann & Hidalgo, 2011; Hausmann et al., 2014). Analogously, products are said to be complex if few countries have enough of the specialised capabilities required to export them competitively (Hidalgo & Hausmann, 2009; Hausmann & Hidalgo, 2011; Hausmann et al., 2014).

Taken together, these observations show that countries are able to build complexity by accumulating capabilities, allowing them to shift production away from simple products toward a large range of complex products. While it is typically the case that these rudimentary products are often mining or agricultural commodities, a shift in production toward more sophisticated manufactured products, which is complexity building, is tantamount to a process of manufacturing-led structural transformation.

The following section details the approach followed by Hidalgo and Hausmann (2009), Hausmann and Hidalgo (2011), and Hausmann et al. (2014) to measure the complexity based on the basket of exports that a country is able to export competitively, relative to the products traded by other countries.

[5] Hausmann *et al.* (2014) used Balassa's (1965) measure of Revealed Comparative Advantage (RCA) to make countries and products comparable. For a given product, it is expected that the volume of exports of a larger country are greater than that for a smaller country. Further, it is expected that products that comprise a large share of global exports should in turn account for a large share of the exports for producing countries.

2.2 MEASURING ECONOMIC COMPLEXITY

We define here, two measures of complexity – the Economic Complexity Index (ECI) – which measures the complexity of a country, and the Product Complexity Index (PCI) – which estimates the complexity of a product. The importance of these indices becomes clear in subsequent sections, where these metrics are used to justify why economic complexity is relevant to the study of economic development.

The process of measuring economic complexity is data-centric, with the existence of a set of capabilities being proxied by the ability of a country to export a related set of products competitively. In this way, it is possible to compare the accumulated capabilities across countries using relative comparisons of these traded products for different countries (Hidalgo & Hausmann, 2009; Hausmann & Hidalgo, 2011; Hausmann et al., 2014).

The approach followed by Hidalgo and Hausmann (2009), Hausmann and Hidalgo (2011), and Hausmann et al. (2014) uses international trade data to identify what products countries make, using this information to infer their productive capabilities.[6] Two measures of complexity are derived as follows[7]: Firstly, the number of products that a country produces and exports competitively is a measure of that country's diversity. A country which has residents and organisations with a wide range of different capabilities is well-equipped to produce a large variety of products. Thus, more complex countries are those with higher diversity. This opposes longstanding economic theory, such as the Ricardian and Heckscher-Ohlin models, which postulate that a country should specialise in the production of a select set of products in order to gain a competitive advantage (Inoua, 2018). Secondly, the number of countries that are able to produce a given product is that product's ubiquity. Products that require large volumes of capabilities can only be produced in highly complex countries where the requisite capabilities are available. It follows that lower ubiquity is indicative of higher economic complexity.

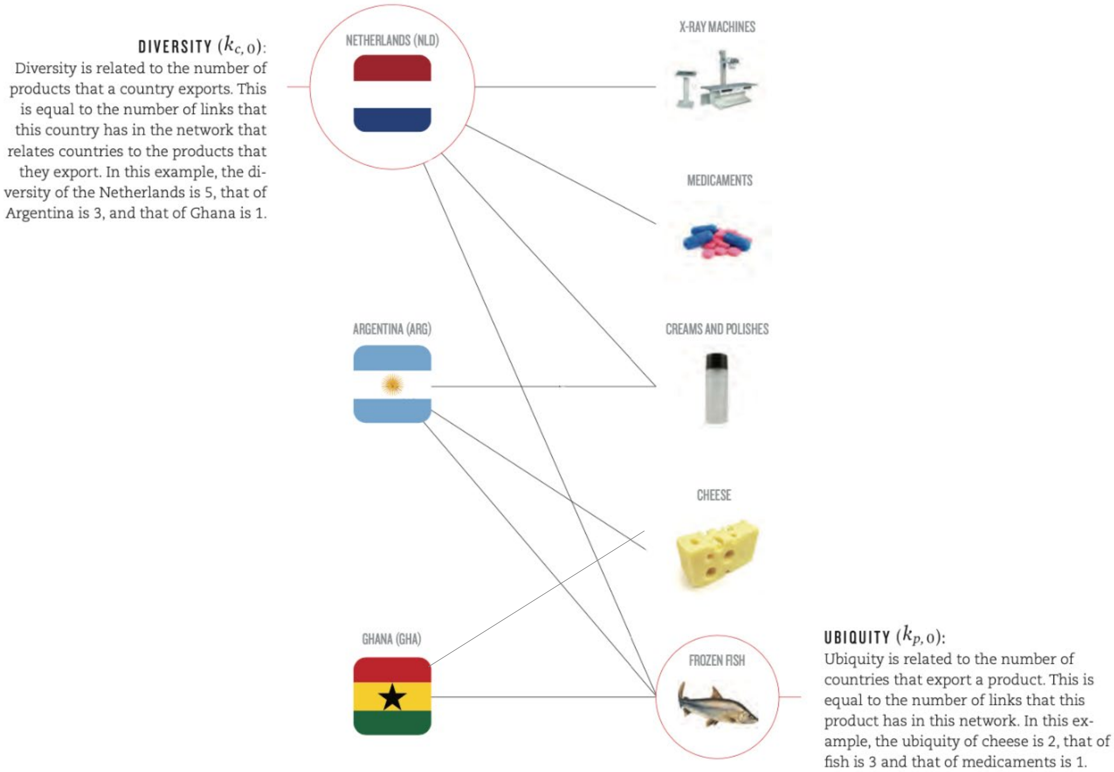
If the global economy is considered to be a network linking products and countries, then the diversity of a country ($\mathbf{d_{c,o}}$) is the number of products that it links to, while the ubiquity of a product ($\mathbf{u_{p,0}}$) is the

[6] Trade date is used in complexity analysis as it allows for the comparison across a wide cross-section of countries over long time periods, while using a consistent set of products. Although export data is used, Hausmann *et al.* (2014) argue that this is a reasonable reflection of a country's productive structure.

[7] The complexity measures used in this paper are calculated using the Python ecomplexity package developed by The Centre for International Development at Harvard University (CID, 2019).

number of countries that it is linked to. Technical Box 1 provides an illustrative example of such a network for three countries and five products.

Technical Box 1. Example of Ubiquity and Diversity



Source: adapted from Hausmann et al. (2014).

In the above example, the Netherlands has the highest complexity as it produces all five products (diversity=5), with two of these, X-ray machines and pharmaceuticals, only being produced by itself (ubiquity=1). Argentina produces creams and polishes, cheese, and frozen fish resulting in a diversity of 3. Taken together these products are, on average, more ubiquitous than those produced by the Netherlands, rendering Argentina a less complex country than the Netherlands. Ghana has the lowest complexity of the three countries, producing only frozen fish (diversity =1) which is also produced by the other two countries (ubiquity=3).

In terms of the complexity of each product, X-ray machines and medicaments are the most complex as they have the lowest ubiquity (ubiquity=1) and are produced by the country with the highest diversity. Frozen fish has the highest ubiquity (ubiquity=3) making it the least complex product. Creams and polishes, and cheese have the same ubiquity (ubiquity=2), so in order to differentiate between the two it is necessary to consider the diversities of the countries that produce each product. This is done by refining the ubiquity measure of creams and polishes, and cheese by taking into account the average diversities of the countries that produce them (3.5 and 2.5 respectively). Creams and polishes are revealed to be more complex as they are produced by a set of countries with higher average diversity than those producing cheese.

This illustration shows that the complexity of a product, as measured by its ubiquity, can be refined by using a measure of the average diversity of the countries that produce it. Further, precision can be obtained by correcting this refined ubiquity measure by the average ubiquity of the countries producing the product in question. Analogously, this adjustment process can be carried out for country complexity, with the original diversity being corrected using the average ubiquities of the products being produced and so forth (Hausmann et al., 2014). Formally, the incorporation of these higher order differences into the calculation of complexity can be done using an iterative mathematical approach call the Method of Reflections, which can be used to show that these manipulations of diversity and ubiquity will converge at a point. The method by Mealy, Farmer, and Teytelboym (2019) circumvents this iterative process using matrix algebra to reach the same point of convergence (we detail this approach in Technical Box 2).

The resultant measures are the Economic Complexity Index (ECI) and the Product Complexity Index (PCI). The ECI captures a country's complexity by analysing patterns of similarity in the types of products exported by other countries. Countries with similarly high ECI values tend to export highly sophisticated products, with the opposite being true of low ECI countries, which export similarly less technical products (Mealy & Teytelboym, 2018). Analogously, the PCI provides the same ranking for the complexity of different products based on the similarity of the countries that export them. Therefore, high PCI products tend to be exported by similar countries, as well as being more sophisticated (Mealy & Teytelboym , 2018). The mathematical definitions of these two metrics are given in Technical Box 2.

Technical Box 2. Measuring Economic Complexity

As a starting point, the matrix $\mathbf{M}$ is defined, with elements $\boldsymbol{m}_{\mathbf{cp}}$, which are 1 if country $\boldsymbol{c}$ produces product $\boldsymbol{p}$ with relative comparative advantage (RCA≥1), and 0 otherwise as follows: (1)

$$\mathrm{M} = \begin{array}{c} \begin{array}{cccc} p=1 & p=2 & p=3 & p=4 \end{array} \\ \begin{bmatrix} \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{1} \end{bmatrix} \begin{array}{l} c=1 \\ c=2 \\ c=3 \\ c=4 \end{array} \end{array}$$

Diversity ($\mathbf{d}_{\mathbf{c},\mathbf{0}}$) and ubiquity ($\mathbf{u}_{\mathbf{p},\mathbf{0}}$) are measured by summing over the rows and columns of the matrix respectively. Diversity vector ($\mathbf{d}$) is the sum of all diversities ($\boldsymbol{d}_{\boldsymbol{c},\mathbf{0}}$) for all countries ($\overline{\boldsymbol{c}}$). Ubiquity vector ($\mathbf{u}$) is the sum of all ubiquities ($\boldsymbol{u}_{\boldsymbol{p},\mathbf{0}}$) for all products ($\overline{\boldsymbol{p}}$). To show summation in the form of a matrix equation we use a column vector of ones $(\overline{\mathbf{1}})$, with the transpose being a row vector of ones $(\overline{\mathbf{1}}')$. Formally this is defined as:

$$\mathbf{d}_{\mathbf{c},\mathbf{0}} = \textstyle\sum_{p} \boldsymbol{m}_{cp} \qquad \mathbf{d} = \mathbf{M} \times \overline{\mathbf{1}} \tag{2}$$

$$\mathbf{u}_{\mathbf{p},\mathbf{0}} = \textstyle\sum_{c} \boldsymbol{m}_{cp} \qquad \mathbf{u} = \overline{\mathbf{1}}' \times \mathbf{M} \tag{3}$$

Based on Hausmann et al. (2014) it is shown that a country's complexity, as measured by the diversity of the products that it produces, can be refined using the average ubiquity of the products that it produces. Similarly, a product's complexity, as measured by its ubiquity, can be refined using the diversity of the country's which produce it.

Therefore, complexity for all countries can be shown by matrix $\mathbf{K}$ and the complexity for all products can be shown by matrix $\mathbf{Q}$ as follows:

$$\mathbf{K} = \mathbf{D}^{-1}\mathbf{M}\mathbf{Q} \tag{4}$$

$$\mathbf{Q} = \mathbf{U}^{-1}\mathbf{M}'\mathbf{K} \tag{5}$$

where, $\mathbf{D}$ is the diagonal matrix whose elements are those of the column vector $\mathbf{d}$, and $\mathbf{U}$ is defined as the diagonal matrix whose elements are those of the row vector $\mathbf{u}$.

Substituting (5) into (4) and rearranging we get:

$$\mathbf{K} = \mathbf{D^{-1}MU^{-1}M'K} \tag{6}$$

With $\widetilde{\mathbf{M}}_{\mathbf{cc}} = \mathbf{D^{-1}MU^{-1}M'}$ being a row-stochastic matrix (its rows sum to one), its entries can also be interpreted as conditional transition probabilities in a Markov transition matrix. When applied to country trade data, one can think of $\widetilde{\mathbf{M}}_{\mathbf{cc}}$ as a diversity-weighted (or normalized) similarity matrix, $\mathbf{S} = \mathbf{MU^{-1}M'}$, reflecting how similar two countries' export baskets are. This is shown as follows.

$$\widetilde{\mathbf{M}}_{\mathbf{cc}} = \mathbf{D^{-1}S} \tag{7}$$

The Economic Complexity Index (ECI) is the eigenvector ($\vec{\mathbf{K}}$) associated with the second largest eigenvalue of $\widetilde{\mathbf{M}}_{\mathbf{cc}}$.[8,9] This is the eigenvector that captures the greatest amount of variance in the system making it the selected measure of economic complexity. Therefore, the ECI is defined as:

$$\mathbf{ECI} = \frac{\vec{\mathbf{K}} - <\vec{\mathbf{K}}>}{\mathbf{stdev}(\vec{\mathbf{K}})} \tag{8}$$

where $\vec{\mathbf{K}}$ is normalised using $<>$ and $\mathbf{stdev}$, representing the average and standard deviation, respectively. Analogously the Product Complexity Index (PCI) is defined in terms of the eigenvector ($\vec{\mathbf{Q}}$) associated with the second largest eigenvalue of $\widetilde{\mathbf{M}}_{\mathbf{pp}}$ as:

$$\mathbf{PCI} = \frac{\vec{\mathbf{Q}} - <\vec{\mathbf{Q}}>}{\mathbf{stdev}(\vec{\mathbf{Q}})} \tag{9}$$

Source: author's own calculations based on the methods of Hausmann et al. (2014), Inoua (2018), and Mealy, Farmer & Teytelboym (2019).

In addition to these measures, Hausmann et al. (2014) used Balassa's (1965) measure of Revealed Comparative Advantage (RCA) to make countries and products comparable. Technical Box 3 presents the definition of the RCA more formally.

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[8] The largest eigenvalue is associated with a vector of 1's, therefore, it does not provide much information (Hausmann *et al.*, 2014).

[9] The correlation coefficients between $\vec{\mathrm{K}}$ and diversity matrix, D, are used to adjust the signs for both the ECI and PCI values so that they make sense as per the method followed in (Hausmann *et al.*, 2014).

Technical Box 3. Revealed Comparative Advantage

Using Balassa's (1965) definition of Revealed Comparative Advantage (RCA), a country is shown to export a product competitively if the measure of RCA for that country-product combination is greater than or equal to 1. This rule avoids marginal exports from entering the analysis. Formally $\mathbf{X_{cp}}$ is used to denote the exports of country $\boldsymbol{c}$ in product $\boldsymbol{p}$ where the Revealed Comparative Advantage that country $\boldsymbol{c}$ has in product $\boldsymbol{p}$ is shown as:

$$\mathbf{RCA_{cp}} = \frac{\mathbf{X_{c,p}}}{\sum_{\mathbf{c}} \mathbf{X_{c,p}}} \Big/ \frac{\sum_{\mathbf{p}} \mathbf{X_{c,p}}}{\sum_{\mathbf{c,p}} \mathbf{X_{c,p}}} \tag{10}$$

The RCA reveals the share of product $\boldsymbol{p}$ in a country $\boldsymbol{c}$'s total exports relative to the share of product $\boldsymbol{p}$ in total global exports.

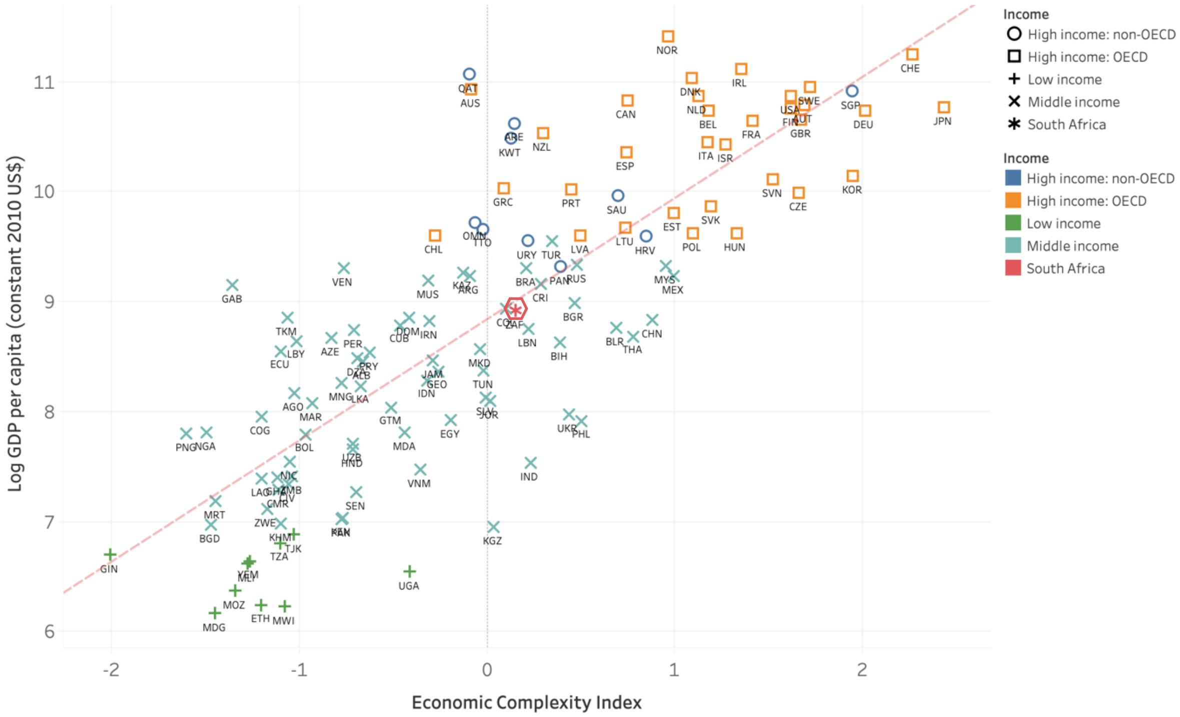
2.3 ECONOMIC COMPLEXITY AND ECONOMIC DEVELOPMENT

The following section is concerned with the contribution of economic complexity to the economic development literature, in other words – why complexity matters.

As shown in Hidalgo and Hausmann (2009) and Hausmann et al. (2014), the relationship between economic complexity and economic development is positive and statistically significant. Figure 2 illustrates this positive correlation using the relationship between the ECI and real GDP per capita for 122 countries. Further, this relationship is relatively strong as evidenced by a statistically significant correlation coefficient of 0.81. As such, countries engaging in complexity building activities stand to experience real economic gains.

Complex countries also appear to be more prosperous, with the highest complexity economies being from the high-income OECD cohort. The income levels of each economy are represented by different shaped markers, with the large group of high-income countries, denoted by orange squares, being located in the upper-right quadrant. Notable examples of high-income-complexity pairs are Germany (DEU), Switzerland (CHE), and Sweden (SWE).

Figure 2. Relationship between GDP per capita and ECI, 2016



Source: author's own calculations based on World Bank (2019) and The Growth Lab at Harvard University (2019).
Note: 1. Red dashed line is line of best fit (correlation=0.808, p-value=0.000). 2. The Syrian Arab Republic is excluded as no GDP per capita information was available for the period.

At the opposite end of the spectrum, the majority of low- and middle-income countries populate the bottom-left quadrant, for example, Guinea (GIN) and Mozambique (MOZ). Further, as anticipated, these countries have low levels of economic development, consistent with their low economic complexity indices.

South Africa (ZAF), denoted by the red star, is classified as a middle-income country and, as expected, lies approximately halfway along the complexity distribution. The country's ECI is approximately 0.15 showing that it performs favourably in comparison with all sub-Saharan African countries. In fact South Africa is the best performer in terms of complexity on the continent, with the mean ECI in Africa being -0.96 (Allen et al., 2019). While complexity rankings in Africa are consistently low, there is heterogeneity across the continent with low-income countries, such as Madagascar (MDG) and Ethiopia (ETH), having lower levels of complexity than middle-income African countries, such as Senegal (SEN) and Egypt (EGY).

On closer inspection, while this correlation is strong and statistically significant, it is not perfect, as shown by the addition of the regression line in Figure 2. It is shown in Hidalgo and Hausmann (2009) that deviations from the regression line are predictive of future economic growth.

For example countries such as the India (IND), South Africa, and Greece (GRC) have approximately the same level of complexity. However, India, lying below the regression line, is not achieving the economic complexity that is expected given its capabilities. India's recent rapid economic growth could be rationalised as the country exploiting the knowledge that it already possess to become wealthier (Hausmann et al., 2014). Conversely, Greece lies above the trend, meaning that it is more developed than is expected based on its knowledge. Another example would be the positioning of many research-rich economies above the regression line, achieving high levels of economic development despite the simplicity of the few products that they produce. Examples include Kuwait (KWT), Qatar (QAT), and Oman (OMN). The position of these countries around the trend can be interpreted as those under the regression line having more developed structures in place to support a trajectory of rapid economic growth, whereas those above the trend are expected to experience slower rates of economic development (Hausmann et al., 2014).

As South Africa is situated on the regression line it can be said that its level of economic development is aligned with the complexity of its export basket. Despite this equilibrium, in order for the country to achieve higher levels of economic growth, it is imperative that it targets the accumulation of capabilities that can shift the economy higher on the regression line.

3. ANALYSING THE ECONOMIC COMPLEXITY OF THE MER SECTOR

In broad terms it has been established that economic complexity may be a useful measure in order to appreciate and understand a country's current prosperity and future growth potential. This section determines whether these relationships hold when considering the five MER sector chambers in isolation – metal and engineering; automotive manufacturing; automotive components; new tyre manufacturing; and plastics.[10] Owing to this narrow focus it is possible to determine whether there are sector-specific factors underlying any potential linkages.

There are three components to this analysis. First, the MER sector and its constituent chambers will be mapped to the economic complexity data to create MER sector groupings within the dataset. Second, following Mealy and Teytelboym (2018), a complexity index is to be calculated for each chamber, as well as for the aggregate MER sector. Using a corresponding pseudo MER sector for comparator

[10] It is important to note that economic complexity data is constructed using global trade data, which pertains to merchandise trade and not services trade. As such, we are not able to measure the complexity of the motor retail chamber. The methodology does allow for the measuring of the complexity of the metal and engineering, automotive, automotive component, new tyre, and plastics manufacturing sectors.

countries, MER sector complexity levels can be compared across countries. Third, using these MER sector complexity indices, the relative trends in economic complexity for each of these sectors are analysed over time.

3.1 MER SECTORS AND ECONOMIC COMPLEXITY: A MAPPING EXERCISE

The dataset required for this report is one which includes a universe of exported products along with their export values, by country over time. In this paper a cleaned version of the UN COMTRADE database, made available by The Growth Lab at Harvard University (2019), is used.[11] The available variables include: the reporting country; its trade partner; the product's Harmonised System (HS) code and description at the 6-digit and 4-digit levels; the year; the direction of the trade (export or import); and the value in US dollar terms.

Hausmann et al. (2014) highlighted the most limiting constraints of the UN COMTRADE data; the first of which is the lack of data on trade in services. This is a real constraint, given ever-increasing service-based trade, and in particular the outsourcing of services by developed countries to developing countries (Hallward-Driemeier & Nayyar, 2018). Another limitation is the lack of data about the volume of production of products that are not exported. On the one hand countries may produce items that they do not export, whereas on the other hand they may re-export products that they have not produced.

The identification of MER sector products in the trade data is made challenging by differences in the coding of industry groupings across datasets. While trade data is collected and compiled using the internationally accepted HS codes, the MER sector products are categorised and identified using a South Africa-specific convention of the Standard Industrial Classification (SIC) nomenclature. Identifying MER sector products in the trade data thus necessitates the creation of a SIC-to-HS crosswalk. The development of this cross-walk is described in detail in Technical Box 4.

[11] The Bustos & Yildirim method is used to clean the data.

Technical Box 4. Developing a HS-SIC crosswalk

The MER sector products are identified by their Standard Industry Classification (SIC) codes. SIC codes are used by Statistics South Africa (StatsSA) and based on the International Standardised Industrial Classification Codes 3rd revision (ISIC). The more detailed each code, the more in-depth the description of the product. The MER sector products were identified in the merSETA Sector Skills Plan (MERSETA, 2019) at the 3-digit SIC level, including an allocation of these codes to specific MER sector chambers. For example, the 3-digit SIC code for 'manufacture of basic chemicals' is 334, with the 4-digit SIC code within this grouping of 3343 relating to 'manufacture of fertilizers and nitrogen compounds'.

Country-level trade data, used to generate the economic complexity indices, is available from The Growth Lab at Harvard University (2019). These data are available for the period 1995 to 2017, when products are coded using the 6-digit level of the HS 1992 revision. Therefore, in order to identify MER sector products in the trade data, it is necessary to create a crosswalk between the trade data, coded using the HS classification, and the SIC classification, which is used to identify MER sector products/industries.

A first step is to map the 3-digit SIC codes provided by merSETA to their 4-digit SIC counterparts. As the SIC code base is based on the more commonly used ISIC definitions, a conversion was performed making minor adjustments for cross-country differences. Following this process, a correspondence table between ISIC codes and 6-digit HS codes, made available from World Integrated Trade Solution (2019), provided the final piece of the puzzle. Due to sparse data for certain products at the 6-digit level, the 4-digit level of the HS system is employed. For example, the 4-digit HS code `compounded unvulcanised rubber', which includes four 6-digit HS codes: compounded unvulcanised rubber; compounded unvulcanised rubber, plate, etc.; compounded unvulcanised rubber, primary, not elsewhere specified; and rubber solutions, not elsewhere specified.

Using this crosswalk, each product in the trade data is categorised as either non-MER sector or MER sector, with the latter being further categorised into the constituent MER sector chambers – metal and engineering, automotive manufacturing, automotive component manufacturing, new tyre manufacturing, and plastics. For countries outside of South Africa, the allocation of products in this manner is equivalent to creating a pseudo MER sector for each country.

Table 1 describes this dataset in terms of both global exports and those products exported by South Africa competitively (RCA $\geq$ 1). Total product exports amount to 1 239 products, of which South Africa exports 223 products – representing 18 percent of the total global non-services export basket. Within this, MER sector export products numbering 476 with South Africa exporting 72 of these competitively, or 15 percent of total global MER sector exports. In value terms, South Africa's competitive exports constitute less than 1 percent of total non-services export value globally in 2016. South Africa's export volumes in turn are 0.3 percent of total MER sector exports globally.

In both cases, exports are dominated by the manufacturing sector, in which MER sector products play a vital role. Of the 1 239 products defined at the 4-digit level of the HS classification, approximately 85 percent are manufactured, with 476 products fitting within the MER sector product universe. The relative importance of MER sector products, in a global context, is evident in the fact that products classified as MER sector products contribute over half of total global exports (USD 8.1 trillion). Similarly, the dominant MER sector chamber is metals, accounting for approximately two-fifths of global trade (USD 5.5 trillion), with the next highest contributions being considerably lower at 7.1 and 6.2 percent for plastics and automotive exports, respectively.

When breaking down South Africa's exports by category, as in Table 1, the highest contributors to the value of MER sector exports are the automotive and metal chambers. Each of these chamber's account for approximately 11 percent of South Africa's total competitive exports. An important feature of the metals chamber is the variety of products produced, which is a hallmark of economic complexity. In total, approximately 17 percent of all of South Africa's competitively exported products are metals products. Another high contributor to the number of products which are in South Africa's export basket is the plastics chamber, accounting for just over one-tenth of local exported products. However, these products are relatively low in export value – nine have an export value less than USD 10 million – and are mostly chemical products.

It should be noted that, contrary to the rest of the world, approximately two-thirds (USD 47.4 billion) of South Africa's exports in terms of value are classified as primary products.[12] This is consistent with the quantity of high value products, such as gold and platinum, which comprise approximately one-third of the country's competitive exports. Another interesting feature of South Africa's competitive exports is that non-MER sector manufactured products contribute a disproportionately smaller share of total exports. This may be partially explained by the fact that these products are predominately low-

[12] The categorisation of products as being primary products is based on Lall's (2000) classification system of exports. In this model, indictors of technological activity in manufacturing are used to assign products to different groupings. In the case of primary products, goods such as fresh fruit, meal, rice, cocoa, tea, coffee, wood, coal, and other unrefined mineral resources are included. These are the most technologically simple exports. The classification of exports as primary in this analysis has been done to ensure that metals in their unwrought, or unrefined form, are excluded from the metals chamber.

value agro-processed products. This is evidenced by the 8.6 percent share of export value from non-MER sector manufacturing, relative to its 39 percent share of total products exported (in count terms). Of these products, nearly a quarter have export values of less than USD 10 million, including agro-processing products such as bone, wool, feathers, and yarn from animal hair.

Table 1. Count and export value of products, 2016

	Number				Export Value (Current US$)			
Chamber	Global products	SA RCA products	% of Global products	% of SA RCA products	Global products (US$ M)	SA RCA products (US$ M)	% of Global products	% of SA RCA products
Primary	196	64	15.82	28.7	2 319 442	47 439	15.66	65.06
Non-MER sector, manufacturing	567	87	45.76	39.01	4 395 091	6 239	29.68	8.56
New tyre	15	1	1.21	0.45	127 567	36	0.86	0.05
Plastics	133	31	10.73	13.90	1 049 852	2 239	7.09	3.07
Automotive components	9	1	0.73	0.45	487 333	138	3.29	0.19
Metals	312	37	25.18	16.59	5 505 910	8 102	37.18	11.11
Automotive	7	2	0.56	0.90	922 888	8 723	6.23	11.96
Total MER sector	476	72	38.42	32.29	8 093 550	19 238	54.66	26.38
All products	1 239	223	100	100	14 808 080	72 917	100	100

Source: author's own calculations based on The Growth Lab at Harvard University (2019).

Having broken down the trade data used to calculate economic complexity into its constituent sectors, it was shown that MER sector exports account for a large share of both global and domestic exports. This finding warrants further investigation into the complexity of individual countries when considering only MER sector products. In the following section this is operationalised by computing a relative complexity ranking for each country in the sample using only values for MER sector exports.

3.2 THE MER SECTOR COMPLEXITY INDEX

Following the method set out by Mealy and Teytelboym (2018), which is used to measure complexity in the green economy, a MER sector Complexity Index (MCI) is developed. The method allows one to compare the complexity of the MER sector, and its constituent chambers, to that of the economy as a whole. As per the method described above, a pseudo-MER sector is created for all countries in the trade data sample, thus allowing for a ranking of these economies based on the relative complexity of their MER sectors.

Unlike the ECI calculated by Hausmann et al. (2014) which is estimated on the basis of the entire set of 1 239 traded products, the MCI focuses on the universe of 476 MER sector products exclusively. Further, while the ECI is equivalent to the mean PCI of all traded products in which the country is competitive, the MCI is the weighted average of these already calculated PCI values limited to those MER sector products that are traded competitively.

This measure increases with both the diversity and complexity of the MER sector products that a country is able to export competitively (Mealy & Teytelboym, 2018).[13] The method for calculating this $\mathbf{MCI}$ for country $\boldsymbol{c}$ is as follows:

$$\mathbf{MCI_c} = \sum\nolimits_{\mathbf{m}} \boldsymbol{\rho}_{\mathbf{m}} \widetilde{\mathbf{PCI}}_{\mathbf{m}} \tag{11}$$

According to this definition, $\boldsymbol{\rho}_{\mathbf{m}}$ is a binary vector indicating whether a country has a comparative advantage (i.e. RCA≥1) in MER sector product $\mathbf{m}$, then $\boldsymbol{\rho}_{\mathbf{m}} = 1$, otherwise it is 0. Intuitively, the $\mathbf{MCI}$ index for country $\boldsymbol{c}$ can be understood as a weighted average of the PCI for all MER sector products that a country exports competitively (RCA≥1).

[13] While it is noted that a number of papers have analysed the economic complexity by specific subsets of products, examples being green products (Huberty & Zachmann, 2011; Mealy & Teytelboym, 2018), and agricultural products (Isdardi, van Schalkwyk & Viviers, 2015), and fibrous products (Allen *et al*., 2019), this research is, to our knowledge, the first of its kind to focus on the mer sector.

Further, $\widetilde{\mathbf{PCI}}_{\mathbf{m}}$ is the PCI value for product $\mathbf{m}$, normalised to be between 0 and 1 as follows:

$$\widetilde{\mathbf{PCI}}_{\mathbf{m}} = \frac{\mathbf{PCI}_{\mathbf{m}} - \mathbf{PCI}_{\mathbf{min}}}{\mathbf{PCI}_{\mathbf{max}} - \mathbf{PCI}_{\mathbf{min}}} \quad (12)$$

where $\mathbf{PCI}_{\mathbf{min}}$ and $\mathbf{PCI}_{\mathbf{max}}$ are the minimum and maximum observed PCI values in the data, respectively. This $\mathbf{MCI}$ measure undergoes a final step of normalisation by subtracting the mean and dividing by the standard deviation, consistent with the process of normalisation used to compute the ECI.

Higher income countries have greater MCIs when compared to low- to middle-income countries. As shown in Table 2, the lowest ten ranked countries fall into the lowest income cohort, of which four are in sub-Saharan Africa and four in Latin America. Table 2 shows that the top ranked countries include Germany (DEU), Sweden (SWE), and Italy (ITA), with these economies having an average MCI approximately 1.5 times greater than their corresponding ECI. South Africa is ranked number 51 in terms of MCI, with its MCI being 0.6 points lower than its economy-wide complexity.

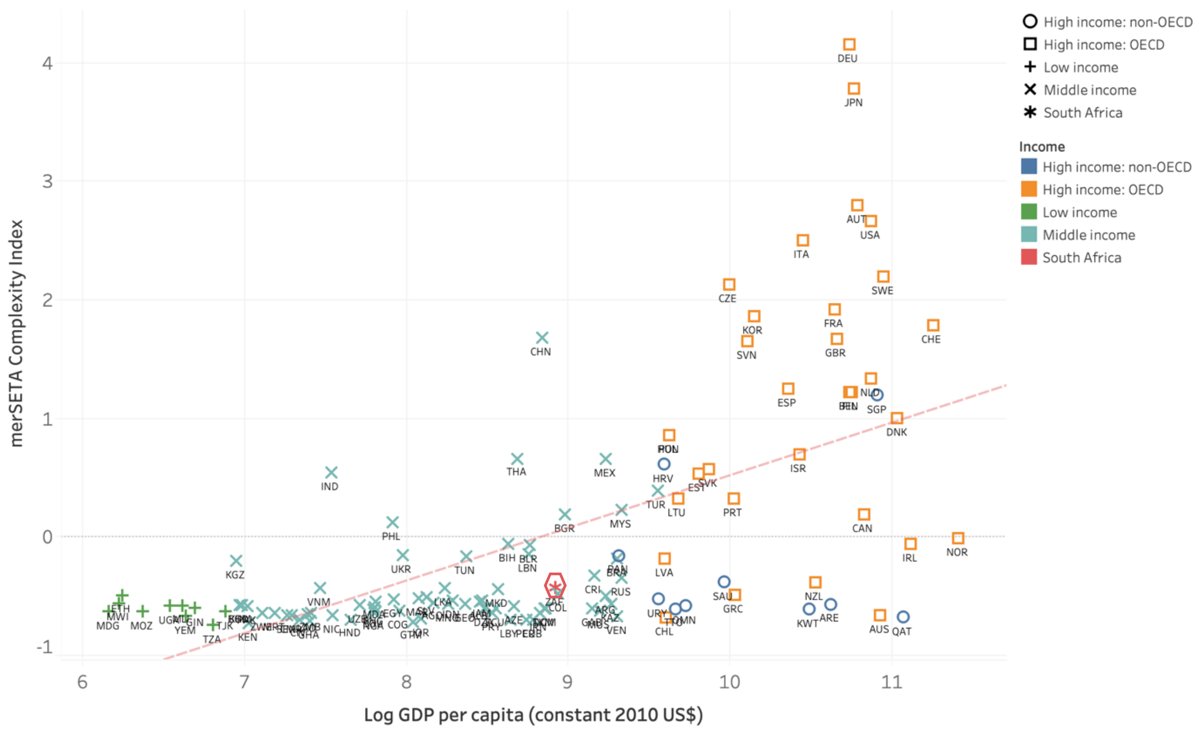
Table 2. Top- and bottom-ranked countries by MCI, 2016

MCI rank	Country	MCI	Mean MCI	ECI	Mean ECI	Income group
1	Germany	4.154		2.013		High-income: OECD
2	Japan	3.778		2.432		High-income: OECD
3	Austria	2.796		1.688		High-income: OECD
4	United States	2.664		1.621		High-income: OECD
5	Italy	2.500	2.577	1.173	1.794	High-income: OECD
6	Sweden	2.190		1.723		High-income: OECD
7	Czech Republic	2.128		1.662		High-income: OECD
8	France	1.917		1.413		High-income: OECD
9	South Korea	1.858		1.950		High-income: OECD
10	Switzerland	1.788		2.264		High-income: OECD
⋮	⋮	⋮		⋮		⋮
51	South Africa	-0.430		0.151		South Africa
⋮	⋮	⋮		⋮		⋮
112	Jordan	-0.692		0.018		Middle-income
113	Cote d'Ivoire	-0.697		-1.057		Middle-income
114	Honduras	-0.697		-0.716		Middle-income
115	Cuba	-0.698		-0.461		Middle-income
116	Peru	-0.699	-0.709	-0.709	-0.743	Middle-income
117	Libya	-0.702		-1.012		Middle-income
118	Ghana	-0.711		-1.116		Middle-income
119	Guatemala	-0.716		-0.508		Middle-income
120	Kenya	-0.733		-0.771		Middle-income
121	Tanzania	-0.748		-1.102		Low-income

Source: author’s own calculations based on The Growth Lab at Harvard University (2019).

When plotting the relationship between log GDP per capita and MCI in 2016, as in Figure 3, the prevalence of low complexity manufacturing within the low- to middle-income income cohort is illustrated by the large clump of countries in the bottom-left quadrant of the graph. This phenomenon can be partly explained by a boom in services in these economies over the last decade, specifically in sub-Saharan and Latin America. This is an example of negative structural transformation, whereby a large share of the labour force shifts from more productive to less productive activities, such as services and informal businesses (McMillan & Rodrik, 2011).

Figure 3. Relationship between GDP and MCI, 2016



Source: author's own calculations based on World Bank (2019) and The Growth Lab at Harvard University (2019).
Note: 1. Correlation=0.605, p-value=0.000. 2. Red dashed line is line of best fit. 3. The Syrian Arab Republic is excluded as no GDP per capita information was available for the period.

The dampening effect on manufacturing complexity as a product of service-led growth is most observable in the group of low-income African countries at the bottom of the distribution including Uganda (UGA), Mozambique (MOZ), Ethiopia (ETH), and Tanzania (TZA). China (CHN) is an outlier, with the inclusion of high complexity products such as electronics in its export basket inflating the MCI above that of other middle-income countries.

Where high-income economies have undergone industrialisation, the complexity of their MER sector can exceed that of the economy as a whole, suggesting a manufacturing-led path to building complexity. Table 2 shows the top ranked countries include early industrialisers, such as Germany (DEU), Sweden (SWE), and Italy (ITA). Included in this group are also more recent Asian industrialisers, such as Japan (JPN) and South Korea (KOR), with their highest value exports being electronic components and motor vehicles. These findings reveal a positive link between a country's shift toward manufacturing-led production – or its structural transformation – and its economic complexity.

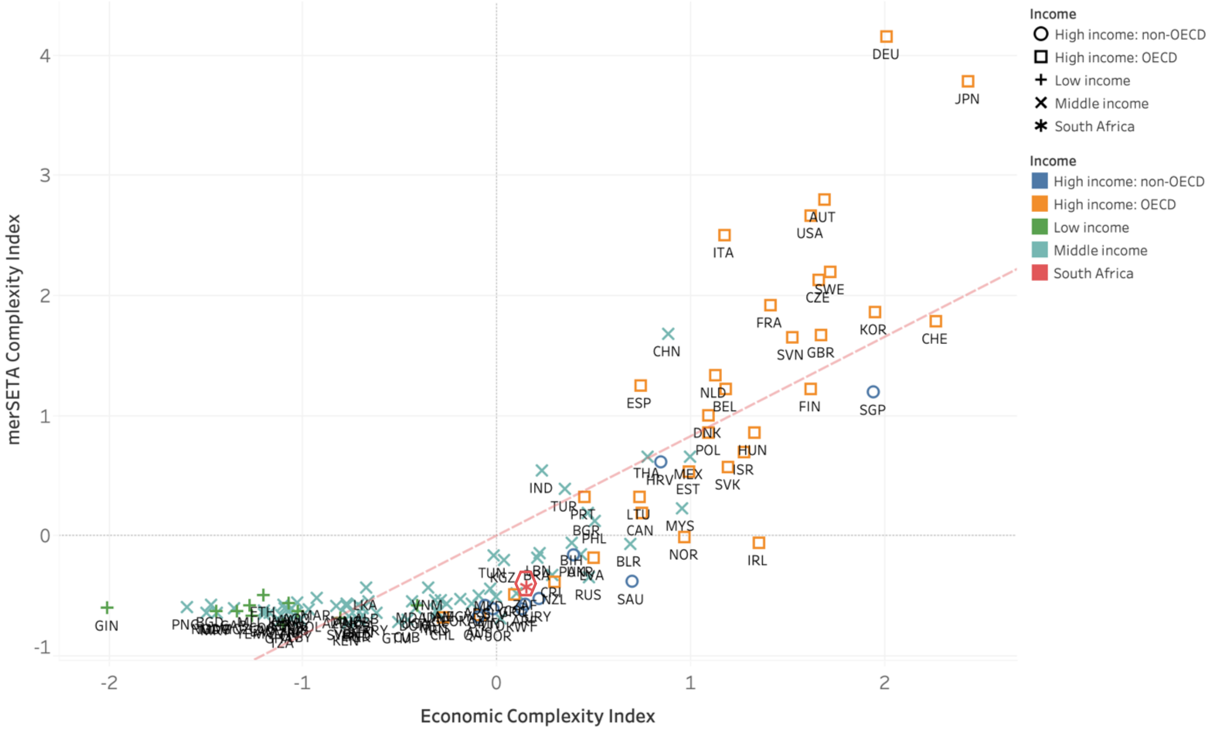
High-income countries that do not exhibit high levels of complexity in their MER sector exports are predominantly those with resource-based economies, which have not prioritised industrialisation. These countries are specialised in resource-based products, which require specialised assets and skills to produce, rendering the country unprepared to diversify into less resource-based products. This heterogeneity at the upper end of the income distribution means that of the 42 high-income countries in the sample, one-third have negative MCIs, including largely resource-based countries such as Chile (CHL), Qatar (QAT), Australia (AUS), Kuwait (KWT), and United Arab Emirates (UAE).[14] Looking at Figure 3, the failing of the linear trend to capture these dynamics could be overcome by controlling for natural resources as was the procedure followed by Hausmann et al. (2014) for economy-wide complexity.

The dampening effect of resource-dependency is also observed in South Africa. Taken in conjunction with the failure of the economy to fully industrialise, it is unsurprising that the country's portfolio of competitively exported MER sector products is considerably less complex than the equivalent measure for the economy as a whole. Further, South Africa's MER sector complexity is lower than is estimated for its level of economic development and income group, as shown by the country's position below the regression line in Figure 3. This gap is suggestive of an underinvestment by South Africa in the MER sector specifically, and manufacturing in general.

There is a positive relationship between economy-wide economic complexity and the complexity of the MER sector, with similar benefits – such as higher levels of economic development and income – accruing to high complexity countries. This is evidenced by the positive linear trend included in Figure 4, which plots the MCI against the ECI. This relationship is found to be both strong and significant with a correlation coefficient of 0.82. This finding is important as it suggests that there is potential to build overall economic complexity by investing resources into developing the MER sector.

[14] The classification of products as resource-based is in accordance with Lall's (2000) classification.

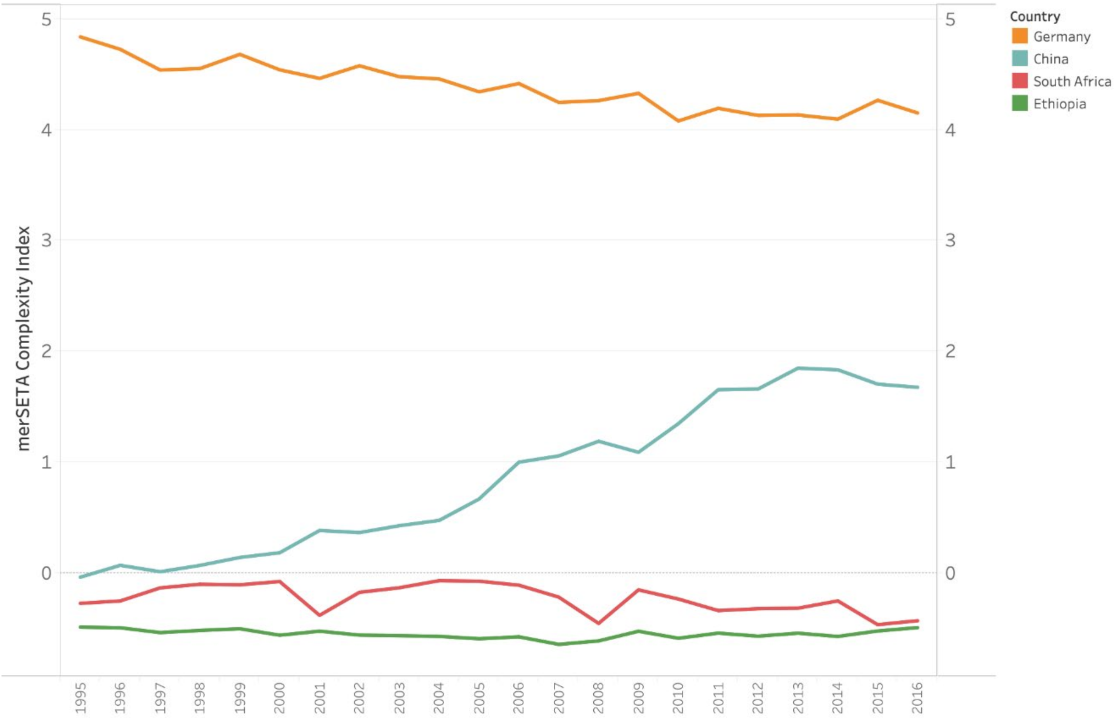
Figure 4 Relationship between ECI and MCI, 2016



Source: author's own calculations based on The Growth Lab at Harvard University (2019).
Note: 1. Correlation=0.823, p-value=0.000. 2. Red dashed line is line of best fit.

The finding of industrialisation as a key driver of economic complexity is supported when viewing the MCI for a subset of countries between 1995 and 2016, as shown in Figure 5. South Africa's failure to industrialise is depicted in its lack of growth in MER sector complexity over time, with a similarly poor degree of growth being observed for a country only starting to consider the path of industrialisation, namely Ethiopia. In the case of Germany, its high MCI has not changed substantially over time, which is expected as the economy has matured beyond the stage of rapid growth from industrialisation. In the case of China, modern industry initially involved labour-intensive production, with little expertise being required (Brandt, Ma & Rawski, 2016). With time, and as a result of various trade reforms, the economy has shifted toward more skilled-labour and capital-intensive products and methods of manufacturing and, in so doing, has developed its capabilities in this sector (Brandt, Ma & Rawski, 2016). This is captured in the upward slope of China's MCI over time, switching from a negative to a positive value in 2006, which coincides with their growing competitiveness in global markets for manufactured products such as computers, automotive components, and other home appliances.

Figure 5. MCI, 1995 - 2016



Source: author's own calculations based on The Growth Lab at Harvard University (2019).

It was established that while the MER sector is a large contributor to exports worldwide, it is predominantly comprised of low complexity manufacturing. However, those countries that achieved high MER sector complexity rankings were high-income, or fast industrialising developing countries. The positive relationship between economy-wide complexity and the complexity of the MER sector highlights that supporting and nurturing these industries is advantageous for both a country's level of economic development and its long-run prosperity.

The following section aims to delve deeper into which products are most complexity-building in the MER sector. This is of interest given the positive association between an advanced MER sector and economic development noted above.

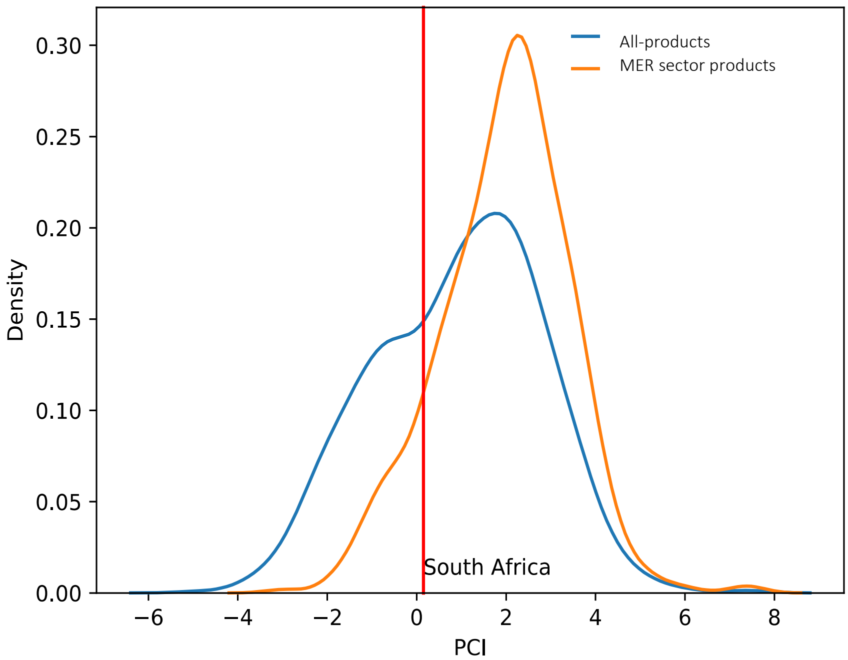
3.3 MER SECTOR PRODUCT COMPLEXITY

Using the PCI measure defined in the complexity literature, products are ranked according to their relative complexity. Focusing on the MER sector universe of products, this approach helps to identify which products in this sector are most complex, thereby providing attractive diversification opportunities for those countries aiming to build economic complexity.

The findings of this analysis are set out using Figure 6 and Table 3 which can be interpreted as follows. Figure 6 shows the distribution of the PCI values for all 367 MER sector products relative to the equivalent distribution for the entire sample of 1 239 products. Further, the red line shows the average PCI of 0.151 for all of the products which South Africa exports competitively, equivalent to its ECI. In Table 3, columns (1) and (2) show the mean and median PCI values for all 1 239 products respectively, while columns (3) and (4) show analogous statistics for the products that South Africa exports competitively (RCA ≥ 1). The final column is the ratio of column (3) to column (1) which can be interpreted as South Africa's mean complexity for competitively exported products relative to the global average.

In comparison with the entire sample of 1 239 products, the 376 products in the MER sector are more complex, suggesting that diversifying production to include more MER sector products should result in countries building their complexity. This is illustrated by the right skewness of the distribution of PCIs for MER sector products in Figure 6 relative to that for all products. Quantifying the difference between the shapes of these distributions, Table 3 shows that the mean and median PCI for the MER sector products are both approximately 2, nearly double that of the corresponding measures for the full sample of products. Comparing only manufactured products, the MER sector remains superior with an average PCI four times greater than that for non-MER sector manufactured products.

Figure 6. PCI of MER sector products and all products, 2016



Source: author's own calculations based on The Growth Lab at Harvard University (2019).
Note: 1. red line represents the ECI for South Africa of 0.151.

Considering all MER sector products, each chamber individually has a mean PCI greater than that for all products. The most complex chambers are automotive and metals, both having average PCIs of 2.3. The average complexity in the automotive sector is largely attributable to cars (PCI = 2.6), with few low complexity products included in this chamber to bring down the average. Conversely, the metals chamber comprises a wide range of products, many of which are characterised by low levels of product complexity, such as basic products of iron. Other products within this chamber are characterised by higher levels of complexity, such as machinery and equipment type products, including X-ray machines (PCI = 2.7) and instruments for chemical analysis (PCI = 4.4)

Table 3. Mean and median PCI by chamber for all products, 2016

			Product Complexity Index		
Chamber	Mean Global Products	Median Global Products	Mean South Africa RCA ≥1	Median South Africa RCA ≥1	Mean South Africa RCA Products/ Mean Global Products
Primary	-0.397	-0.648	-0.820	-1.084	2.07
Non-MER sector, manufacturing	0.483	0.556	0.090	-0.177	0.19
New tyre	1.227	1.225	2.519	2.519	2.05
Plastics	1.653	1.741	0.943	0.776	0.57
Automotive components	1.873	1.985	-0.054	-0.054	-0.03
Metals	2.161	2.271	1.130	1.235	0.52
Automotive	2.258	2.349	2.291	2.291	1.01
Total MER sector	1.985	2.109	1.084	1.155	0.55
All products	0.921	1.093	0.151	0.068	0.16

Source: author’s own calculations based on The Growth Lab at Harvard University (2019).

South Africa's total competitive exports (RCA $\geq$ 1) are largely low complexity with a mean PCI of 0.15, which is 0.76 points lower than the global average. Focusing on MER sector products, the mean PCI of South Africa's competitively exported MER sector goods of 1.08 is higher than the average PCI for all products. However, this figure is considerably lower than the global average PCI of 2 for MER sector products, meaning that South Africa's MER sector exports are predominantly less complex.

In Figure 6 this is depicted by the position of the red line to the left of both distributions. Column (5) in Table 3 quantifies this difference showing that South Africa's mean complexity for competitively exported MER sector products is approximately half of the global average. When considering South Africa's relative mean PCI by chamber, the country does not perform favourably – with the exception of the automotive and new tyre sectors. In South Africa the automotive chamber is equally complex when compared to the full universe of MER sector products. A possible explanation is that the country's competitive exports in this sector comprise only two highly complex products, namely cars and vehicles for transporting products. The country's superior complexity in the new tyre chamber can be attributed to a single high complexity product: conveyor belts of vulcanised rubber.

South Africa does have a dominant in-country profile of MER sector products, but export values can be attributed largely to primary products (i.e. metal products). However, the new tyre and automotive sectors do play a prominent role in the non-primary MER sector in term of the complexity of exports. The main takeaway here is that MER sector products are more complex whether considering global exports, or when limiting the sample to South Africa's competitively exported products.

Up until this point it has been shown that countries which have experienced industrialisation, or manufacturing-led structural transformation, are more complex. These elevated levels of complexity have been linked to higher levels of income and economic development. As countries shift toward more manufactured goods, evidence of the superior complexity-enhancing opportunities provided by MER sector products has been shown.

Based on the above analytical and empirical overview, the next section uses a visual representation of the structure of a country's manufacturing sector, in the form of a network visualisation called a product space, to find evidence of manufacturing-led structural transformation at the country level (Hidalgo et al., 2007; Hausmann et al., 2014). Thereafter, such network visualisations are generated for the MER sector alone, which will later be used to identify the opportunities for diversification available in this sector given a country's existing capabilities.

4. PRODUCT SPACE ANALYSIS OF THE MER SECTOR

In order to build complexity, countries need to accumulate productive capabilities which allow them to diversify toward more complex products, thereby increasing economic growth and development. The countries which have exhibited the highest levels of economic complexity have been those that have undergone a process of industrialisation, or manufacturing-led structural transformation, thereby shifting economic activities from simple agricultural and mining products toward more complex, manufactured products (Hausmann et al., 2014). Further, it has been shown above that the most complexity-enhancing of these manufactured products fall within the MER sector.

This section uses Hidalgo et al.'s (2007) product space network map to show how closely products are related in terms of similarities in capability requirements. Firstly, the product space is used to visualise how economies have changed over time as they shift from product to product, occupying different areas of the map. Those countries which are shown to have moved from lower complexity, agricultural and mining products, to higher complexity manufactured products, exhibit manufacturing-led structural transformation. Secondly, the product space is generated for MER sector products in isolation. Later the MER sector product space is used to draw attention to the diversification opportunities for economic development – being those that are most accessible to a specific country given its knowledge endowment and desire to increase economic its complexity.

4.1 CREATING THE PRODUCT SPACE

Hidalgo et al. (2007) propose that each country will have different revealed opportunities for diversification. Ultimately this path will be dependent on the economy's existing capabilities.

Those countries pursuing a diversification strategy are faced with the following challenge: The capabilities required to produce a given product are imperfect substitutes for those needed to manufacture another product, though the extent of this capability will vary (Hausmann & Klinger, 2006). Consequently, the probability that a country will develop the capabilities required to produce a new product is dependent on its existent capabilities to produce similar, or nearby products. This reduces the co-ordination required to accumulate many capabilities simultaneously, as well as lessening the cost of acquiring difficult to transfer tacit knowledge.

This process is hindered by the fact that, where industries do not exist, it is difficult to justify an investment in capability development. However, without such an investment these industries will never develop (Hausmann et al., 2014). Therefore, the path of least resistance for many countries is from an industry in which they have a large store of capabilities to an industry wherein a large portion of this knowhow also applies (Hausmann et al., 2014). For example, a country with existing capabilities in the production of shirts is well-positioned to shift to manufacturing trousers, as opposed to producing jet engines.

As discussed previously, the measurement of capabilities is not straightforward. An indirect measure of whether a country has the requisite capabilities to produce a product is whether it currently exports that product competitively – it has a revealed comparative advantage (i.e. $RCA \geq 1$). Following this logic it is possible to determine whether two products require similar capabilities to be produced based on whether two or more countries co-export a set of products. As shirts require capabilities that are similar to those required to manufacture trousers, there is a high probability that these products will be exported together. However, as jet engines and shirts require dissimilar capabilities, it is less probable that they will be co-exported. Therefore, the pairwise conditional probability of two products being co-exported competitively is a measure of the similarity of the capabilities required to produce them (Mealy & Teytelboym, 2018). This is termed the proximity between two products, with a mathematical definition given in Technical Box 5. The collection of all proximities is a useful measure in building Hidalgo et al.'s (2007) product space – a map showing a network of traded products.

Technical Box 5. Calculating proximity between products

It is assumed that if two products require similar capabilities to be produced, then it is probable that a country will export both products competitively (RCA >= 1). Conversely it is less probable that countries will co-export a pair of products which do not require similar capabilities.

Using the conditional probability that a country exports product $\boldsymbol{i}$ competitively given that it exports product $\boldsymbol{j}$ competitively, $\mathbf{P}\left(\mathbf{RCA_i} \geq \mathbf{1} \middle| \mathbf{RCA_j} \geq \mathbf{1}\right)$, and vice versa for $\mathbf{P}(\mathbf{RCA_j} \geq \mathbf{1}|\mathbf{RCA_i} \geq \mathbf{1}$, it is possible to construct a measure of proximity between the two products as follows:[15]

$$\boldsymbol{\phi_{i,j}} = \mathbf{min}\,\{\mathbf{P}\left(\mathbf{RCA_i} \geq \mathbf{1}|\mathbf{RCA_j} \geq \mathbf{1}\right); \mathbf{P}\left(\mathbf{RCA_j} \geq \mathbf{1}|\mathbf{RCA_i} \geq \mathbf{1}\right)\} \tag{13}$$

All pairwise proximity values can then be arranged in a symmetric proximity matrix, $\boldsymbol{\Phi}$, which are used in the construction of the product space visualisation.

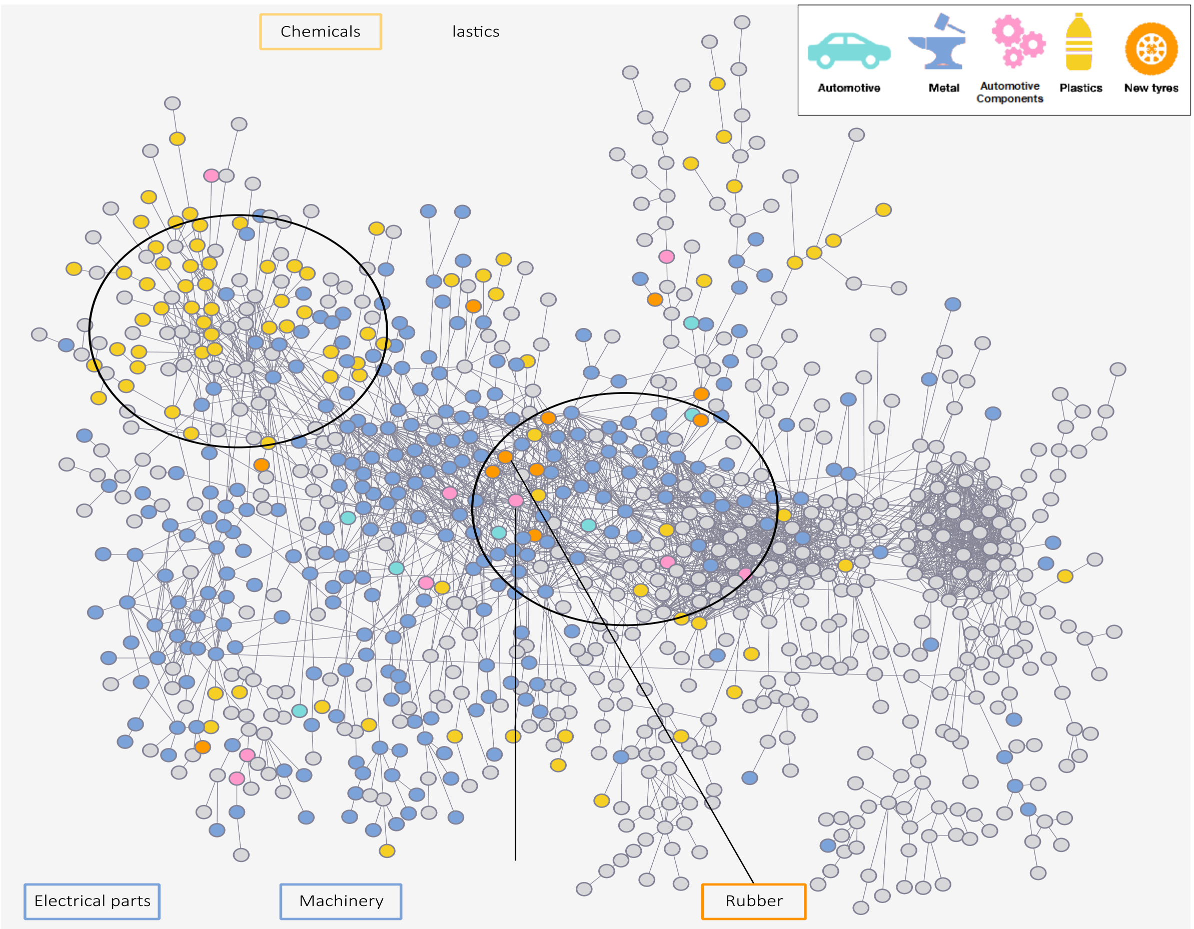
Hidalgo et al.'s (2007) product space provides a visualisation of the interconnected nature of products. The structure of the product space is very important because it provides insight into how easily a country is able to shift to new products and increase its complexity, thereby undergoing a process of structural transformation.

Figure 7 presents the global product space based on the representations used by Hausmann et al. (2014). Each node (circle) in the product space represents a product, with the edges (connecting lines) indicating how closely related a pair of products are – or their proximity.[16] If these connecting lines are shorter then products are closely related and require similar capabilities to produce, thus making it easier for a country to diversify their product offering from the product that it currently produces to the proximate product that it doesn't produce.

[15] As the proximity measure is conceptually related to distance, and that a distance function defined on any metric space must be symmetric (Khamsi & Kirk, 2001), the minimum of these two conditional probabilities is used in order to satisfy this property. This is the notion that a valid distance function, d, defined between the points x and y should satisfy the property that $d(x, y) = d(y, x)$.

[16] A force-spring layout is used to generate the product space, meaning that nodes try to repel one another while edges try to pull nodes back together. The force at which nodes are pulled back to together has a positive relationship with the proximity between a pair of products. Therefore, the higher the proximity between two products, the greater the force pulling them together and the shorter the edge.

Figure 7. Product space with MER sector chambers highlighted, 2016



Source: author's own calculations based on The Growth Lab at Harvard University (2019).
Note: 1. MER sector chambers are represented by the following colours: automotive manufacturing (light blue); metal and engineering (dark blue); automotive component manufacturing (pink); plastics (yellow); and new tyre manufacturing (orange). 2. The product space illustration is generated using Python package product-space (CID, 2017).

An important structural feature of the product space is the existence of a core and a periphery. While the core is made up of highly connected products, which are often manufactured products, the outer branches of the product space are comprised of loosely connected nodes, typically primary products. This can be interpreted as those manufactured products in the core of the product space requiring many similar capabilities to produce, while the peripheral products share few capabilities with other products. The position of a country in the product space determines its ability to undergo a process of structural transformation, whereby the occupation of nodes in the core offers better diversification into a range of manufactured products. Further, these centrally located products are more likely to be complex, as Hausmann et al. (2014) are able to show that the closer to the core products are, the higher their complexity, and vice versa, with less complex products forming the periphery.

After building the product space, it is possible to locate the MER sector products within the network relative to all of the other products. Figure 7 presents the product space based on the structure used by Hausmann et al. (2014), with the nodes representing MER sector products highlighted according to their respective chambers. Some of the main groupings of MER sector products are identified in this figure for ease of reference.

This diagram allows for a number of observations. First, a cluster of metals and transport products – spanning the metals, automotive, and automotive components chambers – are in the highly connected core of the product space. Their centrality indicates that these products are highly complex, a finding consistent with the high PCI measures in the automotive and metals chambers when considering the entire universe of products. Each product in this cluster has a high number of nearby products, thereby creating easily accessible opportunities for the country to diversify into new MER sector products. Specifically, the product space suggests that the capabilities required to manufacture cars overlaps with those needed to manufacture other nearby products such as motor vehicle parts, articles of vulcanised rubber, and other plastic products.

Similarly, there is a central cluster of highly complex machinery products within the metals chamber requiring very similar capabilities to produce. This is suggestive of many opportunities for diversification, for example a shift from less complex appliances for thermostatically controlled valves to nearby more complex machinery such as vacuum pumps. It should be noted, however, that there is a degree of heterogeneity in the metals chamber with a few lower complexity products toward the righthand side of the metals and transport cluster being more closely linked to non-MER sector manufactured products. An example would be the link between metal structures such as bridges and prefabricated buildings being closely related to carpentry of wood and articles of concrete.

Electronics and chemicals form clusters toward the outer edges of the product space, and while these products are similarly highly complex, the specificity of the capabilities required to produce these products are relevant within their cohort, but not outside of it. As a consequence there are many opportunities for intra-cluster diversification, while integration into the rest of the product space is a less attractive prospect.

Using the product space method, it is also possible to develop this visualisation for individual countries where the shaded nodes represent those products that a country exports competitively. The location of a given country in the product space provides information regarding both the capabilities which it currently possesses as well as which nearby, complexity-building products the country could diversify into.

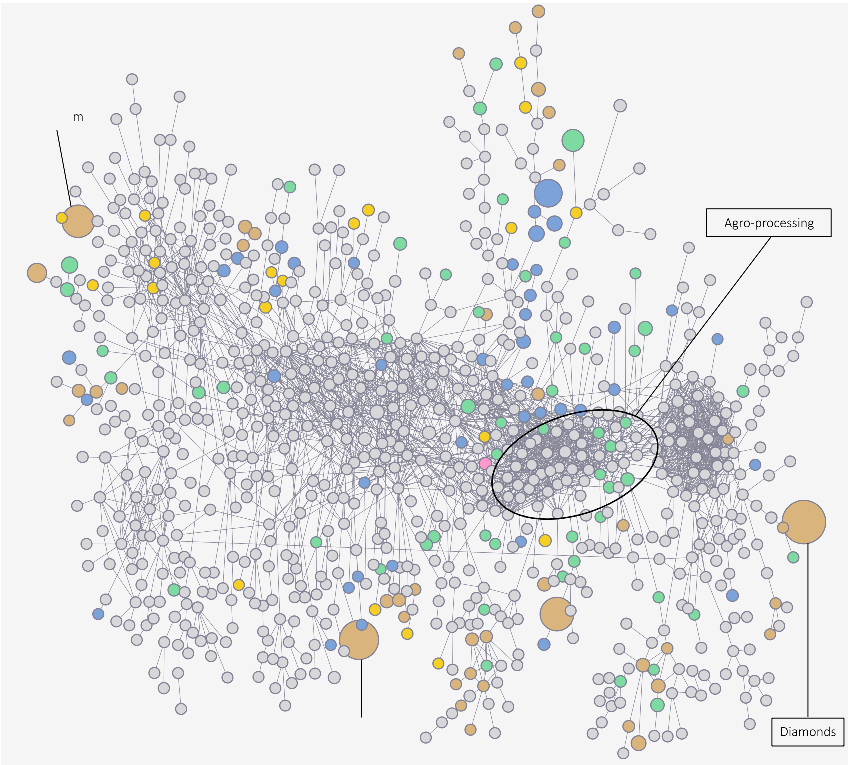
Generating these product spaces at different points in time provides information about how the productive structure of a given country has changed over time as it develops capabilities in different parts of the product space. In understanding these dynamics, it is possible to observe the extent to which a country has undergone manufacturing-led structural transformation, as well as opportunities to diversify into manufacturing-based products based on its existing capabilities. The following section uses South Africa's product space in two periods, 1995 and 2016, as an alternate means of identifying patterns of structural transformation.

4.2 SOUTH AFRICA'S PRODUCT SPACE

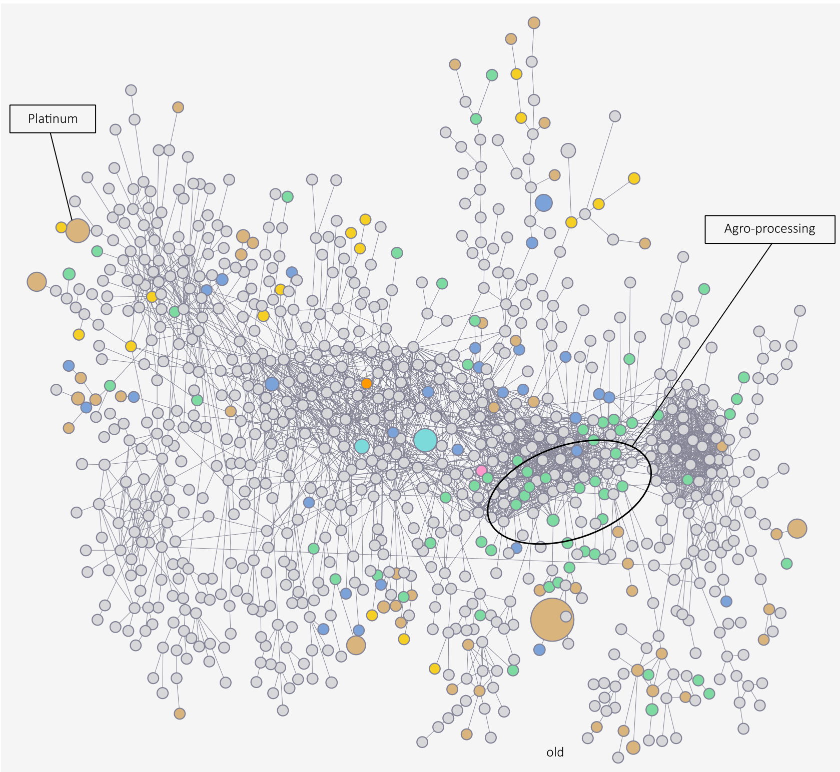
The product space offers a novel way of visualising the universe of products which a country exports competitively. Figure 8 represents South Africa's product space for 1995 and 2016 respectively, allowing for insight into the path of economic development which the country has taken over the last two decades. The products which South Africa exports competitively are shaded according to the MER chamber colours as used previously with the addition of two categories: non-MER sector manufacturing (green) and primary (brown). It should be noted that primary products are categorised as in the latter grouping. Those products that are not exported competitively are opaque. The size of each node represents the export value for each product.

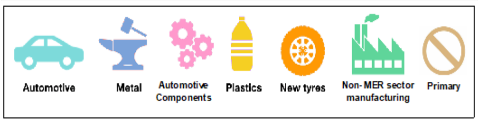
Figure 8. The product space for South Africa, 1995 and 2016

Panel A: 1995



Panel B: 2016





Source: author's own calculations based on The Growth Lab at Harvard University (2019).
Note: 1. The product space illustration is generated using Python package product-space (CID, 2017).

In the South African case, in both 1995 and 2016, there are many poorly connected primary products – mainly commodities such as gold and platinum – on the periphery. While the high export values of these products show that their low complexity makes them easy to export, their loose connection to the rest of the product space suggests that the production of these products requires capabilities which cannot readily spill-over to other products, rendering them poor drivers of diversification. While agriculture is not a main feature of the product space, these primary products are similarly rudimentary, being some of the lowest ranked products in terms of complexity.

In the intermediate position is a small cluster of agro-processed products, in which there was a marginal increase in shaded nodes between 1995 and 2016, though it should be noted that while these products are highly connected, they are not particularly complex.

Though still not densely populated, there were increases in the number of different manufactured products that are exported competitively between 1995 and 2016. Nodes highlighted are largely in the connected core – spanning the metals, automotive, and automotive components chambers – such as machinery and transport. Interestingly, the most substantial growth in this region of the product space occurred in two of the most complex MER chambers – automotive and new tyres. The largest centrally located node is that for cars, with the clustering around this node signalling many diversification opportunities such as products of vulcanised rubber and motor vehicle parts, which are opaque as they are not currently exported competitively in South Africa. This is consistent with South Africa's extensive subsidies in support of the automotive sector from the Motor Industry Development Programme, which was replaced with the Automotive Production Development Plan in 2012, and will be running until 2020 (South African Revenue Service, 2020). Although these gains have largely failed to spill-over to other sectors related to the automotive components sector, there is potential for expansion into these nearby industries in the coming years. This suggests that, though limited, the accumulation of capabilities did occur in a select subset of the MER sector, though notably insufficient to increase economy-wide complexity.

Despite these marginal manufacturing-led advances, South Africa's reliance on commodity-based exports, as well as the boom in services over the period, provide little evidence to suggest that the country has experienced manufacturing-led structural transformation. This failure to shift from the export of a few, low complexity products toward a range of sophisticated products, is tantamount to a failure to industrialise. However, the existence of a few centrally located, competitively exported MER sector products suggests that the economy does have the ability to diversify based on existing capabilities.

The aim of the next section is to build a product space using MER sector products only, to identify pathways for diversification within each of the five chambers.

4.3 THE MER SECTOR PRODUCT SPACE

Providing estimates of a country's capabilities to export complex MER sector products using the MCI provides insight into which countries are currently best positioned to be leaders in the MER sector. However, in order for countries to successfully diversify their MER sector product offering they will need to adapt their existing productive structure to promote the development of different MER sector industries (Mealy & Teytelboym, 2018). This transition is path dependent, whereby countries will shift to products that require similar capabilities.

Although the previous section has identified the MER sector products in the product space, it is also useful to have a visualisation of how the various MER sector products are connected to one another. This section, drawing on work from Hidalgo et al. (2007) and Hausmann et al. (2014), builds a product space for the MER sector products using network analysis. Further, the work that Mealy and Teytelboym (2018) did to generate a product space for a subset of green products has proven to be an important resource. The technicalities behind the generation of the MER sector product space are discussed in Technical Box 6.

Technical Box 6. Building the MER sector product space

Building on the work of Hidalgo et al. (2007) and Hausmann et al. (2014), the product space network can be reworked to include only the products in the MER sector. In doing so, the proximities are calculated for this restricted sample following the method in Technical Box 5.

The MER sector product space should incorporate two conditions as described by Hausmann et al. (2014). Firstly, no products in the network should be isolated, resulting in a connected network visualisation. Secondly, the network needs to be relatively sparse as too many edges means that it is hard to disentangle the most relevant connections. This requires a rule of thumb to be enforced which limits the average number of edges between nodes to 5.

In order to meet the first condition, a Maximum Spanning Tree (MST) of the MER sector matrix is calculated using Kruskal's algorithm. The MST is a set of links connecting every node in the product space using the minimum number of edges while simultaneously maximising the sum of all proximities.

This involves sorting the proximities in descending order and incorporating connections if, and only if, they connect to an isolated node (Hausmann et al., 2014).

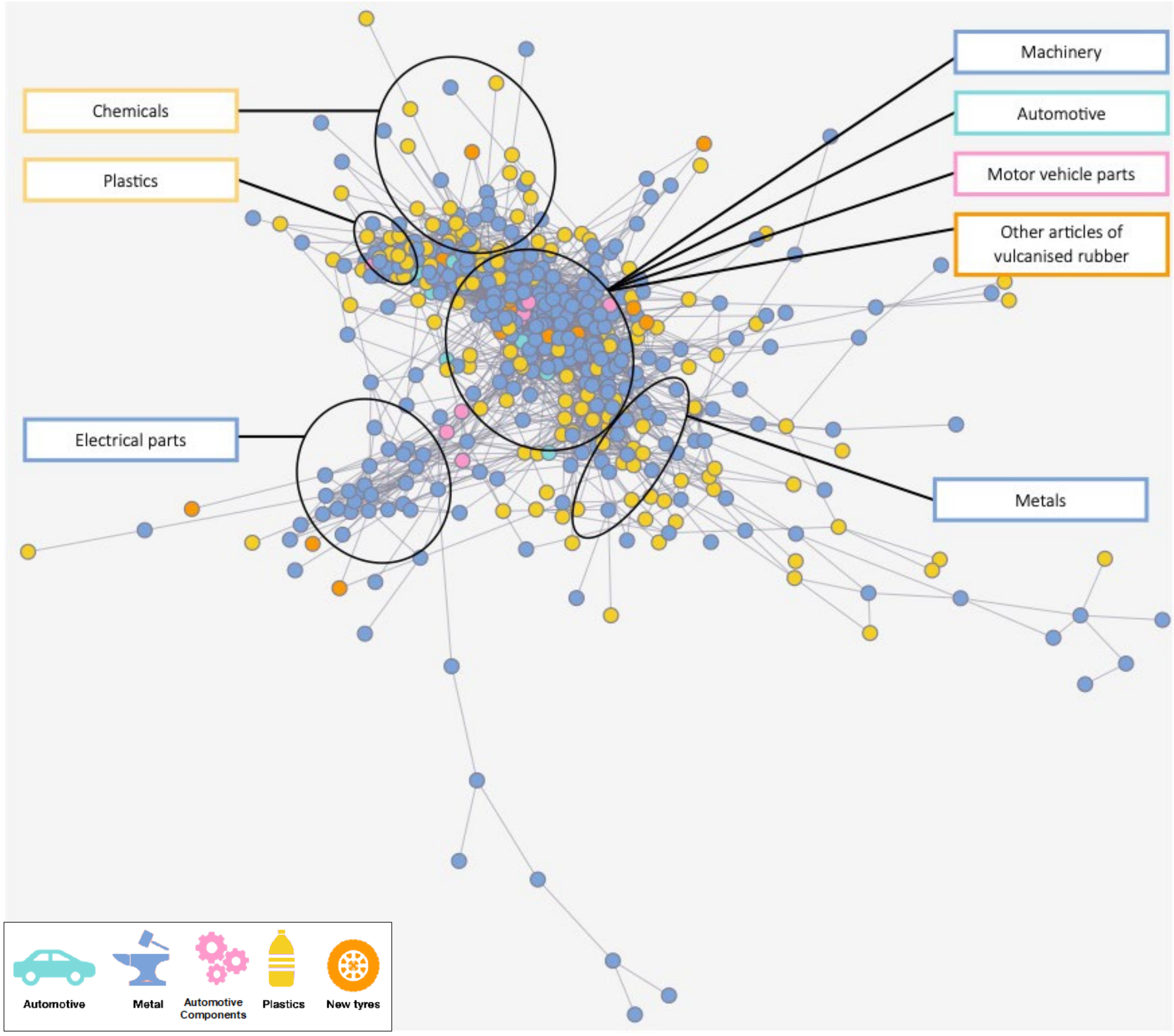
As a result the outcome is a sparse network of products, requiring links with the highest proximities, or strongest links, to be included in order to achieve a dense product space. This creates a dense central cluster with a sparse periphery as is characteristic of the network visualisation. Practically this involves selecting a proximity threshold, $\boldsymbol{\alpha}$, such that if $\boldsymbol{\phi_{i,j}} > \boldsymbol{\alpha}$, the link is included back into the product space. A value of $\boldsymbol{\alpha}$ = 0.4 is chosen.

As a final adjustment, a Directed Force-Spring layout is used following the approach in Hausmann et al. (2014), resulting in the nodes of the product space repelling one another while the edges act as a spring to pull these nodes back together. The force at which nodes are pulled back together has a positive relationship with the proximity between a pair of products. Therefore, the higher the proximity between two products, the greater the force pulling them together and the shorter the edge.

The MER sector product space is shown in Figure 9, drawing attention to a few products in each chamber. As with the aggregate product space, there is a clear core of highly connected products, which were shown to be more complex, while loosely connected patches of less complex products form the periphery. This heterogeneity provides a useful tool for understanding the strategies employed by countries to diversify their MER sectors.

The products forming the outer branches extending from the product space can be found in the metals and plastics chambers. There is much heterogeneity regarding the complexity of these peripheral products. While one peripheral branch contains very low complexity household items such as scissors and knives, another contains some of the highest complexity products such as equipment for photography and endless copper wires. Despite these differences in complexity, it is the lack of overlap in capabilities between these branches of products and their closest neighbours which may limit 'spill-over opportunities' into other MER sector products.

Figure 9. The MER sector product space, 2016



Source: author's own calculations based on The Growth Lab at Harvard University (2019).
Note: 1. The product space illustration is generated using Python package product-space (CID, 2017).

Conversely, there is a core of high complexity products which naturally group together to form a cluster of machinery and transport-related products across the metals, automotive, and automotive components chambers. In this highly connected region of the product space, adding a few capabilities opens up many diversification possibilities. Included in this region of the product space are some products which were shown to be closely related in the full product space such as cars, motor vehicle parts, and other vulcanised rubber products[17].

As with the greater product space, electrical parts and chemicals are intermediate products, forming clusters toward the periphery of the product space. Though these products are usually highly complex,

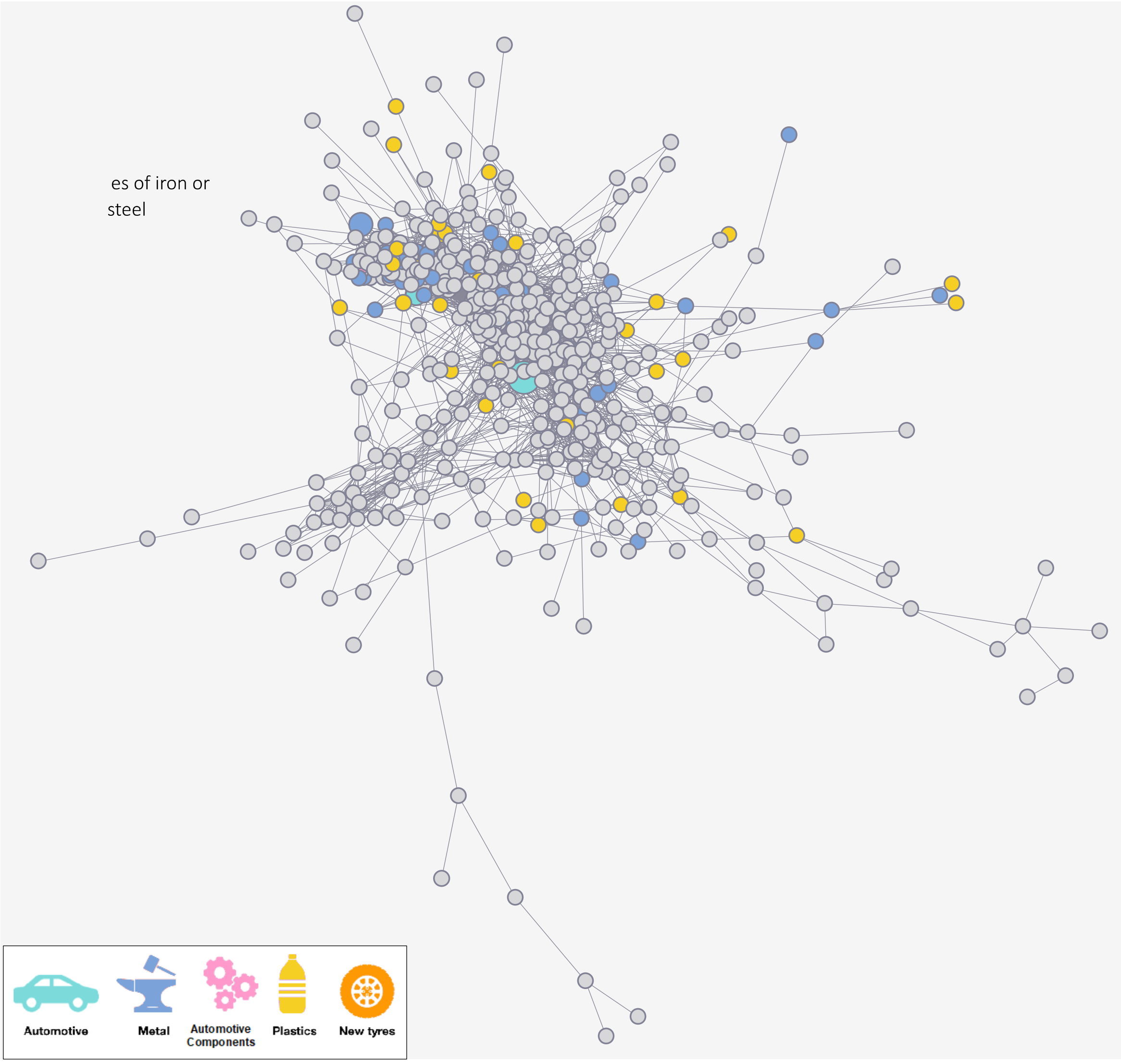
[17] The grouping "Other articles of vulcanised rubber" includes products such as articles of cellular rubber, vulcanised rubber seals, rubber floor coverings, erasers, vulcanised rubber boat fenders, and inflatable vulcanised rubber articles.

their position outside of the core of the product space can be explained by the specialised nature of the capabilities required to manufacture these products which, while relevant within their group, are not transferable to other nearby products within the network. For example, most of the products in the chemicals cluster are basic chemicals, with the closest non-chemical products being basic metal products such as nails and steel bars. Even more tangential are electronics parts, which are linked to the core product space via simple machinery products for which they provide components. Consequently, the diversification opportunities within these cohorts are limited to those products within the cluster.

The MER sector product space provides a new approach to understanding the MER sector products that are exported by a given country competitively. Keeping the underlying network fixed, the nodes highlighted in Figure 10 represent those products that South Africa exports competitively. It is clear that South Africa does not capture a large portion of the MER sector product space, consistent with the prior finding of its underdeveloped MER sector, and correspondingly low MCI.[18]

[18] Comparator pseudo-MER sector product spaces were also compiled. In brief these maps show that highly industrialised countries such as Germany and China have densely populated product spaces, displaying much sharing of capabilities, particularly in metals manufacturing. Conversely, a deindustrialised country such as Ethiopia has but a handful of occupied nodes in the product space which are widely spread, indicating few easily accessible diversification opportunities.

Figure 10. The MER sector product space for South Africa, 2016



Source: author's own calculations based on The Growth Lab at Harvard University (2019).
Note: 1. The product space illustration is generated using Python package product-space (CID, 2017).

As found previously, the most important product in the network is cars, having both very high product complexity and a large share of the country's total exports. This product is positioned well within the middle of the product space, suggesting that the country's occupation of this node holds promise for diversification opportunities within nearby nodes.

Toward the upper-left of the product space lie a subset of light manufacturing products within which capabilities are readily transferrable, as indicated by the interconnectedness of these products. Some of South Africa's most complex products fall within this region of the product space: namely polymers of propylene and centrifuges. Of particular interest is the closeness of the transport-related products, containers and motor vehicles for transporting products, as well as their joint proximity to competitively exported new tyre products. The short distance between this subset of the product space and the other transport-related occupied node, cars, includes products such as motor vehicle parts which seem like promising opportunities to close this gap.

In sum, while South Africa does not currently occupy a large share of the MER sector product space, its position within the network – particularly with regard to transport-related products – suggests that diversification into more MER sector products is feasible.

This section has shown that the location of a country in the product space is a key determinant in understanding how it will diversify and increase its complexity. As there is heterogeneity in the product space, different countries are faced with varying possibilities. While it was established that countries need to accumulate capabilities in order to take up these diversification opportunities and grow complexity, it is only by using the product space that it is possible to map out this path. The next section aims to identify these diversification opportunities for the MER sector at the product level, using network analytics.

5. IDENTIFYING OPPORTUNITIES FOR BUILDING ECONOMIC COMPLEXITY IN THE MER SECTOR

In this section, we use network analytics to identify diversification opportunities within the MER sector. We term these diversification opportunities as 'frontier products'. We use network criteria to identify the frontier products. Following Hausmann and Chauvin (2015) and Bhorat et al. (2019), the main criteria are as follows: Firstly, these frontier products should be more complex than the country's current export basket so as to ensure that diversification is complexity building. Second, the production of these products should be feasible based on the country's current productive structure. And third, this diversification should take place in the core of the product space ensuring potential for future diversification.

Formally these criteria can be stated as follows:[19]

[19] Should one add additional criteria, such as employment intensity or green-friendly, you will possibly get a different frontier product list mix.

Firstly, the set of products that are being investigated is restricted to include only those products that the country does not currently export competitively (RCA < 1) to ensure that there is a diversification in the country's export basket.

Secondly, non-RCA products are then ranked in ascending order of the distance index, and those further than the median distance are dropped. This measure of distance is an aggregate value of how far away a given product is from a country's current export basket. For a technical definition of the distance index see Technical Box 7 below.

Thirdly, to ensure that only complexity building products are included, only products with a PCI value greater than the ECI (average PCI for all RCA ≥1 products) are kept in the sample of potential frontier products.

Fourthly, those products with a negative opportunity gain index are excluded. The opportunity gain index of a given product, $\mathbf{p}$, is determined based on the extent to which diversifying into this product would benefit the economy as a whole. This opportunity gain index speaks to what degree a potential frontier product 'opens doors' to further diversification opportunities, making it more strategically valuable.

Technical Box 7. Density and Distance

Following the method of Hausmann and Klinger (2006), a measure for density of a product is calculated, with the inverse being defined as its distance.

The density of a product measures how densely the exports of country $\mathbf{c}$ are situated around a particular non-RCA product $\mathbf{j}$. Mathematically, density of non-RCA product $\mathbf{j}$ for country $\mathbf{c}$ can be defined as follows:

$$\boldsymbol{\delta}_{\mathbf{j,c}} = \left(\frac{\sum_{\mathbf{p}} \left(\mathbf{M}_{\mathbf{c,p}} \right) \boldsymbol{\phi}_{\mathbf{p,j}}}{\sum_{\mathbf{p}} \boldsymbol{\phi}_{\mathbf{p,j}}} \right) \quad (14)$$

This mathematical definition can be interpreted as the sum of the proximities between non-RCA product $\boldsymbol{j}$ and those products $\boldsymbol{p}$ that are exported by country $\boldsymbol{c}$ with RCA≥1, scaled by the sum of the proximity of product $\boldsymbol{j}$ to all products. The value of density can vary between 0 and 1, where a value of 0 indicates that country $\boldsymbol{c}$ exports none of the products connected to product $\boldsymbol{j}$, and a value of 1 indicates that country $\boldsymbol{c}$ exports all of the products connected to product $\boldsymbol{j}$.

By inverting this measure of density, a measure of distance is obtained as follows:

$$\boldsymbol{\Delta_{j,c} = 1 - \delta_{j,c}} \tag{15}$$

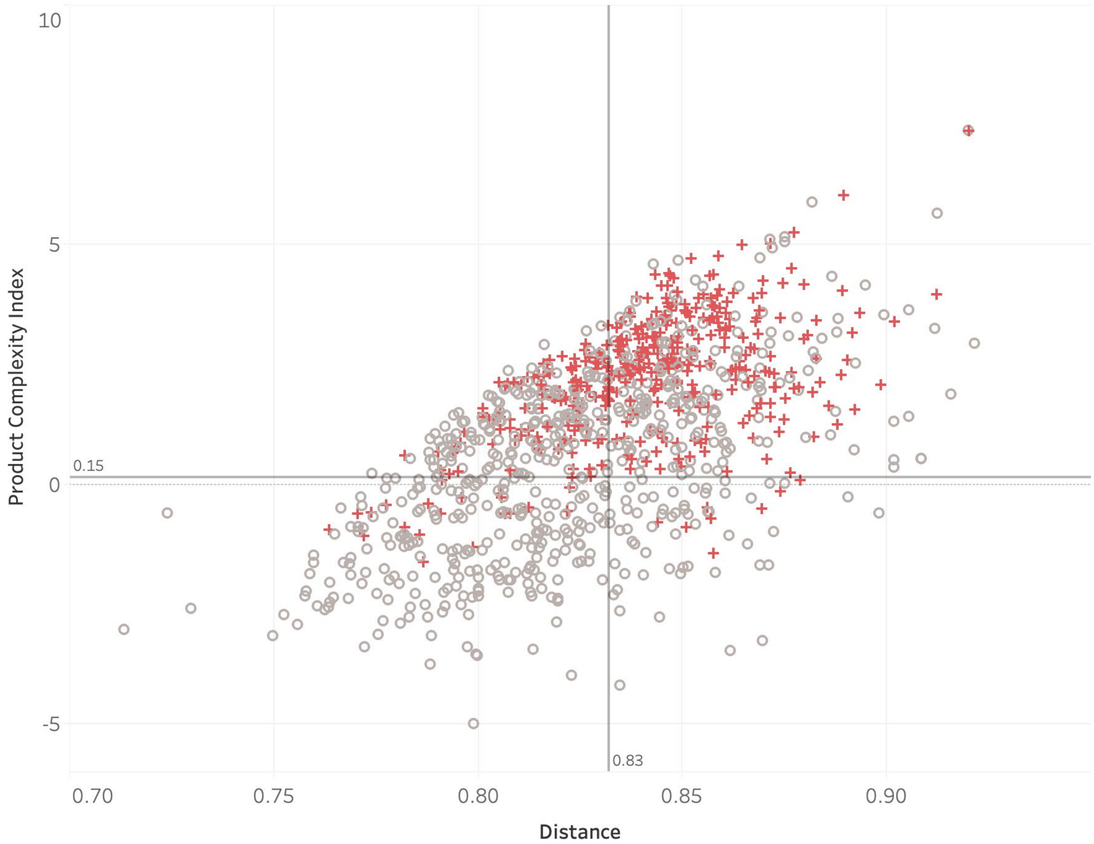
In simple terms, if between each pair of products there is a path, the greater number of paths available to a country to produce a specific product, and the shorter these paths, the lower a country's distance to that product (Hausmann & Chauvin, 2015).

The importance of both the distance and the PCI in differentiating between frontier and non-frontier products is shown in Figure 11, which plots both metrics for South Africa in 2016. The sample is limited to those products with RCA $<$ 1 as was done in Bhorat et al. (2019). The grey circles are non-MER sector products, with the red crosses representing MER sector products.

Frontier products can be found in the upper left quadrant of the graph. The intuition behind this result is as follows: products must be above the horizontal line marking the ECI to ensure that they are complexity building. Simultaneously they should be to the left of the vertical line indicating the median distance to ensure feasibility.

The MER sector frontier products are represented by red crosses in the upper-left quadrant and these products form the universe of frontier products under consideration.

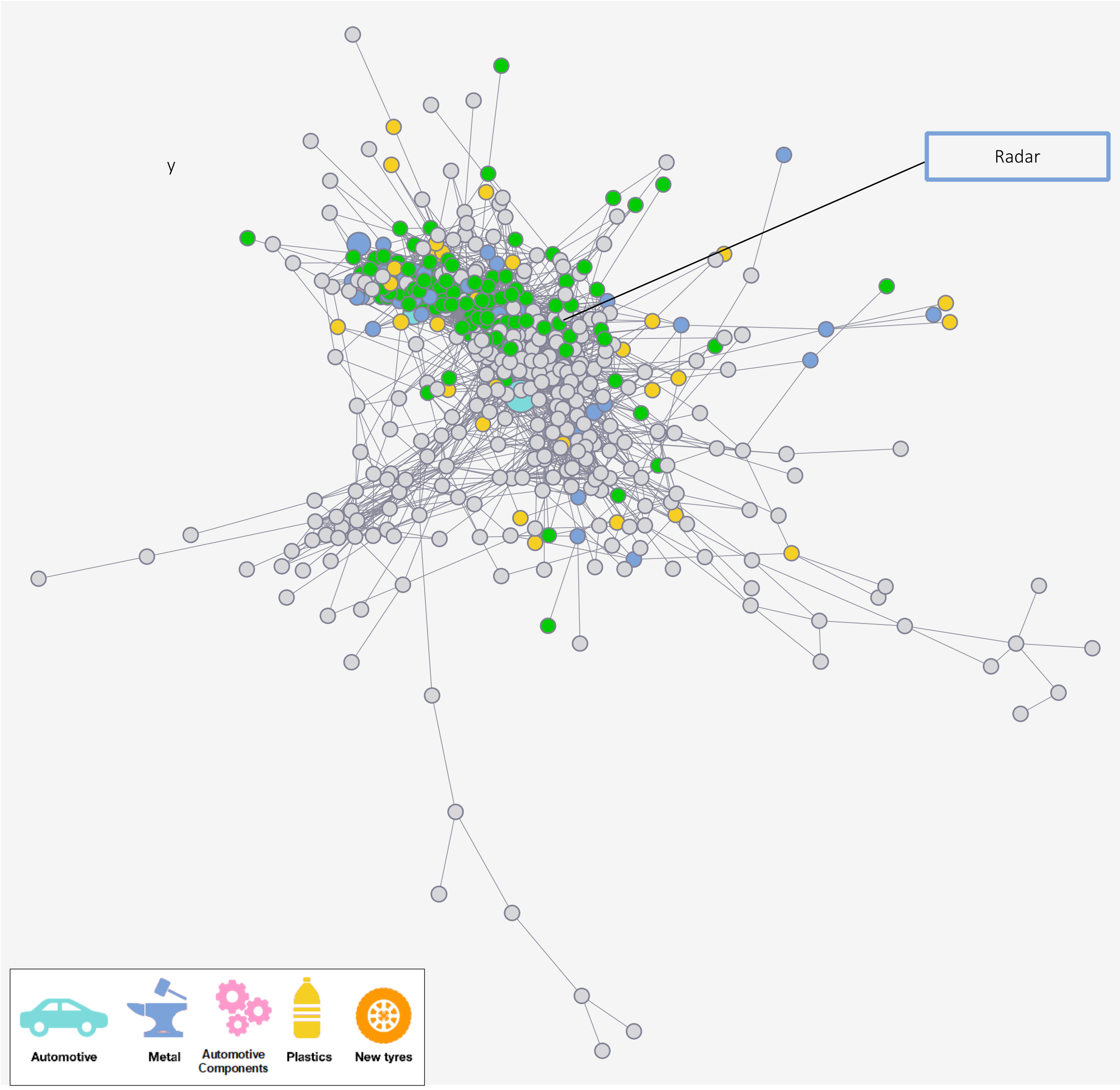
Figure 11. South Africa's non-RCA products in the PCI-distance space, 2016



Source: author's own calculations based on The Growth Lab at Harvard University (2019).
Note: 1. MER sector products are represented by red crosses, whilst non-MER sector products are represented by grey circles. 2. The vertical line represents the median distance for all non-RCA products = 0.83, and the horizontal line represents the ECI = 0.15.

As shown in Figure 12, using the same MER sector product space network as was used previously, the MER sector frontier products are highlighted in bright green so as to provide a visual representation of the effects that diversification into these products could have on the MER sector. A selection of products which have the highest PCI values are highlighted in the figure.

Figure 12. The MER sector product space for South Africa with top ten MER sector frontier products, 2016



Source: author's own calculations based on The Growth Lab at Harvard University (2019).
Note: 1. The product space illustration is generated using Python package product-space (CID, 2017).

Unsurprisingly, given the criteria used to identify frontier products, the majority of the MER sector frontier products are in the core of the product space, as well as being nearby South Africa's competitively exported products. Therefore, diversification will not only grow economy-wide complexity, but also the complexity of the MER sector.

The first aspect of the frontier MER sector product space which is of interest, is the cluster of transport-related products. In the previous section, on the basis of the shape of the MER sector network it was suggested that this subset of products were some of the most closely related, sharing many overlapping capabilities despite being in different chambers. Viewing the product space which includes the frontier products, these opportunities are confirmed with products such as vulcanised rubber parts, and inputs into the manufacture of motor vehicles being introduced as frontier opportunities. In addition to these nearby products being the most feasible given South Africa's existing product structure, they are also some of the most complex. As shown in Table 4 and Table 5, the frontier products in the automotive components chamber have the highest mean complexity, as well as holding three of the top five spots in terms of the complexity of individual frontier products.

Table 4. Mean and median PCI of frontier products for South Africa, 2016

Chamber	Count	Mean PCI	Median PCI
Automotive	2	1.372	1.372
Metals	82	1.619	1.763
Automotive components	4	2.609	2.776
New tyre	5	1.690	1.225
Plastics	29	1.317	1.189
Total MER sector	113	1.629	1.753
Total	270	1.434	1.355

Source: author's own calculations based on The Growth Lab at Harvard University (2019).

Table 5. PCI of top 20 MER sector frontier products for South Africa, 2016

Rank	Chamber	Product description	PCI
1	Plastics	Polymers of styrene	2.921
2	Automotive components	Parts suitable for use with spark-ignition engines	2.898
3	Automotive components	Parts of motor vehicles and tractors	2.813
4	Automotive components	Vehicle Bodies	2.739
5	Metals	Other lifting machinery	2.668
6	New tyre	Vulcanized rubber plates	2.650
7	Metals	Radar	2.637
8	Metals	Other firearms	2.631
9	Metals	Other alloy steel in primary form	2.611
10	Metals	Other agricultural machinery	2.598
11	Metals	Other parts for machines and appliances	2.575
12	New tyre	Other articles of vulcanized rubber	2.534
13	Metals	Water gas generators	2.529
14	Metals	Parts for use with electric generators	2.514
15	Metals	Radiators for central heating of iron or steel	2.513
16	Metals	Direction finding compasses	2.459
17	Plastics	Other articles of plastic	2.457
18	Metals	Industrial furnaces	2.444
19	Metals	Other articles of nickel	2.440
20	Metals	Nuclear reactors and related equipment	2.408

Source: author's own calculations based on The Growth Lab at Harvard University (2019).

The most opportunities for diversification are in the metals sector, with 82 frontier products. There are promising opportunities in machinery products, for example other lifting machinery and agricultural machinery. These are situated in the middle of the core of light manufactured products which South

Africa already exports competitively, offering attractive diversification opportunities which should be more easily accessible due to similarity in capabilities. This advanced type of machinery is also highly complex, coming near the top of the complexity ranked frontier MER sector products. However, there is heterogeneity in the attractiveness of the frontier products in the metals chamber, with some of the lowest complexity products being simple metal products such as metal tubes and pipes – bringing down the mean PCI for frontier products in the chamber.

There are some frontier products on the periphery, but these are mostly plastics products requiring specialised skills. However, it is unclear whether South Africa has these at the present. Further, many of these peripheral products such as packaging and plastic bags are low complexity relative to the other frontier products, suggesting that the productive resources would be better spent developing the other chambers.

In sum, South Africa has a clear diversification path which involves shifting production toward more complex transport-related products such as motor vehicle parts and products made of vulcanised rubber. These goods are nearby in the product space illustrating their relatedness and the overlap in capabilities required to produce each product. This provides an argument for a high-complexity growth path within the MER sector product space, with easy movement between the frontier products identified in the core of the MER sector product space.

However, these movements can potentially be limited by capability constraints – ranging from trade protocols to a lack of biosecurity (Bhorat et al., 2019). The best way to derive the capability constraints, and of course hone in on skills, is to undertake detailed firm surveys, which is the focus of the next stage of this research.

6. CONCLUSIONS

This paper examined South Africa's path of structural transformation through the lens of complexity analytics. Evidence shows that South Africa is undergoing a process of premature deindustrialisation, with its manufacturing sector failing to reach its full potential. The economic complexity approach was applied to generate a ranking for each country based on the complexity of its MER sector product space. This allowed for a comparison between the complexity of South Africa's MER sector and that of comparator countries. This was followed by a product-level approach to building complexity involving constructing a product space to show the relatedness of MER sector products. This product space was then used to identify the frontier MER sector products – which are simultaneously complexity-enhancing and feasible given South Africa's existing capabilities – which could potentially present long-run growth and development opportunities for South Africa's manufacturing sector. The production, and subsequent export, of these frontier products, if successful, could potentially drive a process of manufacturing-led structural transformation.

A strong, positive relationship was found between economic complexity and economic development. Further, MER sector complexity and this economy-wide measure of complexity are similarly positively correlated. This suggests that countries which engage in complexity building activities in the MER sector are well positioned to enjoy real economic gains. However, South Africa's lack of development in its manufacturing sector – of which the MER sector is a vital component – has led to the under-investment in MER sector capability relative to the country's aggregate level of economic complexity. The positive deduction from this result however, is that there are unexploited complexity-building opportunities available to South Africa in the MER sector. A product-level analysis of the products currently exported competitively in South Africa supported this finding, as MER sector products were underrepresented in South Africa's export basket. However, there were exceptions in the automotive and new tyre sectors, which were as complex, and in some cases more complex, than the global average.

Using network analysis, a MER sector product space was created which supplemented this finding. South Africa's MER sector product space was sparsely populated, with a small, highly connected core of automotive, rubber, and metal products. While South Africa does not occupy many nodes in the core, those that are filled represent some of the highest complexity MER sector products, showing that there are diversification opportunities within the MER sector, given South Africa's current capabilities.

In trying to find opportunities for future economic growth in the MER sector space, opportunities – defined as frontier products – were identified to build complexity given the country's current set of capabilities. Our results suggest that the leading set of frontier products are closely connected to the automotive components sector. This speaks to opportunities for South Africa to build its economic complexity through developing, diversifying and building product-specific complexity in the country's motor industry.

The identification of frontier products in the MER sector offers an entry point into the second part of this research, wherein firm surveys are used to assess overall capability constraints, with the focus being on skill constraints. This next step also serves the purpose of verifying the list of frontier products generated in this data-centric analysis, as such acting as a cross-check between what the theory predicts and the reality of producing these frontier products. Further, firm survey data allows for the suggestion of very specific policy interventions at the product level to enhance and further complexity in the MER sector.

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APPENDIX

Table 6. PCI of frontier products by chamber for South Africa, 2016

Rank	Chamber	Product description	PCI
1	Plastics	Polymers of styrene	2.921
2	Automotive components	Parts suitable for use with spark-ignition engines	2.898
3	Automotive components	Parts of motor vehicles and tractors	2.813
4	Automotive components	Vehicle Bodies	2.739
5	Metals	Other lifting machinery	2.668
6	New tyre	Vulcanized rubber plates	2.650
7	Metals	Radar	2.637
8	Metals	Other firearms	2.631
9	Metals	Other alloy steel in primary form	2.611
10	Metals	Other agricultural machinery	2.598
11	Metals	Other parts for machines and appliances	2.575
12	New tyre	Other articles of vulcanized rubber	2.534
13	Metals	Water gas generators	2.529
14	Metals	Parts for use with electric generators	2.514
15	Metals	Radiators for central heating of iron or steel	2.513
16	Metals	Direction finding compasses	2.459
17	Plastics	Other articles of plastic	2.457
18	Metals	Industrial furnaces	2.444
19	Metals	Other articles of nickel	2.440
20	Metals	Nuclear reactors and related equipment	2.408
21	Metals	Parts of military weapons	2.383
22	Metals	Flat-rolled iron, width < 600mm, clad	2.324
23	Metals	Other engines and motors	2.299
24	Metals	Dairy machinery	2.295
25	Metals	Other articles of iron or steel	2.267
26	Metals	Harvesting or agricultural machinery	2.230
27	Metals	Railway track fixtures	2.225
28	Metals	Tractors	2.173
29	Metals	Electrical boards for protecting electrical circuits	2.131
30	Metals	Military weapons, other than pistols	2.123
31	Metals	Flat-rolled iron, width < 600mm, not clad	2.122
32	Plastics	Other colouring matter	2.121
33	Metals	Machinery for soil preparation or cultivation	2.096
34	Plastics	Sulphonitric acids	2.088
35	Metals	Munitions of war	2.084
36	Metals	Other cast articles of iron or steel	2.063
37	Plastics	Non-radioactive isotopes	2.059
38	Plastics	Other plastic plates, sheets etc.	2.051
39	Metals	Parts of other aircraft	2.034
40	Metals	Work trucks	2.004

Rank	Chamber	Product description	PCI
41	Automotive components	Trailers and semi-trailers	1.985
42	Metals	Automatic goods-vending machines	1.982
43	Metals	Nickel waste and scrap	1.960
44	Metals	Pulleys and winches	1.937
45	Metals	Refrigerators, freezers	1.934
46	Metals	Tubes, seamless, of iron or steel	1.876
47	Metals	Electric heaters	1.837
48	Metals	Titanium	1.829
49	Metals	Railway cars, not self-propelled	1.829
50	Plastics	Baths, sinks etc.	1.807
51	Plastics	Ethers	1.800
52	Metals	Railway construction material of iron or steel	1.799
53	Metals	Central heating boilers	1.793
54	Metals	Wire etc. used for welding	1.768
55	Metals	Self-propelled bulldozers, excavators and road rollers	1.758
56	Metals	Other articles of zinc	1.757
57	Plastics	Monofilament	1.753
58	Metals	Other articles of aluminium	1.700
59	Metals	Medical, dental or veterinary furniture	1.645
60	Metals	Other articles of copper	1.633
61	Plastics	Polymers of vinyl chloride	1.596
62	Plastics	Sodium or potassium hydroxides or peroxides	1.589
63	Plastics	Other plates of plastics, noncellular and not reinforced	1.577
64	Plastics	Carbon	1.531
65	Automotive	Motor vehicles for the transport of > 10 persons	1.514
66	Metals	Hot rolled bars of iron	1.481
67	Metals	Aluminium containers, >300 litters	1.444
68	Metals	Stoppers, caps and lids of metal	1.399
69	Metals	Other metals	1.398
70	Metals	Other floating structures	1.389
71	Metals	Tin waste and scrap	1.359
72	Metals	Aluminium structures (bridges, towers etc)	1.355
73	Metals	Hydraulic turbines, water wheels and regulators	1.354
74	Plastics	Plastic builders' ware	1.354
75	Metals	Other arms (air guns, truncheons, etc.)	1.352
76	Metals	Machinery for preparing tobacco	1.306
77	Automotive	Special purpose motor vehicles	1.230
78	New tyre	Used pneumatic tires of rubber	1.225
79	Plastics	Sulphuric acid, oleum	1.189
80	Metals	Cadmium	1.180
81	Metals	Stainless steel in ingots	1.156
82	New tyre	New pneumatic tires of rubber	1.142

Rank	Chamber	Product description	PCI
83	Plastics	Sulphur, sublimed or precipitated	1.139
84	Plastics	Other inorganic acids	1.127
85	Metals	Copper wire, uninsulated	1.110
86	Metals	Prefabricated buildings	1.089
87	Metals	Flat-rolled iron, width > 600mm, cold-rolled, not clad	1.020
88	Plastics	Hydrogen peroxide	0.988
89	Plastics	Rosin and resin acids	0.949
90	Metals	Hand-tools for gardening	0.936
91	Metals	Surveying instruments	0.915
92	Metals	Flat rolled iron, width > 600mm, clad	0.913
93	Metals	Nails and similar articles of iron or steel	0.905
94	New tyre	Rubber hygienic or pharmaceutical items	0.900
95	Metals	Tanks etc. > 300 litres, iron or steel	0.863
96	Plastics	Sulfonated, nitrated derivatives of hydrocarbons	0.861
97	Plastics	Silicates	0.845
98	Plastics	Polymers of ethylene	0.797
99	Plastics	Chlorates, bromates, y iodates	0.746
100	Metals	Other vessels	0.733
101	Plastics	Zinc oxide or peroxide	0.733
102	Plastics	Plastic tubes and fittings	0.686
103	Plastics	Oils etc. from high temperature coal tar	0.663
104	Metals	Stoves and similar non-electric appliances of iron or steel	0.654
105	Metals	Ferrous waste and scrap	0.600
106	Metals	Aluminium wire, not insulated	0.392
107	Metals	Tugs and pusher craft	0.330
108	Metals	Other moving, excavating or boring machinery	0.318
109	Plastics	Turpentines	0.288
110	Metals	Other tubes, pipes and hollow profiles of iron or steel	0.283
111	Plastics	Carbonates	0.266
112	Plastics	Packing lids	0.217
113	Metals	Fishing vessels	0.155

Source: author’s own calculations based on The Growth Lab at Harvard University (2019).

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