Building Economic Complexity in the South African Fibrous Plant Economy

DPRU DSI-NRF CoP/WP201904

by Caitlin Allen, Haroon Bhorat, Robert Hill, Christopher Rooney &
François Steenkamp

October 2019

Development Policy Research Unit (DPRU) Report commissioned by the Towards Resilient Futures *Community of Practice*: "Developing a Fibre Micro-industry to Generate Economic Growth from Degraded Land".

Disclaimer: This research is funded through the Department of Science and Technology (DST) and the National Research Foundation (NRF) via the awarding of a Community of Practice to existing Research Chairs under the South African Research Chairs Initiative (SARChI) funding instrument. The views expressed herein are those of their respective authors and do not necessarily represent those of the University of Cape Town, or any associated organisation/s.

ISBN: 978-1-920633-58-5

Table of Contents

List of Figures

List of Tables

1 INTRODUCTION

Approximately 6000 mines have been abandoned over the past twenty years and a large number are expected to be closed in the coming decade.[1] Once a mine closes, the locality of the mine is left in an economic vacuum, since mine operations drive both direct and indirect economic activity in the locality. Upon closure, most of the economic activity comes to a halt, thus resulting in unemployment and poverty. Post-mining land uses, such as agriculture and downstream manufacturing activity linked to agriculture, have the potential to mitigate the socio-economic consequences of mine closure through the generation of inclusive economic growth in these marginalised areas.

This paper focuses on the potential to develop fibrous downstream activities that stem from fibrous plant production on degraded mining land.[2] To investigate the economic potential of these fibrous downstream activities, we apply an intensely cross-disciplinary approach, which allows us to address the following research objectives:[3] firstly, we examine the economic complexity of the South African fibrous plant economy, with specific focus on bamboo, hemp and kenaf. Secondly, we identify potential diversification opportunities that would build economic complexity through the development of downstream options in the fibrous plant economy. Thirdly, we identify capabilities/constraints that enable/hinder the development of these downstream options. This in turn allows us to generate a set of micro-industrial policy recommendations.

In addressing these research questions there are three components to the empirical analysis: first, we apply economic complexity analytics by extending the methodology applied by Mealy & Teytelboym (2018) to determine the relative economic complexity of the fibrous plant economy in South Africa.[4] This is done by constructing what we term the *fibrous complexity index* (FCI) measure. While a number of studies have analysed the economic complexity of certain subsets of products, such as green products (Mealy & Teytelboym, 2018; Huberty & Zachmann, 2011) and agricultural products (Isdardi, van

1 See https://theconversation.com/finding-ways-to-keep-communities-alive-after-mine-closures-98505.
2 Research by the engineering grouping of the CoP focuses on the potential to grow fibrous plants, such as bamboo, hemp and kenaf, on degraded mining land, and the extent to which these plants can clean the land through the process of phytoremediation.
3 This paper forms part of a cross-disciplinary project. The Towards Resilient Futures Community of Practice (CoP) project explores the potential for post-mining industrial development through the development of a fibrous plant economy. The CoP is interested in determining whether fibre-rich plants, such as bamboo and bast fibres, can be used to remediate degraded mining land in a way that is economically feasible, leads to enhanced economic complexity, promotes the establishment of a fibre micro-industry, creates higher value-add outputs, and provides employment opportunities. This paper represents the economics stream of CoP and is informed by inputs from the engineering and legal streams. More information on the CoP project, Towards Resilient Futures, can be obtained from the following link: http://www.resilientfutures.uct.ac.za/.
4 A description of the economic complexity and product space analytics can be found in The Atlas of Economic Complexity developed by Hausmann, Hidalgo, Bustos, Coscia, Simoes & Yildirim (2014).

Schalkwyk & Viviers, 2015), this paper represents the first, to our knowledge, to consider fibrous plant products.

Second, using network analytics, we locate South Africa's fibrous plant economy within the *product space* and extend the analysis by developing the *fibrous product space*, which serves as an empirical contribution to this growing literature. The underlying network analytics of the *fibrous product space* allow one to determine South Africa's current capabilities in the fibrous plant economy as well as identify feasible paths for future diversification. Drawing on the approach applied by Hausmann & Chauvin (2015), we formally identify product-level diversification opportunities, or *fibrous frontier products*, within the South African fibrous plant economy. We use the *fibrous complexity index* to show how economic complexity can be designed and deliberately built at the micro product-level.

Secondly, we undertook semi-structured firm and industry expert interviews to identify capabilities/constraints that enable/hinder the processing and manufacture of *fibrous frontier products*. The identification of these constraints/capabilities that hinder/enable the development of fibrous frontier products informs the composition of targeted micro-industrial policy interventions.

Further, this paper makes a contribution to the empirical application of economic complexity analytics by following a cross-disciplinary approach. Input from bioprocess engineers and material scientists informs the construction of a fibrous plant product database that is used to generate the *fibrous complexity index* and the *fibrous product space*. Research outcomes from the semi-structured interviews are cross-checked with input from environmental scientists, soil scientists, bioprocess engineers, material scientists, and lawyers.

This research is further motivated by a key economic challenge facing the post-apartheid South African economy: its chronic, long-run inability to undergo productivity enhancing structural transformation in the pursuit of inclusive economic growth (Hausmann & Klinger, 2008; Bhorat, Ewinyu, Lilenstein, Rooney, Steenkamp & Thornton, 2019a). Bhorat, Kanbur, Rooney & Steenkamp (2019b) note that this process of structural transformation is akin to building economic complexity, which is strongly associated with higher levels of economic development (Hidalgo & Hausmann, 2009). Structural transformation refers most generically to the shift of economic resources from low productivity agricultural activities toward high productivity agri-processing and manufacturing activities. Manufacturing- and agri-processing-led industrialisation ultimately generates the necessary employment opportunities for a growing labour force and can thus create the pathways to an employment-intensive growth trajectory for South Africa. This paper explores whether downstream fibrous plant activities can potentially feature in this growth trajectory.

The paper is structured as follows: Section 1 provides a brief description of the fibrous plant economy, specific to bamboo, hemp and kenaf, in the South African context. In Section 2, we describe the mapping of fibrous plant products to the international trade data employed in the complexity and product space analytics. Economic complexity and product space analytics are applied in Section 4 and 5, respectively. Section 6 details the identification of *fibrous frontier products*. In Section 7, we analyse the insights gained from the firm and industry expert interviews, which informs the policy recommendations specified in Section 8. Section 9 concludes.

2 THE FIBROUS PLANT ECONOMY

2.1 Fibrous Plants in the South African Economy

Natural fibres and their products have been prevalent for centuries. Since then, the economic, societal, and environmental benefits of these plants have been established, providing opportunities for development in agriculture and manufacturing. The emphasis by many governments on the use of sustainable alternatives to existing materials has resulted in the increased use of natural fibres. These fibres have certain mechanical and physical properties that make them suitable for a range of applications including pharmacy, textiles, energy, construction, and paper. The following sections provide an overview of the way in which the market for three fibrous plants – hemp, kenaf, and bamboo – has developed over time within the South African context.

2.1.1 Hemp in South Africa

Industrial hemp is a strain of the *Cannabis stevia* plant species of which marijuana is also a variant (Small & Marcus, 2003). Hemp has been cultivated as far back as 8000 BC in Central Asia and was used to make clothing, paper, ropes, and sails (Lash, 2002). Currently there are more than 25 000 individual consumer products that can be manufactured using the hemp plant. The benefits of using hemp fibres as an environmentally friendly alternative to polluting materials has been well documented in industries such as textiles, construction, paper, and biocomposites (Van der Werf, 2004; Piotrowski & Carus, 2011; La Rosa *et al*., 2013; Pil *et al*., 2016). Hemp seed and oilcake are also used in the manufacture of food supplements, cosmetics, and medicine (Johnson, 2018). In more recent years, hemp has been hailed as a sustainable alternative to fossil fuel-based products (Johnson, 2018).

Despite the proven societal benefits of this plant, its similarity in appearance to marijuana resulted in the criminalisation of hemp cultivation in many Western countries, as well as South Africa, in the early 1900s (Lash, 2002; Duvall, 2016). However, starting in the mid-1990s, more than 30 countries have lifted the ban on hemp production, including Canada, New Zealand, Australia, and European countries such as the United Kingdom, Germany, and the Netherlands (Coogan, 2016; Johnson, 2018). In December

2018, the 2018 Farm Bill was passed in the USA to legalise the cultivation and trade of hemp by the federal government (National Conference of State Legislatures, 2019).

In South Africa, it is still illegal to grow hemp, the exception being hemp cultivated for research purposes upon the acquisition of a permit from the Department of Health. Over the last 20 years the Agricultural Research Council (ARC) has conducted studies to determine the feasibility of cultivating hemp for use in textiles and biocomposites (ARC, 2018). Specific research trials include those conducted in conjunction with PG Bison and Masonite Africa (1997-1998) and the Southern Africa Bast Crop Consortium (1998-2005) as well as the Eastern Cape Hemp Pilot Project Initiative (1995-2005) (Coogan, 2016). Two varieties of hemp suitable for these applications are currently under review by the Department of Agriculture, Fishing, and Forestry (DAFF) (ARC, 2018). Further, a Hemp Production Guideline was published in conjunction with the Eastern Cape Department of Agriculture (ARC, 2018). The results of this research showed that the cultivation of hemp in South Africa was feasible in KwaZulu-Natal, the Eastern Cape, and the Western Cape. At present, Hemporium's farming partner, Rapula Farming, is growing hemp as part of a Commercial Incubation Research Trial under the co-ordination of Dr Thandeka Kunene from House of Hemp (Hemporium, 2019).

The above evidence suggests that it is feasible to produce hemp in South Africa, which would serve the dual purpose of creating jobs and diversifying agricultural activity (Blouw & Sotana, 2005). However, legislative barriers have stymied efforts to grow hemp on a commercial scale, which is a prerequisite for the development of this infant industry. The decriminalisation of private and personal use of the marijuana variant of cannabis in September 2018 can be seen as a major step toward the easing of restrictions on the cultivation of hemp in South Africa (*Minister of Justice and Constitutional Development and Others v Prince*, 2018).

2.1.2 Kenaf in South Africa

Kenaf was first domesticated in North Africa as early as 4000 BC. It was traditionally used for medicinal purposes, livestock feed, and as a cordage crop (Dempsey, 1975; Roseberg, 1996; Cheng, Akanda & Nyam, 2016). It was established in the 1950s and 1960s that cellulose from kenaf could be used as an environmentally friendly alternative to wood inputs for paper production (Wood & de Jong, 1997). Kenaf's absorptive properties provide further environmental benefits, while its superior tensile strength makes it a suitable input for the production of nonwovens and other construction materials (Webber & Bledsoe, 1993). More recently, kenaf seeds, which were previously discarded, were used to make products such as edible oils, paints, and lubricants (Kamal, 2014; Cheng *et al*., 2016).

Developments in the field of biocomposites have seen kenaf fibres being blended with resins to provide a more sustainable material in the production of aeroplane and automobile parts. The kenaf biocomposites are used to replace glass-reinforced plastics in the panels for cabin interiors for aeroplanes and in the manufacture of car parts (Kamal, 2014). Internationally, the use of natural fibres as an alternative to synthetic fibres is an appealing alternative due to legislative reform, such as end-of-service life regulations for the automotive industry in the EU, and carbon credits used to minimise greenhouse gas emissions. In South Africa, there is no legislation enforcing the use of environmentally friendly alternatives in the automotive industry. However, manufacturers in South Africa are part of a global value chain, whereby the use of natural fibres in the manufacture of motor vehicle components is determined by international designers. Furthermore, there is an opportunity for the use of domestically grown kenaf to assist car manufacturers to meet their stipulated local content quota.

Kenaf was produced industrially in South Africa in the 1950s, but these activities were discontinued between 1960 and the mid-2000s. The plant was re-introduced in the early 2000s for the purpose of manufacturing biocomposites by the Sustainable Projects Development Group, due to its adaptability to the cultivation conditions in KwaZulu-Natal (Parliamentary Monitoring Group [PMG], 2015). The kenaf plant in Winterton, co-owned by the Department of Trade and Industry (DTI) and Seardel Investment Corporation, was opened in 2006 (PMG, 2015). One of the outcomes was to provide Seardel's Brits Automotive factory with fibre that could be used to manufacture automotive parts. However, this project failed due to, among other things, the poor quality of the fibre produced, resulting in losses of approximately R10 million per year before the plant was closed (PMG, 2015).

Despite the failure of this project, trials were conducted by the ARC to test the potential for up-scaling local kenaf production. Further, over the period 2008 to 2010, there was research conducted at the University of Pretoria's Hatfield Experimental Farm that tested the agronomic practices required to produce a sustainable yield (Kayembe, 2015; Department of Trade and Industry [DTI], 2019). Other kenaf-based projects in South Africa include the trial manufacture of the Nedbank sign and Eco-wash machine by Global Composites that used locally grown kenaf (DTI, 2015). Furthermore, the Council for Scientific and Industrial Research (CSIR) provided scientific evidence of the suitability of kenaf biocomposites in the automobile sector and is continuing research in conjunction with aircraft manufacturer, Airbus, to determine whether kenaf has applications in the aerospace industry (Arockiam, Jawaid, & Saba, 2018). Currently, kenaf-based composites are being used in a South African Mercedes Benz factory using imported fibres (Mandela Bay Composites Cluster, 2017).

In conclusion, kenaf has been characterised as a multi-purpose crop, with its fibres having a variety of specialist industrial applications, providing a green-friendly alternative to traditional materials which can be used as an input for a variety of industries (Centre for Crop Diversification [CCD], 2014). In this respect, kenaf could prove key as economies and companies implement more sustainable forms of production. As is the case with hemp, there is evidence to suggest that cultivation on a commercial scale in South Africa is feasible. Further, there is active research into kenaf's technical properties and adequate demand in the automotive sector.

2.1.3 Bamboo in South Africa

China has cultivated bamboo for 7000 years, making it an integral part of its various regional economies (Wang *et al*., 2008). Ethiopia has the largest bamboo resources in Africa with its 1 million hectares comprising approximately 67 percent of the continent's bamboo resources (Lin *et al.*, 2019). Over 2000 products can be produced using bamboo as an input, which can be sub-divided into two subsectors: traditional, low-end goods and higher-value, industrially processed goods (Enterprise Opportunities Limited, 2006).

Traditional bamboo products include handicrafts, bamboo shoots, and bamboo (or rattan) furniture. The processing and manufacturing activities required to produce these goods are not skill- or capital-intensive, and thus create substantial employment opportunities (Enterprise Opportunities Limited, 2006). However, traditional bamboo products imported from largely Asian countries fulfil a more niche market in developed regions such as the United States and the European Union (van der Lugt & Lobovikov, 2008). Premium processing involves applications such as construction materials – e.g. flooring and particle boards – paper, and bamboo textiles. Owing to the relatively high prices that can be fetched for industrial bamboo goods and their increasing share of the market, most of the countries currently growing bamboo have moved toward the development of a modern bamboo industry (van der Lugt & Lobovikov, 2008). There is also potential for the use of bamboo biomass to produce a variety of energy products as an alternative for fossil fuel (Truong & Le, 2014).

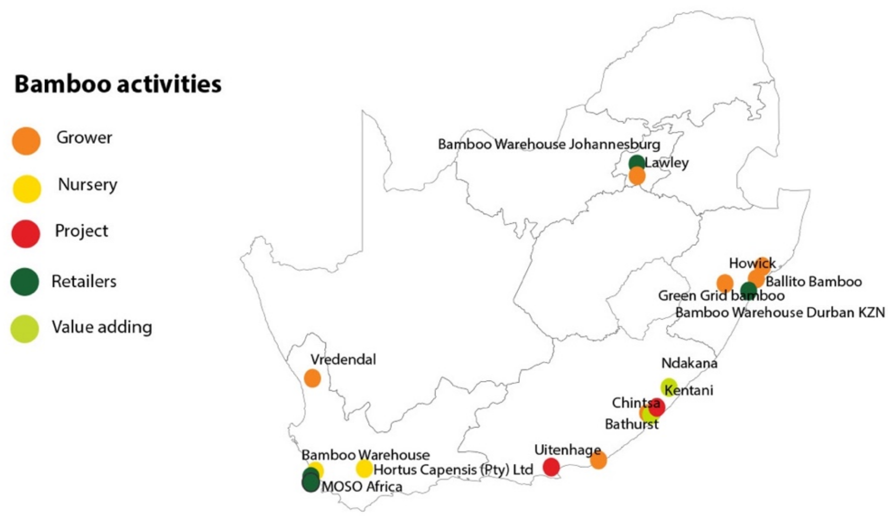
In contrast with China and other countries in Asia, South Africa does not have a culture of bamboo farming. However, there are two indigenous species in the country (Scheba, Mayeki, & Blanchard, 2017). In recent years, several countries in Africa have partnered with the International Network for Bamboo and Rattan (INBAR) with the aim to develop large-scale bamboo plantations and processing factories. South Africa is not currently a member of INBAR. However, there has been interest in the idea of a bamboo industry since 2011, with the Industrial Development Corporation (IDC) and the Eastern Cape Development Corporation (ECDC) partnering to host a bamboo symposium (Scheba, *et al*., 2017), the aim of which was to promote bamboo cultivation on a commercial scale. The outcome was a number of pilot projects and investments from funders, both local and international. However, little conclusive evidence about the feasibility of developing a bamboo industry in South Africa arose from these trials.

One of the major shortcomings of this research was a failure to provide the Department of Water Affairs with sufficient information regarding the need for water permits when cultivating bamboo in water scarce areas.

To date there are two large projects in progress: EcoPlanet Bamboo and Green Grid Beema. They have a combined plantation size of 300 hectares (Scheba *et al*., 2017). To put this in perspective, Chinese bamboo plantations cover up to 6 million hectares. EcoPlanet Bamboo is situated in the Eastern Cape and is owned by a large multi-national corporation that focuses on using bamboo as a sustainable alternative to wood fibres. Green Grid Beema has a plantation in KwaZulu-Natal and is currently testing the feasibility of generating bioenergy using bamboo. Other commercial growers exist in these provinces due to the suitability of the soil, climate, and rainfall for bamboo cultivation.

Further up the value chain, nurseries and tissue culture companies provide support to the domestic bamboo industry by promoting bamboo growing activities in the country and preparing young bamboo species for planting by local farmers (Scheba *et al*., 2017). There are three speciality bamboo retailers in South Africa: Brightfields Natural Trading, Bamboo Warehouse, and MOSO Africa. The distribution of these activities throughout South Africa is illustrated in Figure 1.

Figure 1: Bamboo activities in South Africa (2017)



Source: Scheba *et al*. (2017)

Based on the existing literature, the prospects for the global bamboo market look promising. This is based on the growing demand for a sustainable substitute for wood products (Enterprise Opportunities Limited, 2006). While a market for bamboo exists in South Africa, there is insufficient data to determine the extent of market demand. More importantly, case studies have provided insufficient data to aid government to situate bamboo growing within an appropriate regulatory framework, with data on water usage being a real limitation. Ultimately, more research supported by government and other stakeholders is required to ascertain the feasibility of developing a bamboo industry in South Africa.

In sum, the three fibrous plants discussed have proven to be useful for a diverse range of applications for centuries, growing increasingly sophisticated over time with the advent of new methods of processing. In the South African case, despite lack of success initially, kenaf has key industrial applications and linkages to the automotive industry, offering promising results as a green alternative to traditional materials. While insufficient data has been attained about the viability of a local bamboo industry and the legalities surrounding hemp cultivation are unresolved, there is potential for both of these crops to have a large positive impact on employment and growth in both agriculture and manufacturing.

2.2 Fibrous Plants in the Global Economy

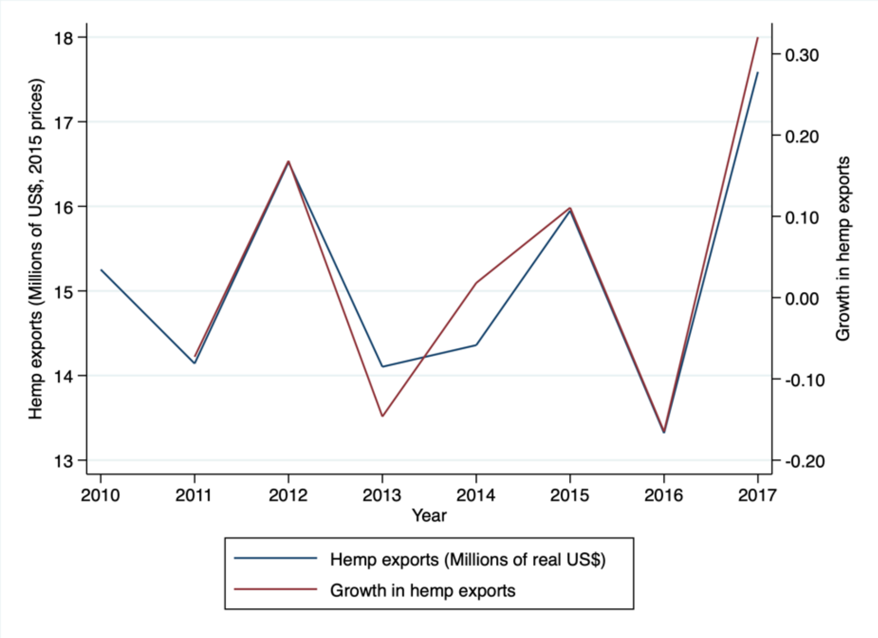
Global natural fibre production in 2018 stands at an estimated 32 million tonnes valued at USD 60 billion (Discover Natural Fibres Initiative [DNFI], 2019). Over 150 countries are involved in the natural fibre trade. In some of these countries natural fibres are the most viable source of economic activity, providing jobs for millions (DNFI, 2019). These resources are attractive commodities as they are storable, durable, and can be produced in a range of climates.

2.2.1 Hemp in the Global Economy

The process of estimating the size of the global hemp market is challenging as the range of products that can be manufactured using hemp is expanding. In addition, the legalities around hemp production in many countries means that only some trade is captured in the data.[5] Figure 2 shows that the value of the global market for hemp between 2010 and 2017 fluctuated between USD 13 million and USD 18 million. There was no obvious trend in the data for the period, but an observed USD 5 million increase between 2016 and 2017 may be indicative of a global easing up of hemp regulations, particularly in the USA.

5 The trade data for hemp and kenaf are based on the Harmonized System Codes (HS revision 1992) at the 4-digit level, with bamboo figures being based on 4-digit Standard Industrial Trade Classification Codes (SITC revision 2). The limitations of these data are twofold. Firstly, kenaf and bamboo cannot be clearly identified in these data, so assumptions are made about the products that best represent these plants in the data. Secondly, these data only capture trade of all three plants in their raw, or partially processed, form, thus trade in finished goods is not captured.

Figure 2: Exports of hemp in 2015 USD (2010 - 2017)



Source: CID (2019). Author's own calculations.
Note: HS code 5302 is used for hemp: True hemp, raw or processed but not spun, tow waste and true hemp (including yarn waste and garneted stock).

France was one of the few countries that continued to produce hemp throughout the 20th century, with a 48 percent share of hemp exports for the period shown in Table 1. Similarly, China did not halt its hemp cultivation and was the largest exporter of hemp textiles globally (Coogan, 2016). In the USA, conflicting interpretations of the legality of commercial hemp exports at the State level have persisted since 2014, resulting in an increase in hemp exports over the period culminating at an export value of USD 2.5 million in 2017 (National Conference of State Legislatures, 2019). While growth in exports has been volatile, the passing of a bill legalising the commercial cultivation of hemp in the USA in 2018, due to its value as an agricultural crop, signals a positive outlook on the growth prospects for this industry (National Conference of State Legislatures, 2019). The main importers were Spain and Germany accounting for approximately 40 percent of the global market. In 2017, the five main importers have trade values in excess of USD 2.5 million with the exception of the UK market, which has been shrinking since a peak import value of USD 1.3 million in 2011, declining to less than USD 0.5 million in 2017. The main reason for these European imports of raw hemp is for further processing to produce more complex goods such as hemp textiles, specifically hemp clothing.

Table 1: Top 5 Exporters and Importers of Hemp in 2015 USD (2010 – 2017)

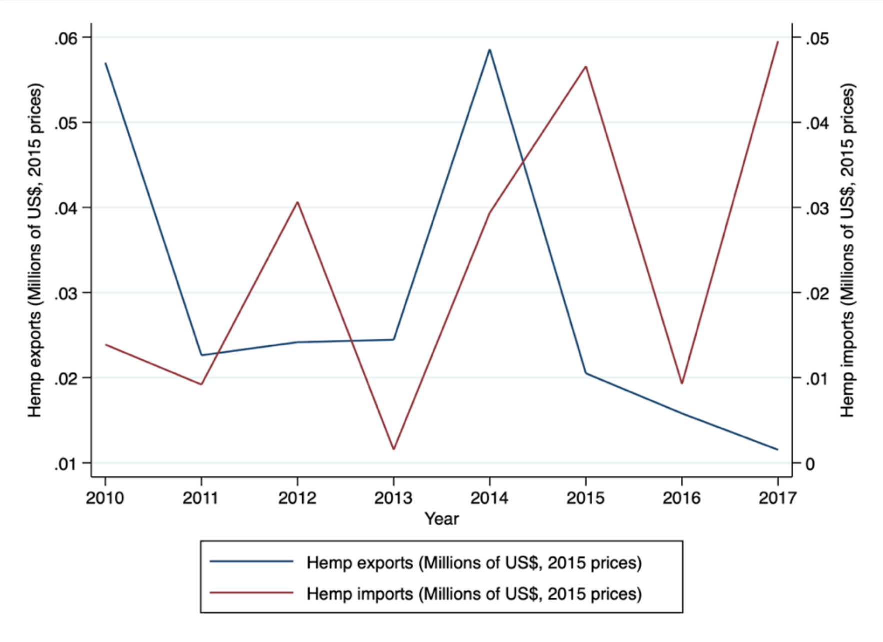
Country	Exports (2017)	Share of exports (2010 – 2017)
France	6 117 484	0.48
Netherlands	3 895 942	0.15
China	696 574	0.07
Germany	423 642	0.06
USA	2 415 143	0.03
Total for top 5 exporters	13 548 785	0.80

Country	Imports (2017)	Share of imports (2010 – 2017)
Spain	2 514 495	0.22
Germany	3 822 593	0.19
Czech Republic	2 507 626	0.17
UK	492 330	0.05
Switzerland	2 501 741	0.03
Total for top 5 importers	11 838 786	0.66

Source: CID (2019). Author's own calculations
Note: HS code 5302 is used for hemp: true hemp, raw or processed but not spun, tow waste and true hemp (including yarn waste and garneted stock).

Figure 3 reveals that exports of hemp from South Africa are consistently under USD 60 000, which is negligible in the global context. Further, for the period 2010 to 2017, total hemp exports were less than 1 percent of the total export value for South Africa's largest non-fruit export, maize. These exports are largely of finished goods manufactured using imported hemp fabric from China (DAFF, 2011). South Africa also has a small cluster of manufacturers that use raw hemp to produce beauty, medicinal, and culinary products that are exported within sub-Saharan Africa (DAFF, 2011).

Figure 3: Exports and imports of hemp by South Africa in 2015 USD (2010 - 2017)

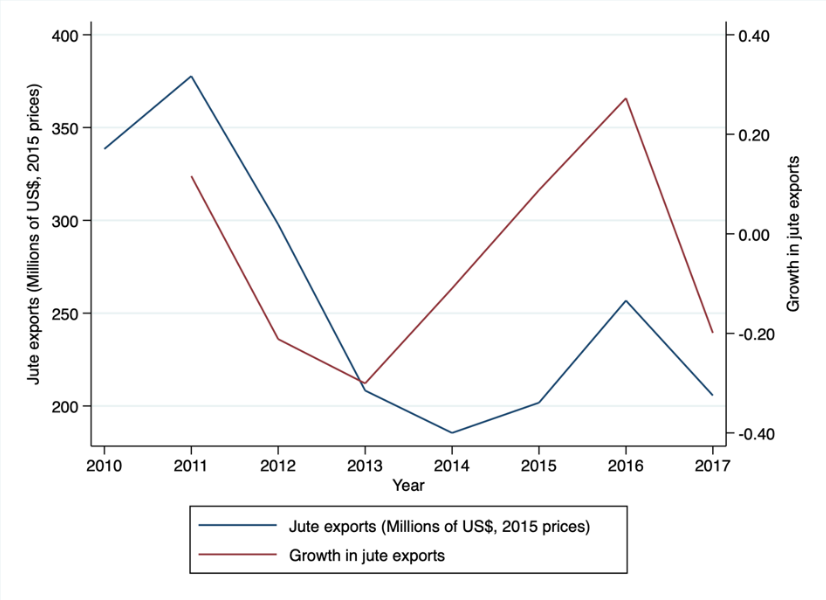


Source: CID (2019). Author's own calculations.
Note: HS code 5302 is used for hemp: True hemp, raw or processed but not spun, tow waste and true hemp (including yarn waste and garneted stock).

2.2.2 Kenaf in the Global Economy

Data from the Food and Agriculture Association (FAO, 2017) provide detailed information about production and trade of kenaf and allied fibres between 2011 and 2016. According to this source, the world production of kenaf and allied fibres was 229 700 tonnes in 2016, with the largest producers being India (140 000 tonnes) and China (75 200 tonnes), accounting for 94 percent of global production. Exports of kenaf and allied fibres increased over time, totalling 2 400 tonnes in 2016, with countries in the Far East being the largest contributors. The export figures for kenaf and allied fibres were substantially lower than the production figures due to a high level of mill consumption during processing.

Figure 4: Exports of jute in 2015 USD (2010 - 2017)



Source: CID (2019). Author's own calculations.
Note: HS code 5303 is used for kenaf: jute and other textile bast fibres (not flax, true hemp and ramie), raw or processed but not spun; tow and waste of these fibres, including yarn waste and garneted stock.

Figure 4 and Table 2 provide trade data for jute and allied fibres, of which kenaf is one, as detailed country data is not available specifically for kenaf. Figure 4 shows that there was a significant decline in jute exports from 2011 to 2013, a marginal recovery up until 2016, and a further decrease into 2017. Overall, the trade in jute nearly halved from approximately USD 400 million in 2011 to just over USD 200 million in 2017. These trends are a direct reflection of the state of the jute industry in the world's biggest producer, Bangladesh. One of the reasons behind the erratic nature of exports from Bangladesh is that jute production is price-sensitive, with land being allocated to food crops as farmers respond to declining jute prices. To put this in perspective, jute prices increased 21 percent between 2005 and 2008, but experienced a reduced growth rate of 6 percent between 2009 and 2012 (International Jute Study Group, 2013). Table 2 indicates that the top importers were India and Pakistan, accounting for 20 percent and 26 percent of imports between 2010 and 2017 respectively.

Table 2: Top 5 Exporters and Importers of Jute in 2015 USD (2010 – 2017)

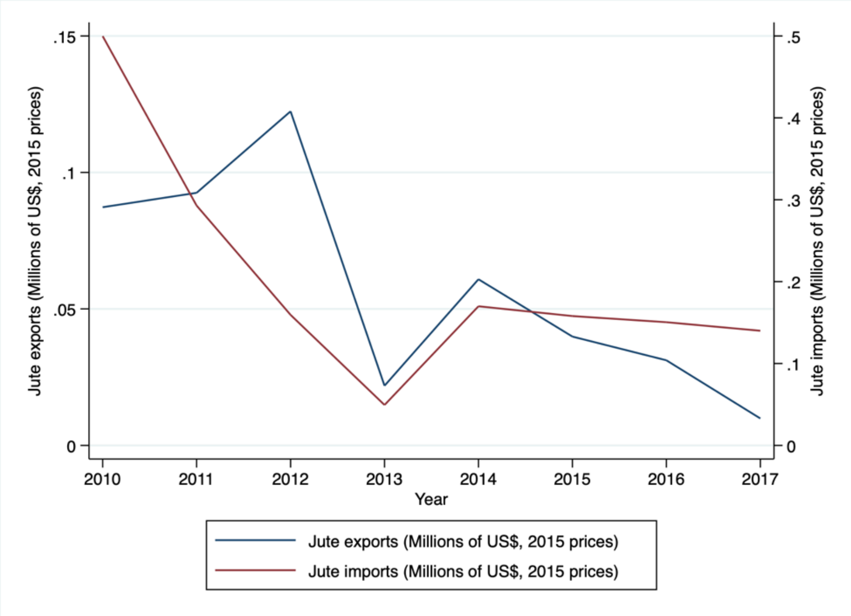
Country	Exports (2017)	Share of exports (2010 – 2017)
Bangladesh	142 944 255	0.75
Tanzania	16 650 406	0.07
India	9 081 456	0.06
Kenya	9 257 326	0.03
China	11 500 709	0.01
Total for top 5 exporters	189 434 152	0.93

Country	Imports (2017)	Share of imports (2010 – 2017)
India	44 095 056	0.26
Pakistan	47 099 305	0.20
China	27 556 573	0.19
Côte d'Ivoire	4 076 189	0.04
Germany	5 397 222	0.02
Total for top 5 importers	128 224 346	0.70

Source: CID (2019). Author's own calculations.
Note: HS code 5303 is used for kenaf: jute and other textile bast fibres (not flax, true hemp and ramie), raw or processed but not spun; tow and waste of these fibres, including yarn waste and garneted stock.

Figure 5 shows that exports of South African jute were insignificant when compared to global trade. Further, exports of jute for the period were less than 1 percent of South Africa's maize exports. These figures are consistent with the lack of commercial scale kenaf cultivation in the country.

Figure 5: Exports and imports of jute by South Africa in 2015 USD (2010 - 2017)



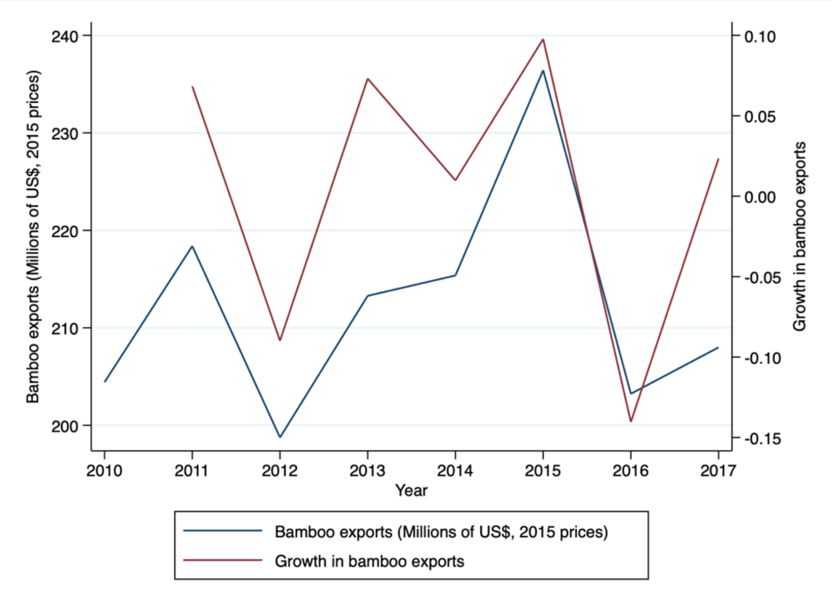
Source: CID (2019). Author's own calculations.
Note: HS code 5303 is used for kenaf: jute and other textile bast fibres (not flax, true hemp and ramie), raw or processed but not spun; tow and waste of these fibres, including yarn waste and garneted stock.

2.2.3 Bamboo in the Global Economy

As shown in Figure 6, bamboo exports fluctuated between 2010 and 2017, peaking in 2015 at approximately USD 235 million followed by a sharp decline in 2016 to just over USD 200 million. [6]

6 The following analysis is based on trade data for vegetable materials for plaiting, a main constituent of which is bamboo. As with kenaf, specific data for bamboo is difficult to identify in the trade data. Further, this data provides information about the imports of bamboo in its raw form. This disguises a potential domestic market for imported bamboo products, specifically speciality bamboo textiles.

Figure 6: Exports of bamboo in 2015 USD (2010 - 2017)



Source: CID (2019). Author's own calculations.
Note: SITC code 2923 is used for bamboo: vegetable materials of a kind used primarily for plaiting.

As discussed previously, China has a long-standing culture of bamboo cultivation and has up to 6 million hectares of bamboo forests. Table 3 shows that China contributed 44 percent to global exports between 2010 and 2017, with the most recent data showing an export value of USD 118 million in 2017. Interestingly, China was also the largest importer of bamboo, though this share is substantially lower at 15 percent. China's imports of raw bamboo are used as inputs into the manufacture of bamboo products, which are later exported as finished goods. The second largest importer of bamboo was the European market, specifically Germany and the Netherlands, with a combined share of imports equivalent to that of China for the period. Contrary to these trends, bamboo imports were highest for the USA in 2017, at a value of USD 25 million. As discussed previously, these import data do not provide an accurate picture of the import market for bamboo as finished goods are included.

Table 3: Top 5 Exporters and Importers of Bamboo in 2015 USD (2010 – 2017)

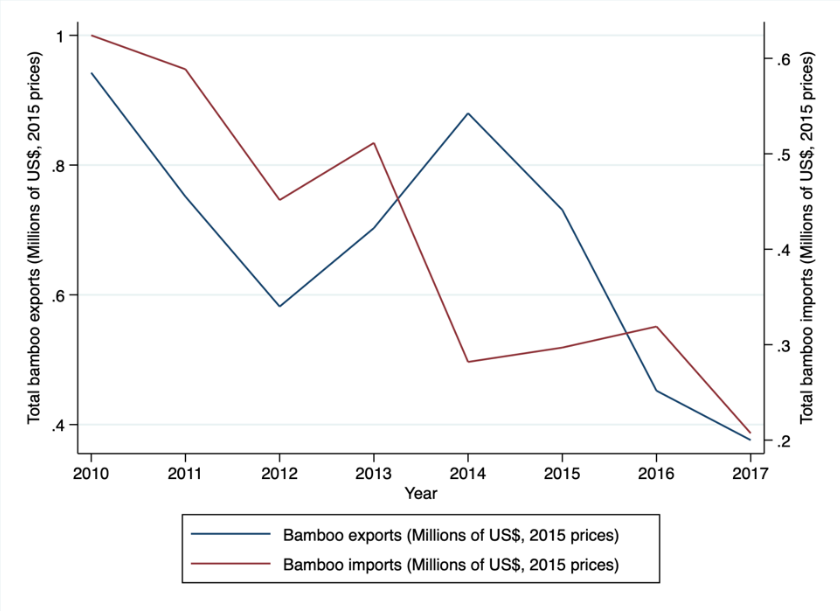
Country	Exports (2017)	Share of exports (2010 – 2017)
China	118 146 961	0.44
Indonesia	2 836 034	0.10
Malaysia	15 746 764	0.06
Singapore	5 666 363	0.05
Vietnam	4 129 339	0.04
Total for top 5 exporters	146 525 462	0.68

Country	Imports (2017)	Share of imports (2010 – 2017)
China	18 661 154	0.15
USA	24 685 529	0.11
Germany	13 420 713	0.08
Netherlands	15 642 527	0.07
India	12 714 293	0.06
Total for top 5 importers	85 124 217	0.47

Source: CID (2019). Author's own calculations.
Note: SITC code 2923 is used for bamboo: vegetable materials of a kind used primarily for plaiting.

Figure 7 shows that South African bamboo exports are marginal – less than 1 percent of the global market, which is consistent with a lack of large-scale commercial bamboo cultivation in the country. This is further evidenced by the fact that the country's bamboo exports between 2010 and 2017 amount to less than 1 percent of South Africa's maize exports for the period despite being broadly defined in the trade data. Figure 7 includes information about the imports of bamboo in South Africa indicating a near non-existent market in 2017.

Figure 7: Exports and imports of bamboo by South Africa in 2015 USD (2010 - 2017)



Source: CID (2019). Author's own calculations.
Note: SITC code 2923 is used for bamboo: vegetable materials of a kind used primarily for plaiting.

In summary, the global hemp market is poised for a significant expansion with the addition of the USA as a global player. The trend of decriminalisation of commercial-scale hemp cultivation is another important driver for growth in the industry. The jute story is one of Bangladeshi dominance with changes in export regulations being translated in the irregular pattern of global exports. China has held a steady lead in the trade of bamboo with no emerging competitors threating their market share, while South Africa's export values for each of these crops is insignificant when compared to global trade. Further, they are also relatively small in relation to other agricultural exports emerging from South Africa – e.g. averaging 0.1 percent of the value of maize exports between 2010 and 2017.

Nevertheless, the evidence discussed above clearly indicates that there is a degree of commercial and public sector interest in these fibrous plants. Further, it appears that the most attractive opportunities exist in the downstream applications of fibrous materials (we discuss this further in Section 3). It is necessary to increase the scale of cultivation to unlock this potential, which can only be achieved through the development of the capabilities required to cultivate and process these plants. The development of cultivation and processing capabilities is in the initial stages, and thus requires further research and development. Institutional support is required to up-scale these projects. Specifically, investigations into the feasibility of hemp and bamboo have been hampered by red tape, with permits being required in both cases. Looking forward, the continued development of these capabilities requires the downstream demand to incentivise the accumulation of these capabilities through research and development (R&D) and learning by doing – i.e. the chicken and egg problem (for which we provide a theoretical discussion in Section 5). The analysis to follow identifies downstream diversification opportunities where the required capabilities overlap with existing capabilities, thus making the shift to fibrous products economically feasible (see Section 6). We further investigate the economic feasibility of various downstream applications by surveying firms and industry experts in Section 7.

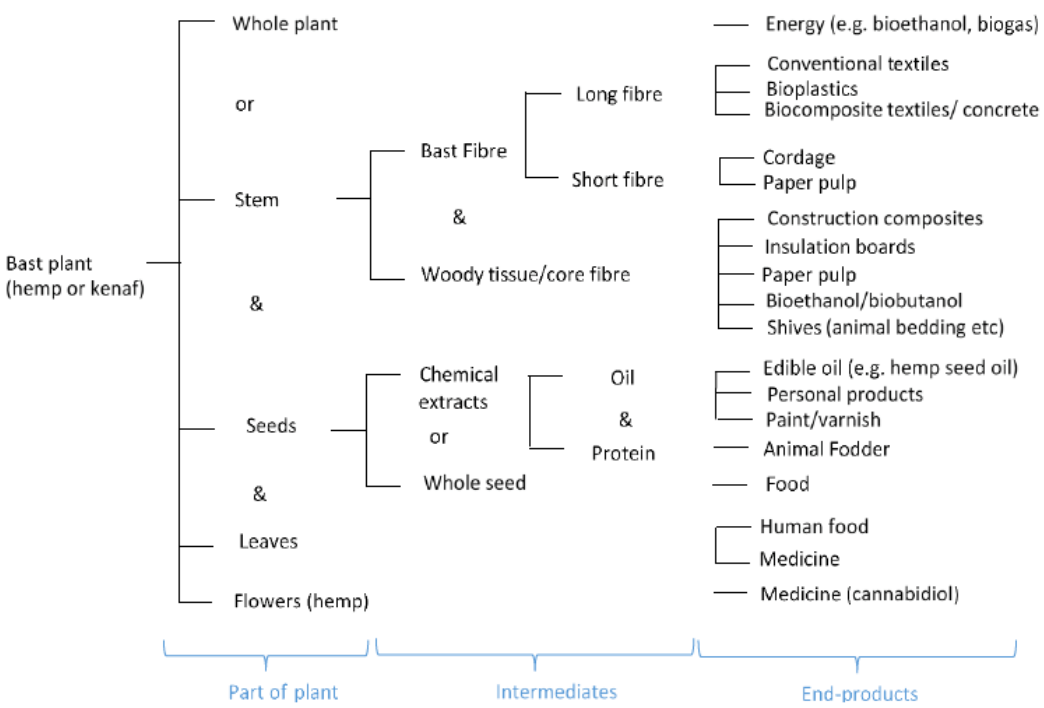
3 FIBROUS PLANT APPLICATIONS – PRODUCT-LEVEL DIVERSIFICATION OPTIONS

Building economic complexity is achieved through the process of diversifying into increasingly complex products, which in turn drives economic growth and creates employment opportunities. This paper is interested in the potential downstream diversification opportunities that emerge from fibrous plants. In this section we detail the construction of a dataset of downstream fibrous products and its mapping to complexity data.

Broadhurst, Chimbganda & Hangone (2019) compile a detailed list of products that can be manufactured using fibrous plants, specifically bamboo, hemp and kenaf, as an input. This is summarised in Figure 8 and Figure 9. For example, a bast fibre such as hemp can potentially be used in the manufacture of bioethanol, textiles, bioplastics, polymer composites, cordage, paper pulp, construction composites, insulation boards, shives for animal bedding, edible oils, personal products, paint, animal fodder, food and medicine. Following a meticulous matching process, we map these products to the Harmonized System (HS) product codes used to define products in the trade data.[7] This provides us with a set of downstream fibrous product applications, which is then used to construct the fibrous complexity index in Section 4.4 and to generate the fibrous product space in section 5.2.

7 As discussed below, international trade data is typically used when applying complexity and product space analytics. We use trade data provided by Harvard's Growth Lab, which is a project within the Centre for International Development (CID) at Harvard University – see http://atlas.cid.harvard.edu/about-data. The Growth Lab team extract data from the United Nations Statistical Division (COMTRADE). We employ the 1992 version of the Harmonized System at the 4-digit level of disaggregation. Hausmann et al. (2014) note that this level of disaggregation allows for a balance between tractability and granularity.

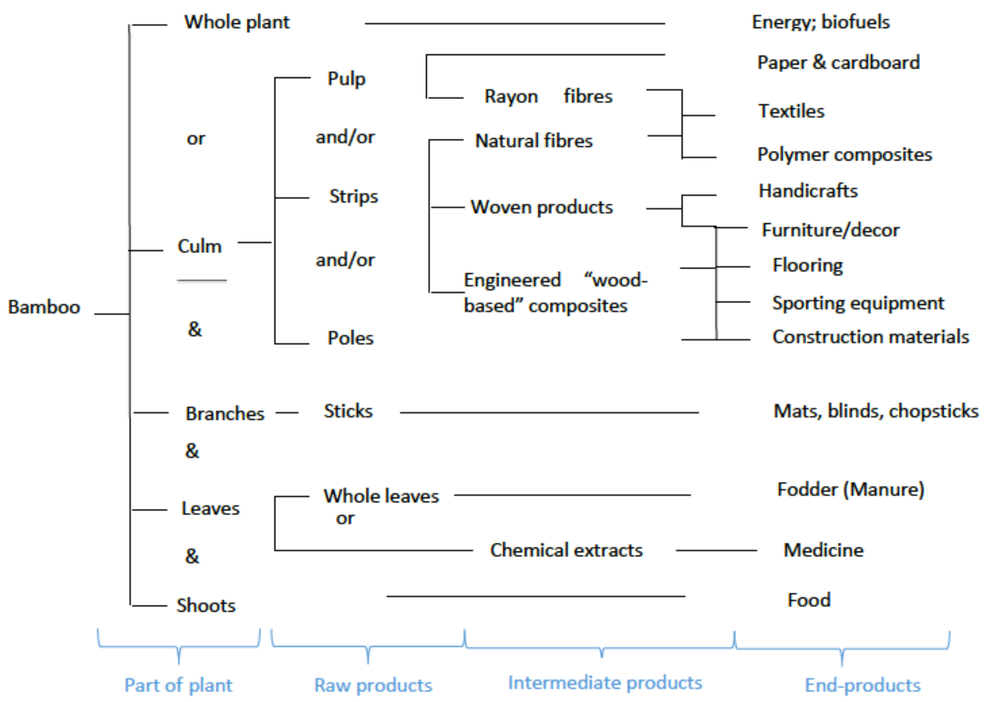
Figure 8: Products that can be manufactured using bast plants



Source: Extracted from Broadhurst, Chimbganda & Hangone (2019)

During the mapping process, a number of assumptions are made: first, we identify a product as 'fibrous' based on the potential that fibrous materials can be used in its production. For the most part, the trade data do not allow us to distinguish whether a product is made using a fibrous material or a non-fibrous substitute. For example, even though nonwoven textiles are typically manufactured using synthetic fibres, we identify this textile as a potential fibrous product since natural fibres, such as kenaf, can be used in its manufacture. Second, and relatedly, where a 'fibrous' version of a product is recorded at the 6-digit level or more in the trade data, we identify the 4-digit category that it fits within as 'fibrous'. For example, the 4-digit product, *wood charcoal* (HS 4402), is marked as 'fibrous' because the 6-digit product, *wood charcoal made of bamboo* (HS 44021010), is a product made from bamboo. We feel that these assumptions are reasonable since the capabilities needed to manufacture the same product using two different raw materials are likely to be the same or overlap substantially. For example, in the case of nonwoven textiles, interviewed respondents noted that, with slight adjustments, the machinery is transferable across synthetic and natural fibres.

Figure 9: Products that can be manufactured using bamboo



Source: Extracted from Broadhurst, Chimbganda & Hangone (2019)

Of the 1240 4-digit HS product codes in the data, 174 (or 14%) are identified as fibrous products. As detailed in Table 4, fibrous products are spread across a number of product communities or sectors. As one might expect, the majority of products fall within the textile & clothing and wood & wood products communities.[8] Other product communities that find a number of fibrous products, include vegetable products, footwear/headgear, foodstuffs, and chemicals.[9]

8 Textile products include various forms of fibre (e.g. hemp, jute, coconut), woven fabrics, twine and rope, netting, non-woven textiles and technical-use textiles. Clothing comprised various forms of apparel, such as knit and non-knit garments. Wood & wood products include various forms of pulp (e.g. mechanical woodpulp), various types of paper and packaging (e.g. composite paper, coated paper, uncoated paper, corrugated paper), construction products, such as fibreboards and plywood, and wood products such as barrels, tools, kitchenware and crates.
9 Vegetable products include seed oils and starches. Foodstuffs include products, such as animal food, processed vegetables, vinegar and pickled foods. Chemicals include medicaments, beauty products, cleaning products, paints and ethanol.

Table 4: Composition of Fibrous Plants

Product Communities	No.	Share
Textiles & Clothing	55	31,6
Vegetable Products	17	9,2
Mineral products	1	0,6
Footwear/headgear	11	6,3
Foodstuffs	10	5,7
Wood & wood products	49	28,2
Miscellaneous	11	6,3
Chemicals & allied industries	15	8,6
Stone/glass	1	0,6
Transportation	2	1,1
Plastics/rubbers	3	1,7
Total	174	100,0

The fibrous product dataset, informed by cross-disciplinary research, is then used to inform the analysis in Section 4.3 where we construct the fibrous complexity index, which allows us to rank countries according to the complexity of the fibrous products that they produce and export. Further, this set of products is used to construct the fibrous product space in Section 5.2. Finally, in Section 6.1. where we identify opportunities for diversification (frontier products) that build economic complexity, we identify fibrous options (fibrous frontier products) using this dataset.

4 ECONOMIC COMPLEXITY AND THE FIBROUS PLANT ECONOMY

Developing the fibrous plant economy should be structured around the aim of building economic complexity. The process of building economic complexity, driven by diversification into more complex products, allows countries to undergo economic growth and transition to higher levels of economic development (Hausmann et al., 2014). The theory of economic complexity provides an opportunity to analyse potential development paths for the South African economy, but with a specific focus on the fibrous products identified in Section 3. This section discusses the concept of economic complexity, before developing its application to the fibrous plant economy, in particular through the construction of the Fibrous Complexity Index (FCI).

4.1 The Notion of Economic Complexity

Rather than focusing on an aggregate view of the economy, which states that a country's level of economic development relies, in part, on the accumulation of factors of production and development of institutions, the theory of economic complexity is concerned with explaining economic development through the diversification of the productive structures of an economy (Hausmann et al., 2014). Economic complexity theory notes that growth in an economy occurs not through simply producing more, but instead through the accumulation of more and more specialised productive knowledge, which allows an economy to diversify into new products using techniques and skills that lie outside their current productive structure. Put simply, by expanding their range of products to include those that are more complex, a country can encourage structural transformation and economic growth in the long run.

This diversification into more complex products occurs though accessing new networks of productive knowledge, which can be described as capabilities. Capabilities are broader than simply an individual's knowledge of a particular production process; they include more tacit aspects such as logistical networks for product distribution, financial networks that will allow firms to access finance needed for capital expansion, or knowledge on how to grow specific crops in certain localities. Capabilities also encompass two types of productive knowledge: explicit and tacit. Explicit knowledge is the productive knowledge, which is easily transferrable between individuals, such as the price of feedstock, or the amount of arable land available for growing a crop. Tacit knowledge, on the other hand, is more difficult to transfer between individuals, encompassing knowledge such as, for example, the best farming practice to extract fibre from a kenaf plant. Accumulating these capabilities leads to the diversification and expansion of a country's productive structure, allowing the country to produce increasingly complex products, culminating in a process of long-run economic development. The complexity of an economy is thus related to the amalgamation of useful productive knowledge, or capabilities, that are embedded within it.

A particular challenge faced in the application of this theory is that productive knowledge is not directly measurable. As a result, it becomes necessary to backward-engineer a measure of a country's available capabilities from the final product observed in their export portfolio.[10] Hausmann et al. (2014) explain that if a country is seen to produce a particular product, one can infer that this country must have the requisite capabilities to produce the product in the first place.[11] They further describe two logical extensions of this observation: firstly, countries that have a larger knowledge base, or a wider variety of capabilities, are able to produce a greater diversity of products. Secondly, if a particular product requires a large volume of knowledge in order to produce it, this product can only be produced in those few countries in possession of the wide variety of capabilities needed. These two observations provide the

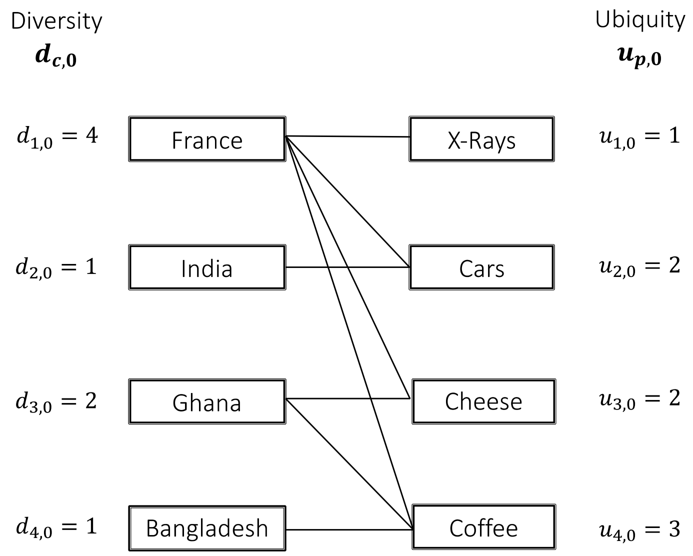
10 In general, complexity analysis makes use of a country's export portfolio as measured from international trade data as an approximation of their productive structure. Hausmann et al. (2014) argue that the use of trade data is largely advantageous as it allows one to conduct cross-country comparisons over a large time horizon using a standardised product classification. In this paper, we use the 1992 revision of the Harmonized System at the 4-digit level (unless otherwise stated).

11 Hausmann et al. (2014) define a country as being a producer of a particular product if they exhibit relative comparative advantage in the production of this product. According to the definition put forward by Balassa (1965), a country, c, has a relative comparative advantage in exporting product p if product p makes up a greater proportion of country c's trade than it does of world trade.

notions underlying two key components that are used in building up a measure of economic complexity: diversity and ubiquity.

Diversity and ubiquity together provide a starting point for developing the notion of economic complexity. Since diversity relates to the number of products present in a country's export basket, and ubiquity refers to the number of countries that produce a particular product, one can categorise complex economies as those countries with a large diversity of products with low ubiquity. Put simply, if a country produces a wide variety of products that are not produced by many other countries, then this economy is likely to be more complex. A simple illustrative example of how diversity and ubiquity are calculated is presented in Figure 10, below.

Figure 10: Illustrative example of diversity and ubiquity



In Figure 10, it is clear that there are four countries under consideration, as well as four products. The lines connecting countries to products indicate that a particular country produces that product. The measures of diversity in the left-hand column, denoted as $d_{c,0}$ where c represents the country, are calculated by counting the number of products produced by each country. For example, France produces x-rays, cars, cheese and coffee, meaning that they have a diversity measure of 4. Analogously, Bangladesh only produces coffee and thus has a diversity measure of 1. When measuring the ubiquity of a product, as depicted in the right-hand column and denoted as $u_{p,0}$ where p represents the product in question, one has to count the number of countries that produce a given product. For example, the countries that produce cheese are Ghana and France, which means that cheese has a ubiquity measure of 2. Similarly, the only country that produces x-rays is France, meaning that x-rays have a ubiquity of 1.

Considering this illustrative example, it is clear that France would be considered the most complex economy. However, when comparing India and Bangladesh, both of which have a diversity of 1, it is insufficient to consider only diversity as a metric for ranking economic complexity. In order to further refine the measure of economic complexity, one should consider the average ubiquity of the products exported by a country. When this is done, it becomes clear that India should be ranked as more complex than Bangladesh, since even though they both only export 1 product, the product exported by India (cars) is less ubiquitous than the product exported by Bangladesh (coffee).

In general, one would calculate the average ubiquity of all products exported by a particular country and use this information to correct the information in the original diversity measure so as to obtain a more refined measure of economic complexity. In order to further refine the measure of economic complexity in an economy, one could consider the average diversity of the countries who produce the products whose ubiquities were averaged above. This iterative method of correcting the information contained in the measure of complexity is known as the method of reflections and eventually stabilises at a value known as the Economic Complexity Index (ECI) of an economy (Hausmann et al., 2014).

Analogously, one could create an index for how complex a particular product is. Beginning with the measure of ubiquity, one can see that x-rays are the least ubiquitous product, and thus the most complex product. However, cars and cheese are both exported by two countries, and so it is unclear how one should rank these products in terms of their relative complexity when considering only their ubiquity. Thus, similar to before, one can use the average diversity of the countries exporting the product in question to refine one's measure of complexity. These calculations, which once again stabilise after a number of iterations, provide a measure of the complexity level of a given product – the Product Complexity Index (PCI).

While the above discussion provides an intuitive understanding of how the ECI and PCI can be understood, applying the method underlying this intuition can raise some mathematical troubles. A description of a more mathematically robust calculation of these indices is included in Box 1, below.

Box 1: A Technical Method of Calculating Economic Complexity Measures

As a starting point, we consider the framework outlined by Hidalgo et al. (2014): consider the matrix M, with elements $M_{c,p}$ which are equal to 1 if country c exports product p with relative comparative advantage (i.e. RCA≥1) and 0 otherwise.[12] Diversity and ubiquity can be calculated by summing along the rows and columns of the matrix, respectively. Formally, we can define these concepts as:

$$Diversity = d_{c,0} = \sum_{p} M_{c,p} \tag{1}$$

$$Ubiquity = u_{p,0} = \sum_{c} M_{c,p} \tag{2}$$

However, diversity and ubiquity by themselves are not sufficient to provide a nuanced measure of economic complexity. Rather, one has to refine the notion of diversity of a country by considering the ubiquity of the products it exports, and vice versa. For example, two countries with the same diversity can be ranked according to the average ubiquity of the products they produce in order to refine our ranking of complexity. Analogously, if two products have the same ubiquity, then one refines the notion of product complexity by considering the average diversity of the countries which export those products. This refinement is mathematically defined according to the following recursion:

$$d_{c,N} = \frac{1}{d_{c,0}} \sum_{p} M_{c,p} \cdot u_{p,N-1} \tag{3}$$

$$u_{p,N} = \frac{1}{u_{p,0}} \sum_{c} M_{c,p} \cdot d_{c,N-1} \tag{4}$$

At this point, it should be noted that simply applying the recursion iteratively until a steady state is reached would correspond to the method of reflections approach to calculating the ECI of country X. However, this method is not the preferred one for computing the ECI due to, among other things: its lack of practical interpretability after a number of iterations, and the fact that the natural fixed point of the system would result in the ECI for all countries being equal, which is uninformative (Calderelli et al., 2012; Cristelli et al., 2013).

Calderelli, et al. (2012) present an alternative method of solving for the ECI through the use of the spectral properties of a linear system. They prove that solving for each country's ECI through the method of reflections is equivalent to the method of solving for the ECI through eigenvectors, however, without the same drawbacks that are present in the method of reflections (Calderelli et al., 2012).

The coefficient matrix of the linear system to be analysed is given by $\widetilde{M}$, whose rows and columns represent countries, and whose elements $\widetilde{M}_{i,j}$ are defined as follows:[13]

$$\widetilde{M}_{X,c} = \sum_{p} \frac{M_{X,p} M_{c,p}}{d_{c,0} u_{p,o}} \tag{5}$$

Equivalently, the matrix $\widetilde{M}$ can be written in matrix notation as

$$\widetilde{M} = D^{-1} M U^{-1} M' \tag{6}$$

where D is a diagonal matrix with the entries along the main diagonal being the diversity measures for each country as defined in equation (1), and U is the diagonal matrix with diagonal entries equal to product ubiquities, as per equation (2).

The vector of ECI values for all countries is then defined by the eigenvector corresponding to the second-largest right-eigenvalue of the matrix $\widetilde{M}$.[14] It is common practice to standardise this ECI vector by subtracting the mean and dividing by the standard deviation of the vector's entries, and it is this standardised version of the ECI which is presented throughout this paper.[15]

As a result, one can define the ECI mathematically as:

$$ECI = \frac{\vec{D} - < \vec{D} >}{sd(\vec{D})} \tag{7}$$

where $\vec{D}$ is the eigenvector associated with the second-largest right-eigenvalue of $\widetilde{M}$, $<\cdot>$ represents the mean of the vector, and $\mathrm{sd}(\cdot)$ represents the standard deviation.

The PCI, which is the equivalent complexity index for products, can be defined as

$$PCI = \frac{\vec{U} - < \vec{U} >}{\mathrm{sd}(\vec{U})} \tag{8}$$

where $\vec{U}$ is simply the eigenvector associated with the second-largest right eigenvalue of the matrix $\widehat{M} = U^{-1}M'D^{-1}M$ (Mealy, Farmer & Teytelboym, 2019). This would be equivalent to applying the method outlined above for calculating the ECI to the transpose of the matrix $\boldsymbol{M}$.

4.2 Economic Complexity and Economic Development

The foundation of economic complexity is that countries with higher economic complexity must be in possession of greater endowments of productive knowledge (Hausmann et al., 2014). Countries that are in possession of greater productive capabilities must in turn be able to produce a greater diversity of complex products that can be exported in order to generate income for the country as a whole. As a result, one would expect a positive correlation between a measure of a country's income and its relative complexity.

Hausmann et al. (2014) present results that show how their ECI measure correlates with various measures of countries' economic development. The general trend from these results is that where economies exhibit higher economic complexity, they also exhibit higher levels of economic development. This therefore suggests that one way to encourage economic development would be to build economic complexity. The relationship between the ECI, as a measure of economic complexity, and the log of GDP per capita, as a measure of economic development, is plotted in Figure 11.

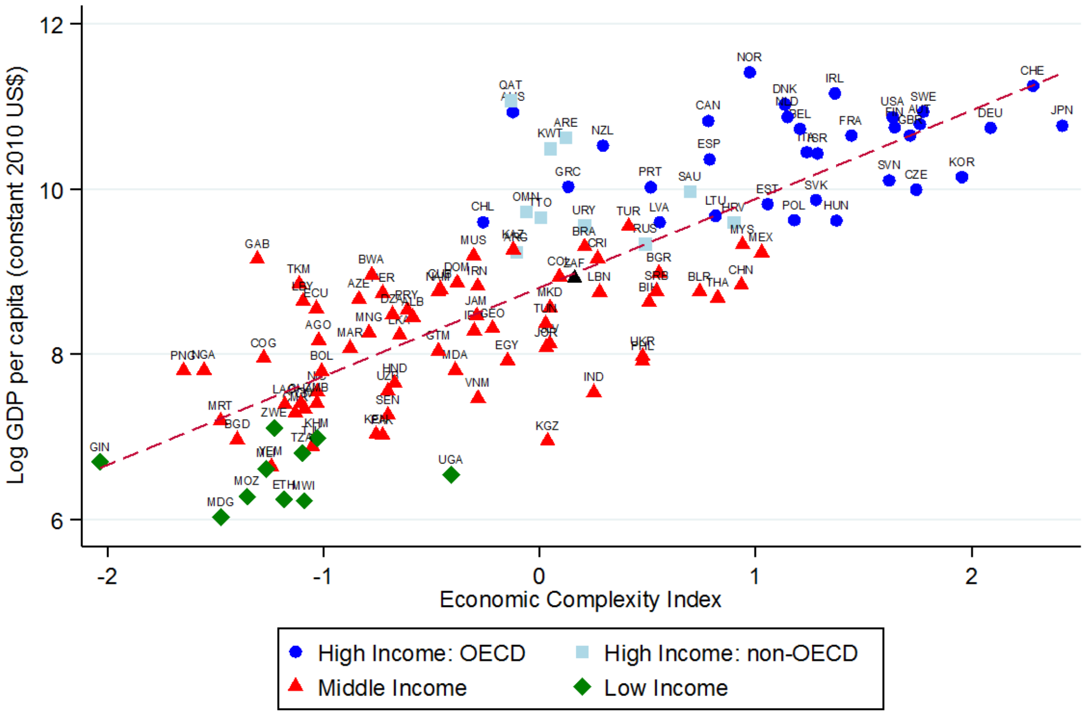
12 Throughout this paper, it should be noted that the calculations for complexity values are time dependent. In other words, all variables vary across time, and thus can be denoted with a time subscript. For the purposes of readability in this paper, however, this time subscript has been dropped.

13 Another measure for calculating complexity indices exists and posits a non-linear relationship between diversity and ubiquity (Caldarelli et al., 2012). Although we acknowledge that this measure exists, it does not form the basis of the analysis in this paper.

14 The eigenvector corresponding to the largest eigenvalue of $\widetilde{\mathrm{M}}$ will always be a vector where every entry is equal to one. Thus, this vector is not practically informative as an index, and the eigenvector associated with the second-largest eigenvalue is used instead, as it captures the largest amount of variation in the system.

15 Hausmann et al. (2014) use the standardized version of the ECI in order to compare countries' complexity indices over time, which is an advantage of the normalised ECI over the non-normalised index.

Figure 11: The relationship between GDP and Economic Complexity, 2016



Source: Authors' calculations from CID (2019) and World Bank (2019).
Note: Correlation=0.797; p-value=0.000. Red dashed line is a line of best fit.

It is immediately clear from Figure 11 that, as expected, there is a strong, positive relationship between economic complexity and economic development measured here by the log of GDP per capita. This diagram also highlights how countries in higher income groupings are also generally more complex: the most complex economies are those among the high-income OECD classification – countries such as Japan (JPN), Switzerland (CHE), and Germany (DEU). Conversely, the incidence of low-complexity economies corresponds with classification as a low-income country. This latter grouping includes countries such as Guinea (GIN), Madagascar (MDG), and Mozambique (MOZ).

South Africa (ZAF), represented by the black triangle marker in Figure 11, is classified as a middle-income country, and, accordingly, lies approximately halfway along the distribution of economic complexity, with an ECI measure of approximately 0.16. It is clear that South Africa compares favourably to other African countries both in terms of GDP per capita, as well as in terms of complexity. In fact, in 2016, South Africa was ranked as the most complex economy on the African continent. Furthermore, as a point of comparison, the average complexity of an African economy in 2016 was -0.96, which lies between the ECI of Angola and Morocco.

Figure 11 also plots the regression line relating ECI to the natural log of GDP. Deviations from this regression line are of practical interest as they allow one to determine whether a country's export basket is relatively more or less complex than expected, given their overall level of economic development. Furthermore, Hausmann et al. (2014) find those countries that are relatively more complex than expected given their level of economic development – i.e. those countries lying below the regression line in Figure 11 – exhibit faster economic growth patterns than those countries who are relatively less complex than expected – i.e. those countries above the regression line. For example, countries such as South Africa, Greece (GRC), and India (IND) would be ranked very similarly in their levels of economic complexity. However, Greece lies above the regression line, indicating that the country is relatively more developed than what would be expected given the products it exports. In the same way, India lying below the regression line indicates that the country is relatively under-developed for the products it is producing. However, when considering the potential for growth in these two countries, India would be expected to grow faster than Greece. This accelerated growth would be symptomatic of India having developed their productive structures in such a way that they produce more complex products than other countries at a similar level of development.

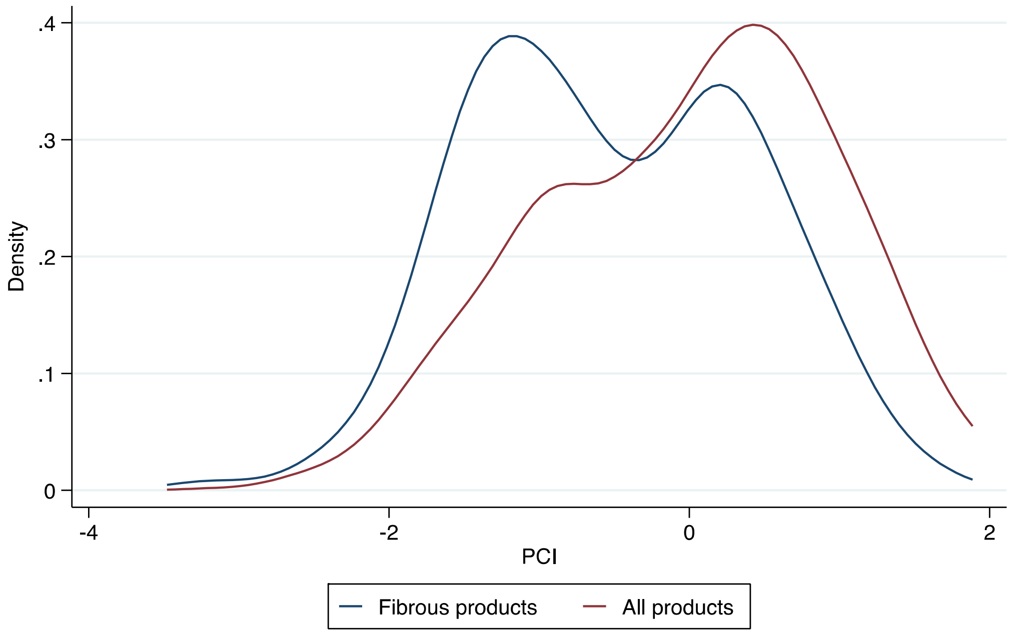
In the case of South Africa, which lies essentially on the regression line, the country is as developed as we would expect given the observed export basket. However, it is still important to encourage growth and development through the building of economic complexity. Following the logic from before, if South Africa can grow its economic complexity through the products it has given capabilities in, this would be the first step towards encouraging a faster growth trajectory in the future. This paper aims to map out such a path to encouraging the building of economic complexity through the development of the fibrous plant economy. The following subsection profiles the complexity of these fibrous plant products in order to provide clarity on how they relate to the broader population of products.

4.3 The Complexity of Fibrous Products

In Section 3, a cross-disciplinary approach is used to inform the identification of fibrous products in the complexity data. In this section, we turn to profiling these fibrous products in order to better understand how they fit into the broader universe of products defined in the complexity data. Understanding the nature of these products is crucial to being able to identify which, if any, products can build a country's economic complexity. Using the analytical tools discussed in Section 4.1, this section provides an overview of the complexity of fibrous plant products, both in general, as well as at a more granular product-level.

As a starting point, we consider the PCI values for products identified as possible to manufacture using the three fibrous plants of interest: hemp, bamboo and kenaf. The PCI, as discussed above, provides a measure of the level of complexity of a product, which speaks to the sophistication of the capabilities required in order to produce these products competitively (Hausmann et al., 2014). Figure 12 plots the distribution of PCI values for the universe of all products against the distribution of the PCI values for fibrous products.

Figure 12: PCI of fibrous and non-fibrous products, 2016



Source: Authors' calculations from CID (2019)
Note: Kolmogorov-Smirnov test p-value of 0.000

The results presented in Figure 12 show that fibrous products are significantly different to the universe of all products in some fundamental ways: the distribution of fibrous products is distinctly bimodal, whereas the distribution of all products is roughly unimodal. Furthermore, the distribution of fibrous plant products lies substantively to the left of the distribution of all products.

These differences in the distributions of PCI values provide valuable insight into the nature of fibrous products, particularly when coupled with the problem of selecting products that will encourage growth. Firstly, the fact that the distribution of fibrous plants lies generally to the left of the distribution of all products indicates that the majority of products which can be produced using fibrous plants tend to be low-complexity products, and as a result, do not require highly sophisticated productive capabilities. This is not to say that there are no high-complexity fibrous products. The bimodality of the fibrous plant PCI distribution speaks clearly to there being two distinct groupings of products within the fibrous product subspace: one that is low-complexity, and one that is high-complexity.

In order to further unpack these two broad groupings of fibrous products, we classify the products into various product communities and investigate the mean and median PCI values within each community. The results of this analysis are presented in Table 5, below. The product communities are listed in order of increasing complexity, with textiles, vegetable by-products, mineral products[16], footwear/headgear and foodstuffs occupying the low-complexity end of the distribution (below the mean and median PCI), while products such as wood & wood products, plastics, rubbers,[17] transportation-related products[18] and chemicals occupy the high-complexity end of the distribution (above the mean and median PCI).

Table 5: Mean and Median PCI by Product Community

Product Community	Number of Products	PCI Mean	PCI Median
Textiles/clothing	55	-1.257	-1.614
Vegetable products	17	-0.967	-0.866
Mineral products	1	-0.767	-0.767
Footwear/headgear	11	-0.624	-0.418
Foodstuffs	10	0.193	-0.039
Wood & wood products	49	0.865	1.190
Miscellaneous	11	0.989	1.027
Chemicals & allied industries	15	1.417	1.497
Stone/glass	1	1.574	1.574
Transportation	2	1.884	1.884
Plastics/rubbers	3	2.662	2.472
All Products	1239	0.483	0.500

Source: Authors' calculations from CID (2019)
Notes: Miscellaneous products include products such as wooden instruments, spectacle frames, brooms and mops, among others.

It is further interesting to note that the bimodality of the fibrous product distribution in Figure 12 seems to be caused primarily due to the large clusters of products in two specific communities: "Textiles/clothing" make up the group of products with lower complexity, while "Wood & wood products" form the higher complexity group of products. It should be noted that although the community of textile products is ranked as the lowest complexity community in the fibrous product universe on average, there are still higher-complexity products among this grouping.[19] Similarly, although there are a substantial number of wood products which do not require complex processing, the presence of wood products as relatively high-complexity products speaks to the presence of more specialised papers and pulps, including products such as newsprint, coated papers, chemical-grade

16 This community of products includes the fibrous product refined petroleum at the HS4 level. Fibrous plants can be used to produce biodiesel, which is one of the more disaggregated products captured under this HS4 product classification.
17 Fibrous products in the plastics/rubbers community comprise cellulose and natural polymers, as well as the products produced using these as inputs.
18 This community of products includes motor vehicle parts, including non-load bearing vehicle panels, which could be created using biocomposite materials.
19 For example, products such as nonwoven textiles and textiles for technical use have much higher complexity rankings than products such as yarns and woven textiles.

dissolving wood pulp, and others. In order to provide more clarity on the distribution of products' PCI values, Table A. 1, in the Appendix, provides a more detailed breakdown of the 10 top- and bottom-ranked individual fibrous products by PCI.

By classifying fibrous products into their product communities and comparing the average PCI of these communities, it becomes clearer as to which communities of fibrous products will contribute towards growing economic complexity. However, the bimodality of the distribution does still imply a choice needs to be made: countries can opt to follow a lower-complexity route, which may involve diversifying into products such as woven textiles, waxes, and wooden furniture. Alternatively, countries can opt to follow a higher-complexity diversification path, which would require diversification into products such as lubricants, motor vehicle parts made from biocomposites, and nonwoven textiles. A country's choice of diversification path depends on what capabilities are currently available in the economy. In particular, when assessing diversification into fibrous plants, the current capabilities available for processing fibrous plants are of importance. The following section will develop a measure of fibrous complexity, which will assist in characterising the level of fibrous product sophistication within a country, and as a result, provide the first step in determining which of these two diversification paths may be best suited to the economy in question.

4.4 The Fibrous Complexity Index

Characterising the fibrous plant economy is an important step towards understanding which capabilities for the processing and production of fibrous products are currently available in a country. In much the same way that Hausmann et al. (2014) construct the ECI to characterise a country's performance across the entire universe of products, one can limit the products under analysis to a particular subset as needed.[20] In the case of this paper, we consider the subset of fibrous products and we aim to construct an index of economic complexity to specifically describe the fibrous economy in a country.

Research by Mealy and Teytelboym (2018) on the green economy provides a point of departure for our own research. In their study of the green economy, Mealy and Teytelboym (2018) restrict their analysis to the subset of green or renewable products and create the Green Complexity Index (or GCI), which characterises the complexity level specifically related to the production of green products within a country. The method for calculating this GCI for country c is presented in equation (9), below.

20 While a number of studies have analysed the economic complexity of certain subsets of products, such as green products (Mealy & Teytelboym, 2018; Huberty & Zachmann, 2011) and agricultural products (Isdardi, van Schalkwyk & Viviers, 2015), this paper represents the first, to our knowledge, to consider fibrous plant products.

$$GCI_c = \sum_g \rho_g \widetilde{PCI}_g \tag{9}$$

In this definition, ρ_g is an indicator whereby if a country has comparative advantage (i.e. RCA≥1) in green product g, then $\rho_g = 1$, and it is 0 otherwise. Furthermore, $\widetilde{PCI}_g$ is the PCI value for product g, normalised to lie between 0 and 1. In essence, then, the GCI index for country c can be thought of as a weighted average of the PCI of all green products a country exports with RCA≥1.

In an analogous manner, we can define the Fibrous Complexity Index (FCI), in which the indices for green products can simply be exchanged for those for fibrous products. More specifically, this allows us to define the FCI for country c in the following way:

$$FCI_c = \sum_f \rho_f \widetilde{PCI}_f \tag{10}$$

where

$$\widetilde{PCI}_f = \frac{PCI_f - PCI_{min}}{PCI_{max} - PCI_{min}} \tag{11}$$

The normalisation described in equation (11) ensures that the values for $\widetilde{PCI}_f$ lie between 0 and 1, with PCI_{min} and PCI_{max} representing the minimum and maximum observed PCI values in the data, respectively. The FCI measure resulting from equation (10) is finally normalised by subtracting the mean and dividing by the standard deviation, as was done when calculating the ECI and PCI values as described in Box 1.

The FCI provides a ranking of countries' relative presence in the global fibrous product market. As a way of providing a brief overview of these rankings, the top and bottom 10 countries by 2016 FCI value are presented in Table 6. The first striking result from the table is the fact that those countries with the 10 highest FCI values all have higher-than-average ECI values (i.e. strictly positive ECI values) and are classified as relatively high-income countries.[21] On the other hand, those countries with the lowest FCI values have relatively low ECI values and are generally classified as low-income or middle-income countries. It is also interesting to note that the top-ranked fibrous economies are also generally clustered in Europe, while the bottom-ranked countries are clustered mostly in Africa and South America.

In the case of South Africa, it is clear to see that it falls in the bottom half of countries regarding its level of fibrous complexity. Its FCI score of -0.401 is below the mean FCI score of zero. Ranked 70th out of 123

21 Due to the normalisation of ECI, described in Section 4.1, the mean ECI across the sample of countries is zero. Thus all, above average ECI scores are positive.

countries, we can see that although South Africa's economy is above average in terms of overall complexity, this does not filter through to the fibrous economy. This is evidenced in the nature of fibrous products that South Africa exports with RCA≥1: in general, these products lie within the vegetable and foodstuffs communities[22], as well as some low-complexity wood products, such as charcoal and notebooks. Only 7 of the 23 fibrous products exported competitively by South Africa lie more than 1 standard deviation above the mean PCI of 0, indicating that there is a general lack of complex fibrous products present in South Africa's export basket. Table A. 2 in the appendix provides a more detailed breakdown of all the fibrous products South Africa exported competitively in 2016.

Table 6: Top- and Bottom-Ranked Countries by FCI, 2016

FCI Rank	Country	FCI	Mean FCI by top/bottom 10	ECI	Mean ECI by top/bottom 10	Income Group
1	Portugal	2.242	1.969	0.513	1.011	High income: OECD
2	Italy	2.144		1.236		High income: OECD
3	Poland	2.083		1.178		High income: OECD
4	Spain	2.081		0.786		High income: OECD
5	China	2.066		0.933		Upper middle income
6	Austria	1.946		1.760		High income: OECD
7	Croatia	1.916		0.899		High income: non-OECD
8	Lithuania	1.908		0.814		High income: OECD
9	France	1.683		1.442		High income: OECD
10	Bulgaria	1.620		0.552		Upper middle income
⋮	⋮	⋮		⋮		⋮
70	South Africa	-0.401		0.161		Upper middle income
⋮	⋮	⋮		⋮		⋮
114	Yemen	-1.223	-1.256	-1.242	-0.509	Lower middle income
115	Mali	-1.225		-1.267		Low income
116	Botswana	-1.230		-0.777		Upper middle income
117	Kuwait	-1.241		0.050		High income: non-OECD
118	Congo	-1.242		-1.278		Lower middle income
119	Algeria	-1.252		-0.681		Upper middle income
120	Venezuela	-1.253		-0.783		High income: non-OECD
121	Libya	-1.294		-1.095		Upper middle income
122	Mauritania	-1.296		-1.477		Lower middle income
123	Angola	-1.302		-1.023		Upper middle income

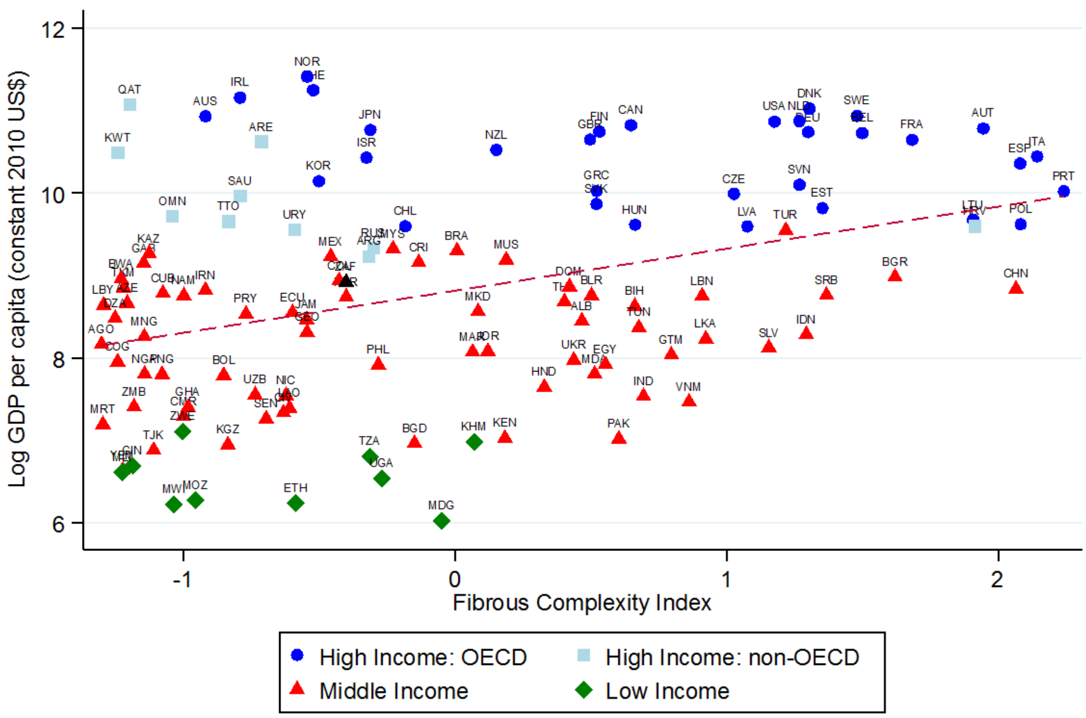
Source: Authors' calculations from CID (2019) and World Bank (2019).

Figure 13 plots the relationship between the log of GDP per capita in 2016 and the FCI. While this relationship is not as clearly positive as the relationship between GDP and ECI, there is still a statistically significant positive correlation between them. Once again, the variation around the regression line is interesting: in the case of South Africa, which lies above the regression line, it is clear that the level of fibrous complexity present in the economy is low relative to its overall level of economic development.

22 These products include seeds used for sowing, flours of oil seeds, sunflower seed oil, ethyl alcohol (>80%), margarine, soap and essential oils, as some examples.

However, it should be noted that the gap in this case is not very large. Nevertheless, this gap suggests that South Africa's development plans have been relatively less focused on fibrous products or subsectors of the economy that would lend themselves towards developing a fibrous economy.

Figure 13: Relationship between GDP and FCI, 2016

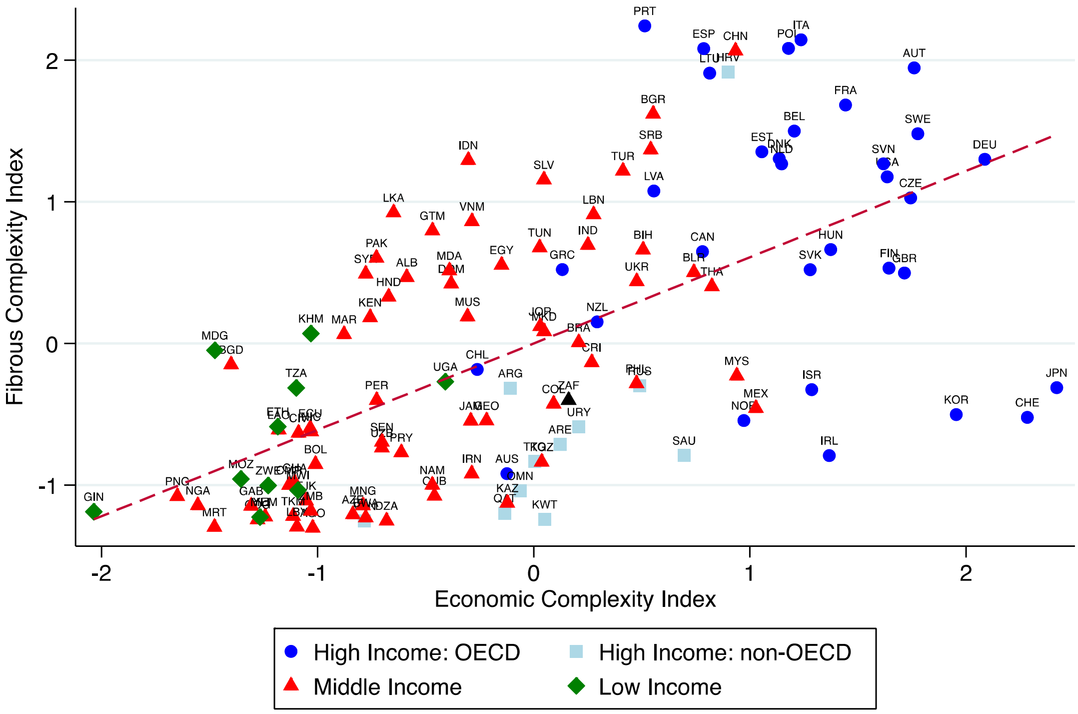


Source: Authors' calculations from CID (2019)
Note: Correlation=0.378; p-value=0.000. Red dashed line is line of best fit.

In a similar vein, when plotting ECI against FCI, as is done in Figure 14, we can compare the level of complexity within a country's export basket to the level of fibrous complexity it exhibits. This comparison speaks to the relative focus countries may have placed on fibrous products relative to other non-fibrous products. Once again, there is a positive relationship between the complexity of the overall export basket and the complexity of the fibrous products in the export basket, and this correlation is relatively strong at approximately 0.61. Put differently, this implies that a country that is highly ranked when it comes to ECI is likely to be highly ranked in FCI as well.[23] Furthermore, because of the relatively strong correlation between ECI and World Bank income classification, it is unsurprising to see that, for the most part, high-income countries occupy the top-right quadrant of Figure 14, while low-income countries tend to occupy the bottom-left quadrant.

23 A graph plotting countries' ranks in ECI against their ranks in FCI is presented as Figure A. 1 in the Appendix.

Figure 14: Relationship between ECI and FCI, 2016



Source: Authors' calculations from CID (2019)
Note: Correlation=0.610; p-value=0.000. Red dashed line is line of best fit.

Figure 14 also provides another interesting metric for contextualising the level of development of the fibrous plant industry within a given economy. Specifically, in this case, the interpretation of the deviation from the regression line is of interest: in this case, the line of best fit indicates the average relative investment in increasing fibrous complexity, relative to overall complexity. As a result, deviations from the regression line speak to whether countries have over- or under-invested in the development of their fibrous plant industries and, as an extension, their fibrous complexity. To clarify, for countries above the regression line, whose FCI is greater than expected for their particular level of ECI, there is a relative over-investment in the development of fibrous complexity. The converse holds true for those countries below the regression line.

South Africa, as one of the countries below the regression line, is thus an economy that has relatively under-invested in the development of its fibrous economy. This relative under-investment in a fibrous economy could speak to active redirection of investment decisions, or simply missed opportunities for diversification. No matter the underlying reason, South Africa finds itself with a 'fibrous complexity gap' – a disparity in the level of overall economic complexity and the level of fibrous complexity present in the economy. The presence of this fibrous complexity gap suggests that there are perhaps fibrous product opportunities that are easily achievable in the South African economy and, as a result, there may be a strong economic case for investing in the fibrous plant economy.

Although the presence of a fibrous complexity gap indicates that countries may have missed opportunities to diversify into fibrous plants in the past, it is as yet unclear which diversification path a country should pursue in developing their fibrous plant industry. The FCI measure, however, does not provide any insight into which products should be targeted in this approach. Instead, it simply provides a summary of the average level of complexity of those fibrous products that appear in a country's export basket with RCA≥1. The following section outlines a method for visualising the relationship between products so as to better understand how to choose the optimal development path for the fibrous plant industry and the economy as a whole.

5 THE FIBROUS PLANT PRODUCT SPACE

Hausmann et al. (2014), as noted above, argue that building economic complexity is contingent on developing the requisite productive capabilities. Put simply, to increase the complexity of the products you export, you have to accrue the productive capabilities needed to produce these goods. However, the accumulation of productive capabilities in order to grow economic complexity suffers from the 'chicken and egg' problem: countries cannot create products for which they do not have the capabilities. However, in the same breath, countries are unlikely to want to accumulate new capabilities if the production processes that demand these capabilities do not exist (Hausmann et al., 2014).

A potential solution to this circular problem is for economies to develop new capabilities that are similar to the capabilities that are needed for goods produced under the current economic setup. Hidalgo et al. (2007) put it as follows: If the set of all products were visualised as a forest, and the firms producing goods in the economy are monkeys in the trees, then in order to swing to a new tree, one would need to consider where the monkey starts from and the distance to the adjacent tree. In order to ensure the monkey can reach this new tree in its swing, the tree must be relatively close to the tree from which the monkey starts its jump. Knowing which tree the monkey starts from is equivalent to knowing which products are currently being produced in the economy. Adjacent trees would then be products that firms could diversify into, and firms would want to diversify into related products that are similar – or close – enough to their current products for the diversification to be practically feasible.

Analytically, it is important to visualise this network of products so as to understand the inter-relatedness of the productive economy. Hidalgo et al. (2007) developed the notion of the product space – a visualisation of the interconnected network of all products defined under the 4-digit Harmonized System (HS) or Standard Industrial Trade Classification (SITC) of products. This section will draw on the work of Hidalgo et al. (2007) and Hausmann et al. (2014) in order to apply the product space methodology to the subset of fibrous plants in an attempt to visualise these products in the context of an interrelated network. Once this has been done, it is possible to start isolating the products that are proximate enough to our current productive structure that they would be possible to target in a complexity-enhancing diversification strategy.

5.1 Constructing the Product Space

In their quest to accumulate productive knowledge, countries have been found to diversify from industries that currently exist within the economy to those industries that require similar capabilities or are related (Hidalgo et al., 2007; Hausmann et al., 2014). This idea of diversifying into industries that are proximate in terms of required productive knowledge marries with the notion of the monkeys swinging to trees that are nearby, as discussed previously. However, in order to determine which products or industries are candidates for diversification, it is important to characterise the capabilities that each product requires for production.

As mentioned in Section 4.1, however, productive knowledge or capabilities are not directly observable, and as a result, the similarity in capabilities between two products cannot be identified without the use of a proxy. Hidalgo et al. (2007) develop such a proxy, which infers the relatedness, in terms of required productive capabilities, between two products based on the probability that the two products are both exported by a given country. The logic behind this measure is as follows: where two products, such as shirts and blouses, share similar capabilities, the probability of a country exporting both goods is relatively high. However, where two products are dissimilar in the capabilities required in their production, such as shirts and jet engines, these products are unlikely to be co-exported. The probability of two goods being co-exported thus gives a measure of how proximate the capabilities required for the production of the two products are.[24] This measure is defined as the proximity of one product to another and is a useful measure in building a visualisation of the interconnected network of products known as the *product space*. A more technical discussion of how proximity is calculated is presented in Box 2, below.

Box 2: Calculating the Proximity Between Products

Hidalgo et al. (2007) make use of trade data at the 4-digit product-level to construct their measures of proximity, which feed into the network visualisation of the *product space*. Although one can use either the HS or SITC product classifications, this paper has opted for the 1992 revision of the 4-digit HS classification throughout. However, the method is easily adaptable and can be applied to other variations of the trade data.

24 In the extreme case where only one country exports both goods, however, this notion becomes tricky – if only one country exported both shirts and jet engines, it would be impossible to tell whether the capabilities for these products are related, or whether the industries simply developed together in that country by chance. This extreme case is highly unlikely to occur in these data.

Hidalgo et al. (2007) identify which products a country exports competitively by calculating the revealed comparative advantage (RCA) measure according to the definition in Balassa (1965). As defined above, a country, c, has revealed comparative advantage in a product, p, if product p makes up a greater fraction of country c's trade than it does of world trade. More formally, this can be defined mathematically as the result of the following expression being greater than unity:

$$RCA_{c,p} = \frac{X_{c,p}}{\sum_c X_{c,p}} \Bigg/ \frac{\sum_p X_{c,p}}{\sum_{c,p} X_{c,p}} \tag{12}$$

Using this definition of RCA accounts for heterogeneity in the size of countries' exporting presence as well as the size of the market for different goods in the global market, and, as a result, makes countries comparable for analysis (Hausmann et al. 2014).

By extending this logic to two products, i and j where a country exhibits RCA≥1 for both, one could conclude that the country must have the requisite capabilities to produce both product i and product j. If, however, many countries that produce product j also possess the capabilities to produce product i, then it is likely that these products use many of the same capabilities and are thus proximate or related to one another. Conversely, if few countries that produce product j also possess the capabilities to produce product i, then it is unlikely that the capabilities are similar, and a more likely explanation is simply that the country under analysis has developed the industries for these two products separately.

As a result, the proximity between two products i and j can be defined as

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

where $\mathrm{P}(RCA_i \geq 1 | RCA_j \geq 1\,)$ is the probability that a country exports product i competitively (i.e. with RCA≥1), conditional on the fact that it already exports product j competitively and vice versa for $\mathrm{P}(RCA_j \geq 1 | RCA_i \geq 1\,)$. Given that the proximity measure is conceptually related to distance, and that a distance function defined on any metric space must be symmetric[25] (Khamsi & Kirk, 2001), the minimum of these two conditional probabilities is used in order to satisfy this property.

All pairwise proximity values can then be arranged in a symmetric proximity matrix, Φ, which will be used in the construction of the product space visualisation.

The product space as originally developed by Hidalgo et al. (2007) is a visualisation of the interconnected nature of products with nodes representing products, and edges, or links between nodes, connecting related products. Highly connected nodes are generally pushed towards the core of the product space, while unconnected nodes fall towards the periphery. The proximity between two products dictates the

25 This is the notion that a valid distance function, d, defined between the points x and y should satisfy the property that $d(x,y) = d(y,x)$.

length of the edge connecting two nodes.[26] Shorter edges indicate that a movement between nodes is easier to accomplish due to the products requiring similar productive capabilities. Furthermore, products that are more complex are typically clustered towards the core of the product space, while less complex products lie around the periphery of the product space. Supplementary material to Hidalgo et al. (2007), as well as the work done by Hausmann et al. (2014), detail the methods by which the network of products is adjusted in order to provide an economically meaningful visualisation.

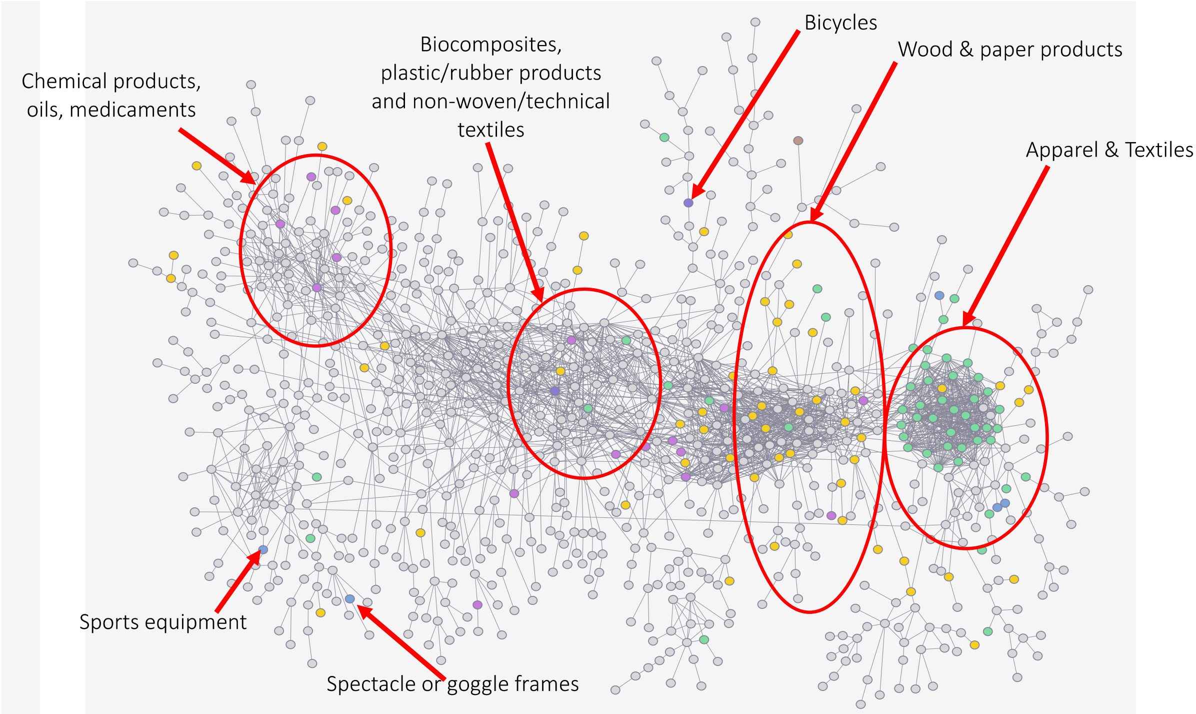
After building the product space visualisation, it is possible to identify where fibrous products lie in relation to all other products by highlighting them in the product space. This visualisation is represented in Figure 15, below. In Figure 15, the *product space* structure as presented by Hausmann et al. (2014) is used as the basis for the visualisation, and nodes representing fibrous products are highlighted in colours signifying their relevant community. Some of the main communities of related fibrous products have been indicated on the diagram for clarity.

A number of points emerge from the *product space* visualisation: first, one observes a disconnected cluster of fibrous apparel and textile products to the right of the *product space* (light green nodes). These products are characterised by relatively low levels of economic complexity and are relatively distant from the connected core of the *product space*. As such, subsequent diversification from these products is limited. Second, to the left of the *product space*, there are a number of fibrous chemical products (e.g. bioethanol, cellulose) that are located within the relatively complex chemicals cluster (light purple nodes). Chemical products are clustered and connected since the capabilities needed to manufacture various types of chemicals overlap substantially, thus increasing the probability of diversification within the cluster. Third, there are a number of wood and paper products (yellow nodes) that are either positioned in the periphery of the *product space* (e.g. plywood; twine and ropes) or in the core (e.g. fibreboard; particle board; wood carpentry). Those products positioned within the connected core are more complex and offer greater opportunities for diversification. Finally, there are several complex products located in the very core of the product space (motor vehicle parts, nonwoven textiles; technical use textiles; mineral wools and insulating materials). Diversification toward these high connected products is desirable since they are connected and close to a number of other products, which allows for subsequent diversification and building of complexity.

---

26 The use of a force-spring algorithm in the construction of the product space means that nodes try to repel one another, while edges try to pull nodes back together. The force with which nodes are pulled back together is positively related to the proximity between the two products, and as such, higher proximity would result in a greater force pulling nodes together, and thus, a shorter edge.

Figure 15: Locating fibrous products in the product space



Source: CID (2019)
Note: Product groupings or clusters are represented by the following colours: Textiles & Furniture (light green); Vegetables, Foodstuffs & Wood (yellow); Stone & Glass (light brown); Minerals (dark brown); Metals (red); Chemicals & Plastics (light purple); Transport Vehicles (dark purple); Machinery (blue); Electronics (turquoise); and Other (dark blue)

5.2 Building a Fibrous Product Space

Although it is possible to identify the fibrous products in the context of the larger *product space*, it would be informative to have a visualisation of how the different fibrous products relate to one another. As a result, in this section of the paper, we build a *product space* visualisation for fibrous products. To our knowledge, the first of its kind, and thus an empirical contribution. This follows the method outlined by Hidalgo et al. (2007) and Hausmann et al. (2014) for creating the *product space* for all products, as well as drawing on the work of Mealy and Teytelboym (2018), which developed the *product space* for the subset of green and renewable products. A technical discussion of the method used to create the *fibrous product space* is included in Box 3, below.

Box 3: Building the Fibrous Product Space

Drawing on the discussions in Hidalgo et al. (2007) and Hausmann et al. (2014), one can rework the visualisation of the overall *product space* to apply to any subset of products defined in the trade data. Using the 1992 revision of the 4-digit HS classification of products, we restricted the products to only those that could be produced using hemp, kenaf, bamboo, or a combination of the three, and calculated the proximities between products according to the method outlined in Box 2.

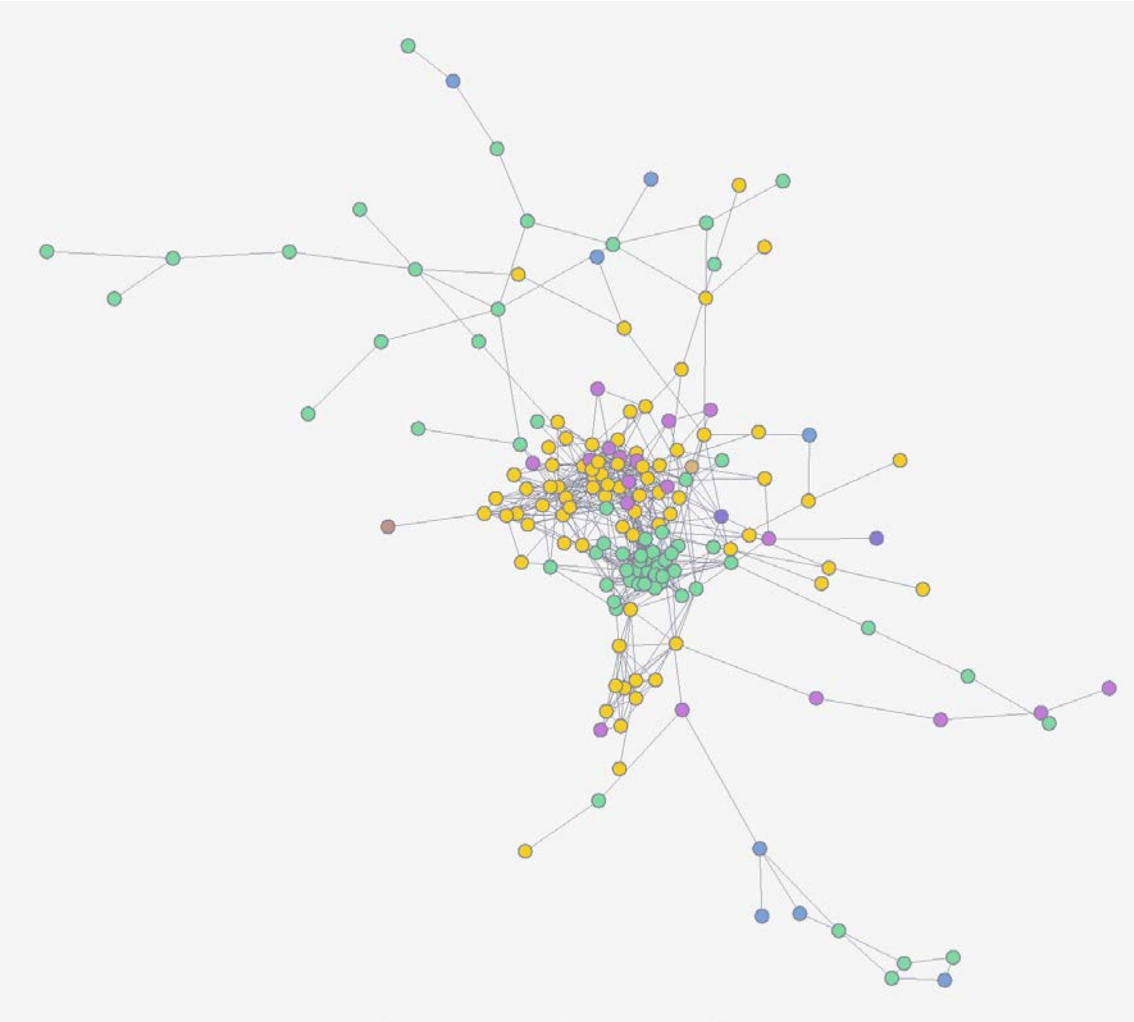
The network visualisation should ascribe to two conditions, as described by Hausmann et al. (2014): firstly, there should be no isolated products in the network. In other words, every product must be connected to the grand network in some way, even if tangentially. Secondly, the visualisation needs to be relatively sparse so as to be sensible to look at. This requires the enforcement of a rule of thumb, which speaks to the average number of edges between nodes being no greater than 5.

In order to satisfy the first condition, network analytics were applied, and the Maximal Spanning Tree (MST) of the fibrous product proximity matrix was calculated using Kruskal's algorithm. The MST is the set of weighted links that connects all nodes using the minimal number of edges with the maximal weight (Welsh, 1968; Hausmann et al., 2014). Put differently, the MST is the network which connects all product nodes using the smallest number of edges, but simultaneously maximising the sum of all proximities. This translates to sorting through proximities in descending order and including links if and only if they connect to an isolated product (Hausmann et al., 2014).

By the nature of the MST algorithm, the resulting network analysis is visually sparse, and as a result, in order to create a dense network, it is important to add back those links with the highest proximities. This provides the product space with its centrally clustered appearance, whereby highly connected products are represented in the centre of the network and sparsely connected products lie on the periphery of the network. Practically, this involves choosing a proximity threshold, α, such that if $\phi_{i,j} > \alpha$, the link is added back to the network visualisation. This threshold is chosen to balance visual density with ease of comprehension of the network. In the case of the *fibrous product space*, a value of α=0.4 was chosen.

Hereafter, the resulting network is laid out according to a Directed Force-Spring layout, following the method outlined in Hausmann et al. (2014). The result is the *fibrous product space* as presented in Figure 16, below.

Figure 16: The Fibrous Product Space



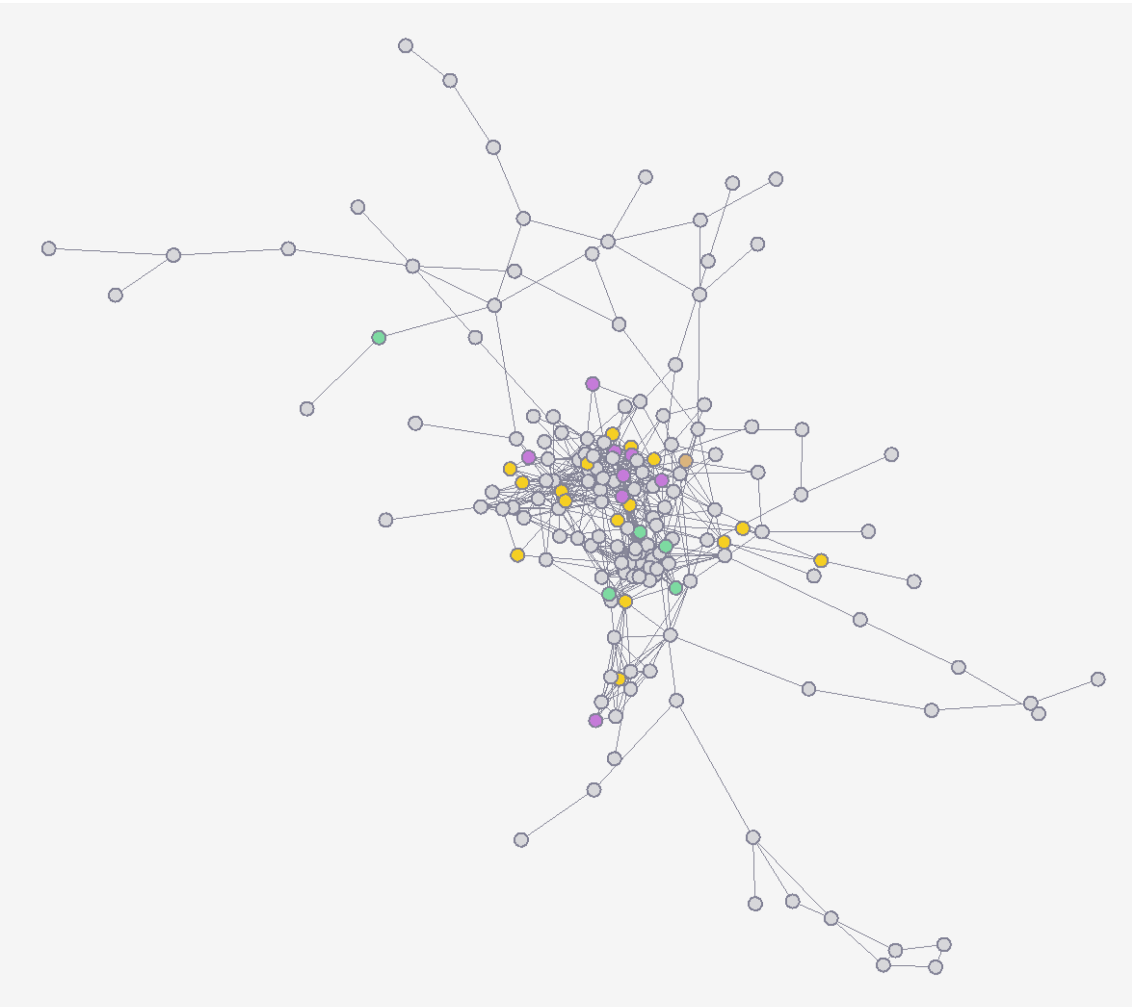
Source: CID (2019)
Note: Product groupings or clusters are represented by the following colours: Textiles & Furniture (light green); Vegetables, Foodstuffs & Wood (yellow); Stone & Glass (light brown); Minerals (dark brown); Chemicals & Plastics (light purple); Transport Vehicles (dark purple); Machinery (blue); and Other (dark blue)

Figure 16 shows the *fibrous product space*, with all nodes coloured to represent their product community. It is clear to see that the most connected part of the fibrous product space is made up, predominantly, of products from the "Textiles and Clothing" and "Vegetables, Foodstuffs and Wood" communities, with some products from the "Chemicals and Plastics" community also featuring. By and large, these groupings correspond to the communities which make up the two peaks in the distribution of fibrous product PCI values, which was discussed in relation to Figure 12.[27]

27 In examining the products in the "Wood & wood products" community, there are a large number of products related to paper and pulp, including products such as newspaper, maps, letterstock and tissue paper. It is unsurprising, then, that these products are highly connected, as they require many of the same capabilities. Similarly, in the "Textiles" community, many products are related to spun or woven textiles, which explains their highly connected nature.

Shifting focus to South Africa, we present the South African *fibrous product space* in Figure 17. Here, only those products which South Africa currently exports with RCA≥1 are represented by coloured nodes.[28] All other nodes remain greyed out. What is immediately obvious from this diagram is that South Africa does not occupy a large proportion of nodes in the *fibrous product space*. This is consistent with the finding from Section 4.4 that South Africa is relatively under-developed in the fibrous economy space, and hence finds itself with a 'fibrous complexity gap'.

Figure 17: Fibrous Product Space, South Africa, 2016



Source: CID (2019)
Note: Product groupings or clusters are represented by the following colours: Textiles & Furniture (light green); Vegetables, Foodstuffs & Wood (yellow); Stone & Glass (light brown); Chemicals & Plastics (light purple)

28 See Table A. 2 for a list of these products.

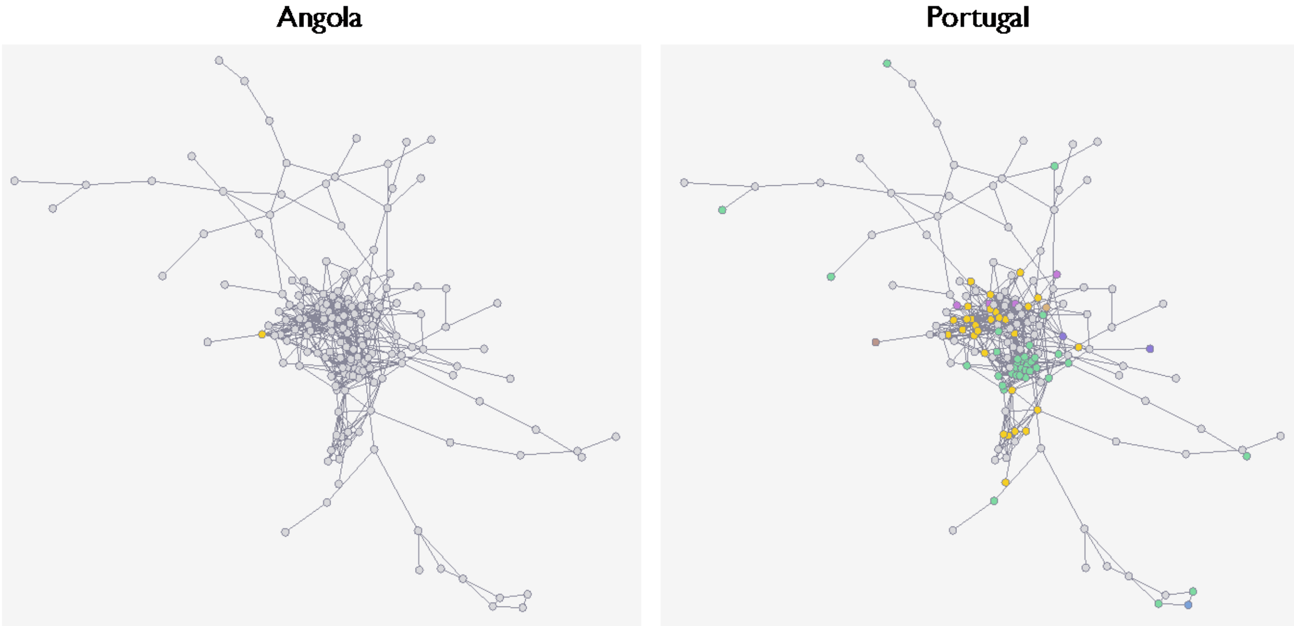
However, the positioning of these occupied nodes in the connected core of the *fibrous product space* suggests that diversification into other fibrous products is indeed feasible.[29] Products such as seed oils and margarines; polishes, soaps and creams; tall oil; and chemical dissolving wood pulp are the products that are highlighted in the core of the *fibrous product space*, while products such as charcoal; clothing accessories; and essential oils are represented by those occupied nodes more on the periphery of the *fibrous product space*.

As a point of comparison for the South African case, the *fibrous product spaces* for the most and least fibrously complex countries are presented in Figure 18. These countries are Angola and Portugal, respectively. As in Figure 17, the products which are exported with RCA≥1 are highlighted for each country. It is immediately clear from the left-hand panel of Figure 18 that Angola, as the least fibrously complex country, hardly occupies the *fibrous product space* at all – in fact, they only have one product which is exported with RCA≥1 in the *fibrous product space* in 2016, and this product is "Wood in the rough". There is thus little opportunity for future diversification. In stark contrast to this, Portugal is shown to occupy a much larger proportion of the *fibrous product space*, with a total of 89 fibrous products exported competitively.

Another key insight gained from Figure 18 is that the fibrous products in which Portugal has relative comparative advantage are generally clustered in the core of the *fibrous product space*. This is directly comparable to the result found by Hausmann et al. (2014), which says that economies that are more complex tend to occupy the core of the *product space* more fully. This is indicative of these countries being in possession of more productive capabilities since they are easily able to diversify into new, nearby products. Analogously, by comparing Portugal, South Africa, and Angola, we see that as countries become more fibrously complex, they begin to increasingly occupy the core of the *fibrous product space*.

29 It should be noted that although South Africa occupies these nodes in the fibrous product space, it is not to say that we produce these products with hemp, kenaf or bamboo, as it is impossible to discern this from the trade data.

Figure 18: Fibrous Product Spaces for Angola and Portugal, 2016



Source: CID (2019)
Note: Product groupings or clusters are represented by the following colours: Textiles & Furniture (light green); Vegetables, Foodstuffs & Wood (yellow); Stone & Glass (light brown); Minerals (dark brown); Chemicals & Plastics (light purple); Transport Vehicles (dark purple); Machinery (blue); and Other (dark blue)

As discussed above, South Africa finds itself with a 'fibrous complexity gap', which indicates that it may have missed opportunities to diversify into fibrous plant products in the past. However, the fact that South Africa produces a substantial number of fibrous products located in the core of the *fibrous product space* – i.e. it is well positioned within the fibrous product space – suggests that it has sufficient capabilities to allow it to diversify into other proximate fibrous products that require similar capabilities. As such, there are a number of potentially feasible fibrous diversification opportunities that would allow South Africa to grow the complexity of its fibrous economy, and in turn build economic complexity. In the next section, applying a data-centric approach, we identify these fibrous diversification opportunities at the product-level.

6 Economic Opportunities in the Fibrous Plant Economy

This section identifies fibrous diversification opportunities that would allow for the building of economic complexity and associated economic growth and development. The fibrous product space indicates that South Africa is well positioned to diversify into other fibrous products. This section, following Hausmann and Chauvin (2015) and Bhorat et al. (2019a), uses the network analytics behind the *fibrous product space* network visualisation to identify these diversification opportunities or 'fibrous frontier products'.

6.1 Identifying Fibrous Frontier Products

Hausmann and Chauvin (2015) and Bhorat et al. (2019a) use the economic complexity framework to identify frontier products in the cases of Rwanda and South Africa, respectively. These products would both increase the average complexity of the economy and be related to current production in such a way that diversification is practically feasible. By using this guide to identify these so-called 'frontier products', one obtains a list of criteria that these 'frontier products' must fulfil: firstly, frontier products should be more complex than the current export basket in order to ensure increased complexity when diversifying into them. Secondly, they must be feasible given the country's current productive knowledge. This implies that the products must be close enough to the current export basket to make the diversification feasible. Finally, the product should open up opportunities for future diversification, implying, in essence, that diversification should occur towards the core of the product space rather than away from it.

In this paper, we follow the methods adopted by both Hausmann and Chauvin (2015) and Bhorat et al. (2019a). This method can be effectively simplified as follows:

1. The set of products under investigation is restricted to only those which are not currently exported with RCA≥1. This ensures that frontier products do actually result in diversification of the export basket.

2. These non-RCA products are then ranked by ascending order of the distance index. Products further than the median product distance are disregarded.[30] This measure of distance is an aggregate measure of how far removed a product is from a country's current export basket. A technical discussion surrounding the calculation of the distance index is presented in Box 4, below.

3. Only those products which would increase complexity are considered. In other words, only those products whose PCI value is strictly higher than the country's ECI are considered as candidate frontier products.

4. Only products with a positive opportunity gain index are considered. The opportunity gain index of product p is measured as how much diversifying into product p would benefit the economy through the provision of capabilities proximate to more complex products. Put differently, the

30 This measure of distance need not be the median – in fact, one could use any cut-off value for distance, however, the median is proposed by Hausmann and Chauvin (2015) and has been adopted by Bhorat et al. (2019a) as a result.

opportunity gain index speaks to what degree a new, non-RCA product connects one to opportunities to develop more complex products.

Box 4: Density and Distance

As identified in Step 2 of the methodological process outlined above, it is important to be able to rank how far a particular non-RCA product lies from a country's current export basket. Following the method of Hausmann and Klinger (2007), it is possible to create a measure for density of a product, the inverse of which is defined as distance.

The density of a product is essentially how densely the exports of country $\mathbf{c}$ are located 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:

$$\delta_{j,c} = \left(\frac{\sum_p (1 - M_{c,p}) \phi_{p,j}}{\sum_p \phi_{p,j}} \right) \tag{13}$$

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

In order to obtain a measure for distance, then, one needs to simply invert the measure for density obtained as per equation (13). Two main methods exist for inverting $\delta_{j,c,t}$ and these include finding the multiplicative inverse or finding the additive inverse (Bustos & Yildirim, 2016). For the purposes of this paper, distance was calculated using the additive inverse of density[31] as follows:

$$\Delta_{j,c} = 1 - \delta_{j,c} \tag{14}$$

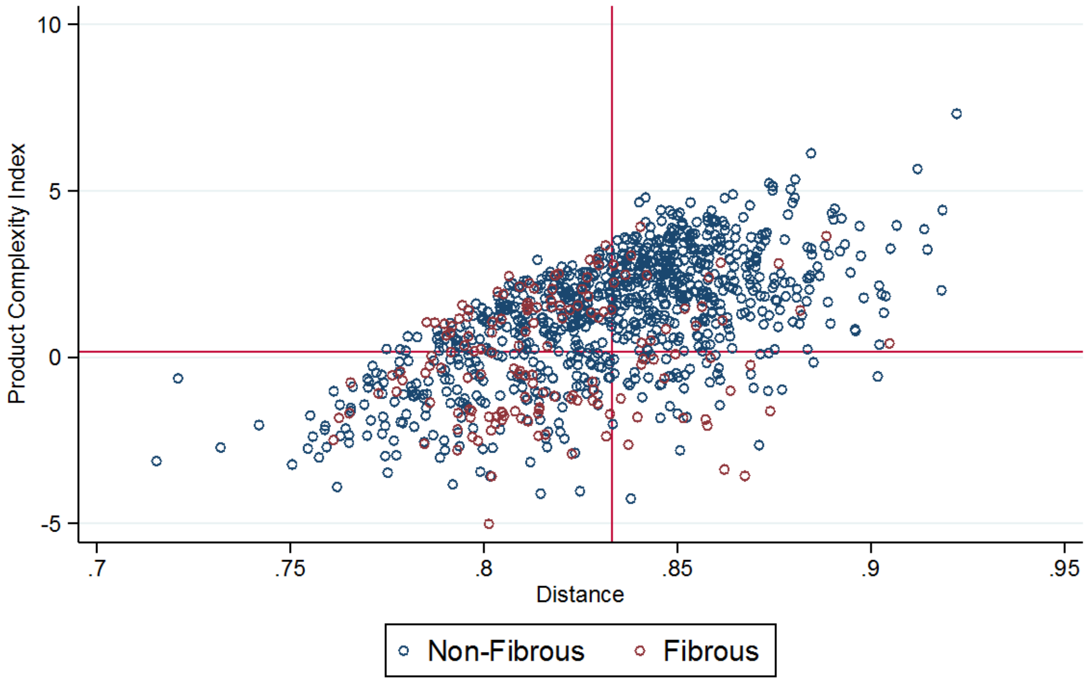
Based off the five-point method outlined above, it is clear that distance and PCI play a key role in determining whether a product would be considered a frontier product or not. Bhorat et al. (2019a) plot all non-RCA products according to their PCI and their distance index and identify candidate frontier products according to this method. Since Bhorat et al. (2019a) were not focused on the fibrous plant industry specifically, we recreate their plot below as Figure 19, but we differentiate between fibrous and non-fibrous products.

By applying the criteria that frontier products must be more complex than the current export basket, and that they must be proximate enough to current capabilities for diversification to be feasible, one can graphically locate the frontier products in the lop-left quadrant of Figure 19. By restricting analysis

31 The additive inverse of density was chosen as it has the desirable mathematical property of being bounded between 0 and 1. The multiplicative inverse of density is unbounded above, and as such is not used in this paper.

to only those products that would increase economic complexity, and by understanding that the ECI is simply the average PCI of those products exported with RCA≥1, it is clear that the only products under consideration should be those above the level of South Africa's current ECI (which is represented by the horizontal line in Figure 19). Furthermore, if frontier products need to be proximate to current capabilities, we need to choose those products that are close to South Africa's current export basket. Put differently, we need products with low distance indices. By picking the median distance of 0.83 as the cut-off, we can identify candidate frontier products as those to the left of this cut-off in the diagram. As a result, those products in the top-left quadrant of Figure 19 are identified as frontier products.

Figure 19: South Africa's non-RCA products in the PCI-Distance Space, 2016



Source: CID (2019)
Note: Distance calculated as $\Delta_{j,c} = 1 - \delta_{j,c}$; horizontal line is South Africa's ECI (0.16); vertical line is South Africa's median distance in 2016 (0.83)

Now that we have identified a set of frontier products, we focus the remainder of the analysis on the fibrous subset – or fibrous frontier products.[32] There are two key motivations for focusing on the fibrous subset: first, as discussed in the introductory remarks to this paper, approximately 6000 mines have been abandoned over the past twenty years and a large number are expected to be closed in the coming decade. As such, there is a very real notion that South Africa's economic development path will be

32 It must be noted that we identify fibrous frontier products from frontier products that emerge from the full set of traded products (fibrous plus non-fibrous). We term these 'fibrous frontier products'. One can also identify frontier products for the full set of fibrous products, what we term frontier fibrous products. We focus on the former and provide a clarification in Appendix II.

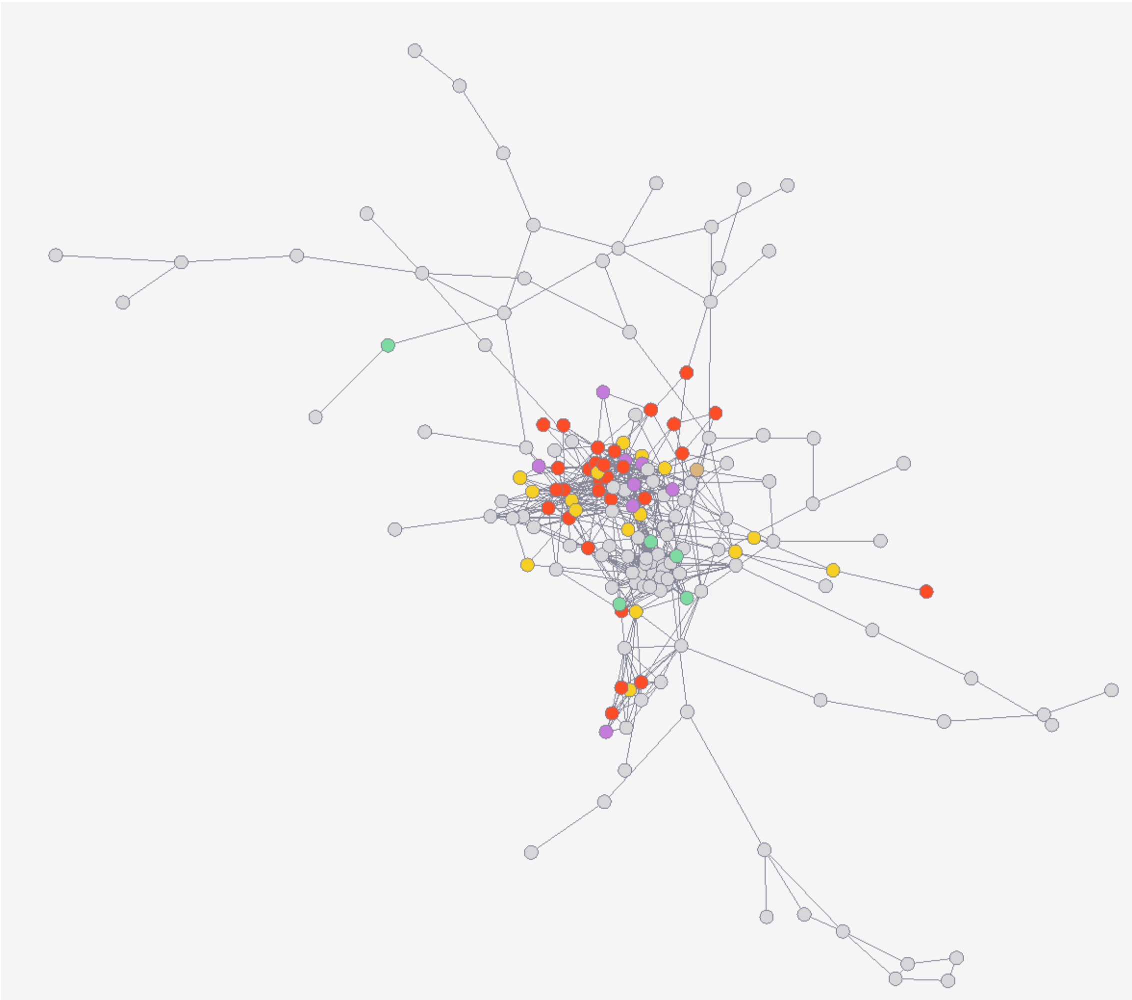
curtailed when these mineral resources are depleted. Therefore, as a resource-rich economy, there is an economic imperative to diversify the economies of these mining localities, and thereby set South Africa on a more sustainable and inclusive growth path. The development of a fibrous plant economy, and hence diversification into fibrous frontier products, offers a key avenue for the realisation of this growth path. Further, the cultivation of fibrous plants on degraded mining land plays an important role in cleaning this land and increasing its economic value. Second, while we acknowledge that there are many other (perhaps more important) frontier products, which could be greener and more employment-intensive, we continue to note that in the mining landscape, the frontier products which must dominate should be those derived from fibrous plants.

As a result, we focus our attention on the fibrous frontier products – a subset of all of South Africa's frontier products that can be produced using fibrous plants. The following section provides a brief overview of these fibrous frontier products in an attempt to provide clarity on the diversification path that South Africa could follow in developing downstream industries out of hemp, kenaf or bamboo.

6.2 A Profile of Fibrous Frontier Products

After applying the method outlined in the previous section, we obtain a list of 50 fibrous frontier products. A full list of these products is provided in Table A. 3, in the appendix. Representing these products in the *fibrous product space* provides insight into how diversifying into these new products could affect the South African fibrous plant economy. This graphical representation of South Africa's fibrous frontier products is given in Figure 20, below. Nodes coloured in red represent the fibrous frontier products for South Africa.

Figure 20: South Africa's Fibrous Frontier Products, 2016



Source: CID (2019)
Note: Fibrous frontier products are represented in red. Product groupings or clusters are represented by the following colours: Textiles & Furniture (light green); Vegetables, Foodstuffs & Wood (yellow); Stone & Glass (light brown); Minerals (dark brown); Chemicals & Plastics (light purple); Transport Vehicles (dark purple); Machinery (blue); and Other (dark blue)

Examining Figure 20, it is clear that the fibrous frontier products are moving South Africa more into the core of the *fibrous product space*. This result seems to suggest that diversification into these fibrous frontier products will not only potentially grow the economic complexity of South Africa's broader economy, but will also grow South Africa's fibrous complexity. This is a positive result as it implies that there is a level of symbiosis between developing overall economic complexity and developing fibrous complexity.

Table 7, below, groups the set of fibrous frontier products and reports their mean and median PCI values. It is immediately clear that the most complex fibrous frontier product available to South Africa is in the transportation product community. This product is motor vehicle parts and would comprise of non-loadbearing biocomposite panels for transport vehicles. Relatedly, Bhorat et al. (2019a) found that motor vehicle parts is one of the top 20 frontier products for South Africa. Thus, this is a strong potential avenue for diversification.

By far the largest community of fibrous frontier products is that of wood and wood products. The majority of these products are related to various grades of paper and pulp, although they do include certain other products such as wooden tools or fibreboards. The chemical and allied industries community is mostly comprised of beauty products, although it does also include ethers and varnishes as potential fibrous products to diversify into. The textiles and clothing community includes the high-complexity subset of textiles, which is made up of nonwoven textiles, felt, technical-use textiles and wadding.

Table 7: Mean and Median PCI of Fibrous Frontier Products by Community

Product Community	Number of Products	PCI	
		Mean	Median
Vegetable products	2	0.541	0.541
Foodstuffs	4	0.843	0.891
Miscellaneous	2	1.097	1.097
Wood & wood products	29	1.561	1.547
Chemicals & allied industries	8	1.731	1.729
Textiles and clothing	4	2.112	2.161
Transportation	1	2.925	2.925
Total	50	1.544	1.556

Source: Authors' calculations from CID (2019)

As identified in Section 4.3, there are two potential diversification paths available to countries aiming to grow complexity through fibrous products: a high-complexity path and a low-complexity path. It is clear that the fibrous frontier products identified in Table 7 have PCI values that are in line with the high-complexity path rather than the low-complexity path. The low-complexity diversification route is mostly infeasible in the South African case as it would require diversification into products that would, in general, decrease overall economic complexity. The pursuit of the high-complexity development path will serve a dual purpose in South Africa of closing the fibrous complexity gap present in the economy, as well as building economic complexity overall.

The difficulty, however, is that the analysis up to now has been driven exclusively by trade data. As has been discussed previously, this method is flawed in that it does not pick up what proportion of the product identified by the HS4 code is produced using fibrous plants and, as a result, it is not clear that the findings of the paper thus far are directly applicable to the development of the fibrous plant economy. Furthermore, given that this methodology aims to inform micro-industrial policy through encouraging firms to diversify, it is imperative that the suggestions put forward are in the interests of firms. For example, although biocomposite door panels are identified as a fibrous frontier product with great theoretical potential, it is not immediately clear that the most cost-effective and profitable method of producing this product is by making use of natural fibres and not synthetic fibres. This information cannot be gleaned from the trade data as it stands and, as a result, further information needs to be gathered to inform policy decisions and to further narrow down the ideal diversification path for the South African economy. Accordingly, the following section aims, through the use of firm surveys, to refine the findings of this section by interrogating the practicality of expanding into the production of fibrous frontier products using fibrous plants as an input.

7 UNDERSTANDING THE POTENTIAL FOR A FIBROUS PLANT ECONOMY

7.1 Research Approach

The method used to sample firms in this research project is based primarily on the process undertaken by Bhorat et al. (2019a). This method included a stratified sampling design, whereby a number of predetermined product communities were identified, and a sample was chosen within each of these product communities. The communities in question for this paper were those into which fibrous frontier products fall.

Stratification was carried out at three levels: firstly, industry experts for each of the identified product communities were identified. Secondly, where possible, firms using each of the fibrous plants as an input to their production process were selected, whether or not they were currently producing products within the fibrous frontier product groupings. Finally, firms identified as key players in the market for each of the identified fibrous frontier product communities were identified and interviewed.

In total, 25 semi-structured firm and industry expert interviews were conducted. Table 8 shows the product communities of interest and a summary of the fibrous frontier products that fall within these communities.[33] The interviews focused on the following product communities: wood, paper and pulp products, chemicals and allied industries, textiles and clothing, and transportation.[34] The number of interviews detailed in the table do not aggregate to 25 because interviews with certain respondents covered multiple product communities and fibrous frontier products.

---

33 A more detailed list can be found in Appendix III.

34 The vegetable product and foodstuffs product communities were dropped from the analysis because it became clear in the interviews that should fibrous plants be cultivated on degraded and polluted mining land, food products would not be safe for consumption. This is due to the plants absorbing heavy metals through the process of phyto-remediation. Similarly, in the case of certain chemical products used for consumption (e.g. medicaments, hair products, make-up preparations).

The survey instrument used to conduct the interviews was a mixture of short-answer and open-ended questions. The survey instrument was designed to determine, among other things: the potential for fibrous plant material to act as a feedstock to the processing and production of fibrous frontier products, the factors that may constrain the use of fibrous plant material as a feedstock, general factors that constrain or enable the development of these products, and the employment potential of these products.

Table 8: Survey Interviews by Fibrous Frontier Product Community

Product Community	Frontier Products	No. Interviews
Wood, paper and pulp products	Wood products: Fibreboard; Particle board; Wood carpentry (flooring) Paper products: Uncoated composite paper; packing boxes; other uncoated paper and paperboard; bobbins, spools, cops of paper; corrugated paper and paperboard Pulp products: Chemical woodpulp; semi-chemical woodpulp; cellulose wadding; mechanical woodpulp	8 firms 2 industry experts
Chemical and allied industries	Ethers (bioethanol)	4 firms 2 industry experts
Textiles and clothing	Nonwoven textiles; technical-use textiles	4 firms 2 industry experts
Transportation	Parts of motor vehicles	4 firms 2 industry experts

Although every attempt was made to ensure that the sample of firms provided generalisable results, this was impossible to guarantee. The small sample size precludes the sample from being representative of the industry as a whole. Further, the selection of certain firms based on referral introduces an element of selection bias to the sample. A number of steps were undertaken to address this bias (these are detailed in Appendix III). Despite the steps taken to mitigate this bias, the bias is not wholly eradicated. However, even with a biased sample, the results obtained are valuable in that they provide insight into the workings of various industries in the South African context. This insight, coupled with desktop research, can provide a strong foundation from which micro-industrial policy can be developed.

Following the discussion of the sampling design, the following subsections turn to the results obtained from the interviews. To begin, a synthesis of the factors that may impact the continuity of supply of fibrous feedstocks to downstream applications is presented. Thereafter, the product community specific findings are presented.

7.2 Fibrous Plants as a Feedstock into Downstream Manufacturing Applications

A key factor that would enable the successful diversification into the fibrous frontier products, identified in Section 6, is continuity in the supply of fibrous feedstocks such as bamboo, kenaf and hemp. This section alludes to the factors that may affect the supply of these feedstocks to downstream applications. These factors are summarised in Table 9.

There are plant-specific factors that impact on where the respective fibrous plants can be grown in South Africa. These factors include: preferred soil type, preferred annual rainfall, temperature tolerance and pH tolerance.[35]

Another factor to consider is the type of land targeted for the cultivation. Two major concerns emerge in relation to land: first, as noted by Scheba, Blanchard & Mayeki (2017), the cultivation of fibrous industrial crops should not compete with food production. The best soil should be prioritised for food production. This motivates for the cultivation of industrial crops, such as bamboo, hemp and kenaf, on degraded mining land. However, the degraded nature of the land may adversely impact on crop yields. Second, the topographical features of the land are also important to consider, since the use of harvesting machinery requires reasonably flat land.

It has been mentioned by industry experts that the attainment of water permits is a key constraint. For example, it was noted by a respondent in the forestry industry that water permits are required for agricultural activity that feeds into industrial use, and that the Department of Agriculture, Forestry and Fishing (DAFF) is no longer issuing water permits in the locality specific to their industry. It was noted that water permits are still being issued for food-related agricultural activity. It is worth noting that in the case of mining land, water infrastructure is often in place, which motivates for the cultivation of these plants on abandoned mining land.

A related issue is the need for research and development into the cultivation and processing of fibrous plants. A number of industry experts have noted the lack of knowledge regarding various aspects related to the cultivation of these fibrous crops. For example, is was noted that there is insufficient expertise and knowledge on the water usage of various bamboo species. This dearth of information on water usage in turn adversely affects the DAFFs ability to issue water permits for cultivation. As mentioned earlier, one of the factors linked to the failure of the Winterton kenaf project was the low-quality fibres obtained from the crop. Respondents noted that farmers did not have the requisite productive capabilities or knowhow to grow kenaf for industrial fibre purposes. This lack of knowhow with respect

35 These factors are detailed in Harrison, Rumjeet, Mabase & Verster (2019).

to cultivation according to downstream application and associated processing necessitates the need for targeted research and development.

Table 9: Factors Constraining Fibrous Plant Cultivation in South Africa

Constraint	Bamboo	Kenaf	Hemp
Regulatory			Illegal to cultivate hemp for commercial purposes.
Environmental	Environmental factors, including preferred soil type, preferred annual rainfall, temperature tolerance, and pH tolerance.		
Land type	Land use for cultivation of industrial crops should not compete with land use for food. Use of degraded mine land may impact on crop yields.		
Access to water	DAFF is not issuing water permits for industrial crop cultivation.		
R&D	Lack of productive capabilities or knowhow in fibrous plant cultivation necessitates further R&D into cultivation methods and practices.		
Scale and logistics	Scale of cultivation constrains the potential downstream applications of fibrous plants.		

Two further issues to consider with respect to the continuity of supply of these fibrous feedstocks relate to the scale of production required by the downstream application and thus the ability to store the feedstock. Certain downstream applications require substantial volumes of fibrous material. For example, supplying natural fibres for the manufacture of biocomposites used in motor vehicle parts, such as interior trims, requires sufficient fibre to consistently manufacture enough parts to feed into the on-going vehicle assembly process at the OEM. However, with fibrous plants, you typically only get one crop per annum. This means that, provided one can get enough land to cultivate the requisite volume of natural fibre needed for sustained production, one needs to be able to store all this fibre. Further, in order to use the fibre, one needs to keep it dry, which presents a significant fire hazard.

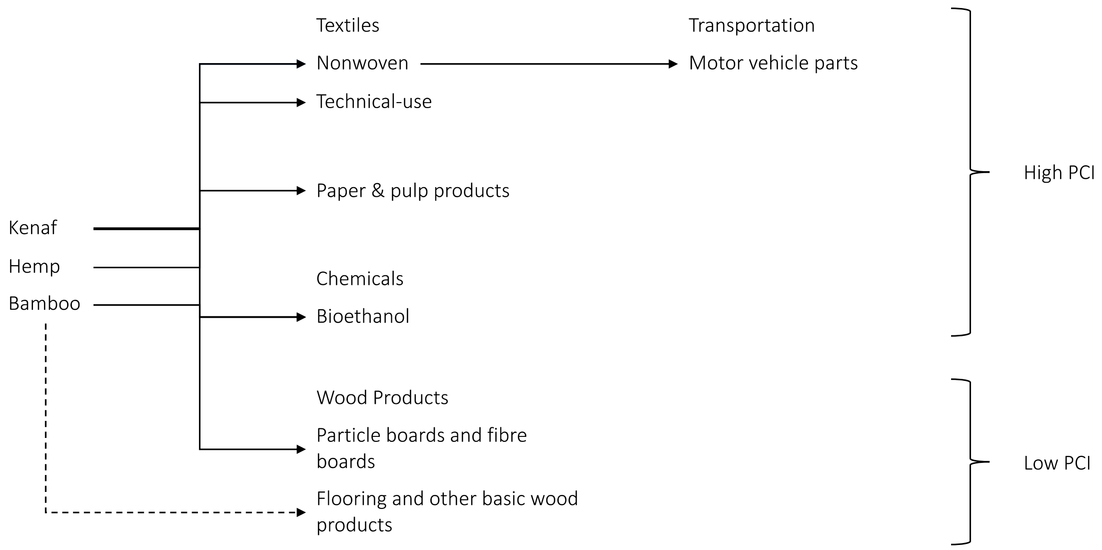
A factor specific to hemp is current legislation, which prevents commercial production of hemp due to its relation to the *marijuana* species of *cannabis* (Mostert, Paterson, Young & van Schalkwyk, 2019). Permits, issued by the Department of Health, are accessible but for research purposes only and not industrial use. The decriminalisation of private and personal use of the marijuana variant of cannabis in September 2018 can be seen as a major step toward the easing of restrictions on the cultivation of hemp in South Africa (*Minister of Justice and Constitutional Development and Others v Prince*, 2018).

To develop downstream applications (fibrous frontier products) in the fibrous plant industry, there needs to be a reliable supply of fibrous feedstock. As it currently stands, only 750ha of land is allocated to bamboo cultivation, 1000 ha to hemp cultivation, and an indeterminable but small amount of land allocated to kenaf (Kayembe, 2015; Scheba, Blanchard and Mayeki, 2017). This is a small fraction of the 78 million hectares currently used as farming land (Bureau for Food and Agriculture Policy, 2018). Downstream industries cannot develop without a reliable supply of feedstock, and the prospect for a substantial increase in land allocated to bamboo, hemp, and kenaf seems remote in the short term. However, in the medium term, we could reasonably expect land allocated to hemp to increase exponentially given the legal trends in South Africa and globally. The potential expansion of bamboo and kenaf appear to be more uncertain, with no major policies planned which could potentially give these industries the boost that they need.

7.3 Fibrous Downstream Manufacturing Applications

In this section we report the analytical outcomes of the firm and industry expert surveys. The structure of the discussion to follow is depicted in Figure 21, which provides a graphical depiction of the flow from fibrous plant to fibrous frontier product. A number of points are worth mentioning. First, the fibrous frontier products are grouped within their product communities: textiles, transportation, paper and pulp products, chemicals, and wood products. Second, the diagram depicts the flow of production from nonwoven textiles to vehicle parts, since nonwoven textiles are used as an input into the manufacture of certain motor vehicle components. Third, except in the case of flooring and basic wood products, the three fibrous plants can be used to manufacture all of the fibrous frontier products. Flooring and basic wood products are manufactured using bamboo (this is depicted by the dashed line). Fourth, there is a clear delineation between high and low complexity fibrous frontier products, with textiles, motor vehicle parts, bioethanol and paper and pulp products falling within the former, and wood products falling within the latter.

Figure 21: Feedstock to Product



7.3.1 Nonwoven and Technical-use Textiles

In Section 6, four downstream applications for the use of fibrous plants as inputs in the "Textiles/clothing" community of products were identified. These four product classifications are technical-use textiles; nonwoven textiles; felt; and wadding. These products can all be broadly grouped together under the heading of nonwoven textiles, as they are produced without the use of looms that weave yarns together to form fabric. Nonwoven textiles fall into three distinct categories: dry-laid nonwoven textiles, wet-laid nonwoven textiles and spun-melt nonwoven textiles, depending on their method of production (Textile Innovation Knowledge Platform [TIKP], 2019).

According to Lee and Cassill (2006), South Africa has a relatively well-developed nonwoven textile industry. However, as part of the clothing, textiles, leather and footwear (CTLF) sector, it contributed less than 1% to overall South African GDP in 2014 (FP&M SETA, 2014b). Even though the industry is small, it does provide opportunity for downstream linkages into other, larger industries: nonwoven textiles are a highly versatile set of products and can be used as an input into a number of other industries, including, but not limited to, motor vehicle components, insulation for buildings, furniture, and mattresses. In fact, by diversifying into the production of nonwoven textiles, it is possible to not only build complexity through the nonwoven industry, but also to feed into industries that lie further downstream and produce other products that will further increase complexity in the future. Since South Africa faces a fibrous complexity gap, nonwoven textiles are an ideal product to investigate for building complexity at the present time. This is due, particularly, to nonwoven textiles' linkages to other fibrous frontier products, particularly motor vehicle parts.

<u>Potential to Use Fibrous Plant Materials in the Manufacture of Nonwoven and Technical-Use Textiles</u>

The use of fibrous plants as an input for nonwoven textiles is not without precedent in South Africa: a number of firms have used, or attempted to use, fibrous plants as inputs to nonwoven textiles in the past, with varying degrees of success. Products such as mattresses and upholstery were historically successful at using natural fibres in their construction. However, as noted by one respondent, due to a change in public perception, the production processes for these products have changed to encompass synthetic fibres.[36]

It is also important to note that in certain cases, natural fibres are simply impractical for use in producing a specific product. For example, when producing the lining for a tailing dam, a natural fibre-

36 Respondents noted that mattresses and cushions made out of natural fibres are now considered "dirty" by the public since the fibres are not homogeneous in colour. Further natural fibres absorb liquids more readily, and as a result, are more prone to harbouring odour or rotting due to liquid spills (Fogorasi & Barbu, 2017).

based textile would not be appropriate as it would biodegrade. In this case, the use of synthetic fibres is necessary in the production process, and there is no scope to shift production into using fibrous plants as an input.

Other products, however, are the focus of current research and development programmes by firms. One respondent indicated that their firm was currently in the process of setting up a plant to process jute fibres to produce nonwoven textiles, possibly with a view to supplying the construction industry with insulation materials. In this case, it was noted that the price of the imported raw natural fibres is substantially below that of synthetic fibres, indicating that there is potential for the adoption of natural fibres as an input in this production process. One specific challenge that this respondent noted, however, was that they currently still need to develop a cost-effective flame retardant to coat natural fibres, as untreated natural fibres would be a fire hazard. This is not the case with synthetic fibres, which would not pose a fire hazard if used in construction.

A further challenge faced by firms in adopting natural fibres as an input into the production of nonwoven textiles include the access to quality fibre. Currently, although firms are willing to shift production into natural fibres and potentially into the fibrous plants identified in this paper, the lack of consistent good-quality supply of fibre hampers firms' ability to diversify. The challenges surrounding consistency of supply are discussed in detail in Section 7.2. This inconsistency in supply was mentioned by numerous respondents, and they indicated that this was a key reason for their previous ventures with fibrous plants having failed.

Furthermore, any shift to fibrous plants as an input needs to be market driven. As noted by a responder, the types of products that are produced by the firm are based on whether or not there is an end-market available for the product. Firms would be unwilling to invest in the production of a product where there is no guaranteed end-user available to them. Currently, the public perception of natural fibres as "dirty" prohibits large-scale shifts towards the use of fibrous plants in production. However, one respondent noted that the current drive towards environmental consciousness could help to dislodge the current market perception.

This is not to say that fibrous plants cannot be used in the nonwoven textile industry. A particularly promising diversification opportunity arises through the linkage of nonwoven textiles to the automotive industry. The possibility of an integrated value chain presents itself here, whereby fibrous plants could be used to produce motor vehicle parts for an environmentally friendly – or "green" – car. Respondent firms have indicated that should market demand swing towards the production of these green cars, they would be willing to supply the parts needed to produce the end product. Furthermore, it was indicated that this linkage between nonwoven textiles and the automotive industry has been explored previously, and it is a possible expansion path for the South African economy. South African firms would simply need to hone their existing capabilities to feed into this downstream industry, and this could grow a viable value chain in South Africa.

A further application of fibrous plants in the textile industry is through technical-use textiles for environmental conservation. These products are essentially loosely woven, natural fibre mats that are impregnated with viable plant seeds. The mat is then laid out over an embankment at risk of erosion, and the seeds will sprout, anchoring the soil with their root systems. The mat will subsequently biodegrade, providing nutrients and fibres to the soil, improving its long-term structure (Kaytech, 2015).

Finally, respondent firms in the nonwoven textiles industry noted that the machinery currently used to manufacture synthetic nonwoven textiles could easily be adapted to natural fibres. This was not the case for technical-use textiles, however, where it was indicated that there may be substantial changes in machinery required to process natural fibres as opposed to synthetic fibres. Respondents in the nonwoven textile industry also indicated an enthusiasm for the potential of adopting fibrous plants as an input, and indicated that, provided the final product was comparable to the current product and met all the correct standards, they would be amenable to changing their production processes accordingly.

General Constraints Facing the Industry

The nonwoven and technical-use textiles industry seems to present a promising diversification opportunity for fibrous plant-based inputs. Furthermore, spillovers from this industry could impact on downstream production and, as a result, truly bolster both economic and fibrous complexity in South Africa. Up to now, the constraints and opportunities specific to the adoption of fibrous plants have been discussed. This subsection aims to detail the more general constraints and opportunities faced by the nonwoven and technical-use textiles industry in order to understand what may assist or constrain growth of the industry as a whole.

To begin, respondent firms indicated that the capital outlay required in order to purchase the requisite machinery for their industry is prohibitively expensive. This acts as a barrier to entry for new firms, as well as a barrier to expansion for those firms that currently exist in the market. However, it was indicated that government support was available through the Clothing and Textile Competitiveness Programme (CTCP), administered by the Department of Trade and Industry (DTI). This funding aims to assist firms in the clothing and textile industry to upgrade their equipment, among other things, in order to remain competitive in the global market (DTI, 2019b).

Further issues highlighted by respondent firms include a lack of infrastructure availability and reliability in the South African context. Firms in the technical-use textiles industry indicated that the deterioration of the mining sector and the lack of infrastructure development has hampered sales, as these sectors comprise large portions of their demand. Numerous respondents also indicated inconsistent supply of electricity to be a challenge faced in production. Certain machinery, such as a continuous filament machine, requires a constant electricity supply. Interruptions of the supply may at best decrease productive capacity and at worst, damage the machine. Firms also noted that the lack of reliable electricity supply also impacted on worker morale. When electricity cuts out at the factory, workers cannot continue operations, and as a result will return home. However, if electricity returns later in the day, workers are unwilling to return to the factory, and as such, productive capacity is lost.

A further concern regarding labour was raised by one respondent who indicated that a limited pool of labour available for hire impacted severely on their ability to expand operations. Moreover, even if there were sufficient bodies available, the labour force does not have the requisite skills to operate the machinery in factories. One respondent indicated that although there used to be a specific nonwoven textiles training institute, this has begun the process of shutting down operations. As a result of this skill gap, there are insufficient workers available for the industry. Those workers who are hired generally have to undergo intensive on-the-job training before they are considered appropriately skilled for the industry.

Respondent firms also indicated that transport costs were particularly high for products produced in this industry, as they are bulk-density adverse. In other words, products are not dense, and as a result it becomes difficult to transport them as large quantities of the final product require exceptionally large vessels to transport them, making shipping costs infeasibly high. This is a particular hindrance to exporting products from the nonwoven and technical-use textiles industry. However, respondents noted that even though their products were not directly exported, they saw opportunities for indirect exports through the incorporation of nonwoven textiles into downstream industries, such as motor vehicle parts. This, once again, highlights the importance of integrating the value chain for fibrous products in order to increase South Africa’s competitiveness in the global market.

A final challenge faced by firms was the inefficiency of the South African Bureau of Standards (SABS) in certifying products as fit for sale. The inefficient operation of SABS hampers development of the industry, as firms are unable to get newly developed products certified, and as a result they cannot be sold on the market. One respondent indicated that they had to conduct their own quality assurance in order to test whether they felt a fibrous plant-based construction material met the requisite flame-retardant properties as they could not get certification from official institutions. This poses risks for the future: if firms cannot rely on an official certification, then they either have to abandon developing new products, or they have to undergo a costly process of rigorously assessing their own products.

Employment Potential of the Industry

Employment potential in the nonwoven and technical-use textiles industry alone is limited due to the capital-intensive nature of the industry. It was noted by respondents that current trends of mechanising production are evident in their industry, and as a result, those jobs that would generally be filled by low-skilled workers are now becoming fully automated. For the workers that are able to find jobs in this industry, the skill requirement is generally high, with a completed matric certificate with maths being a minimum requirement for an operator-level job. Hereafter, there are very few employment opportunities for workers until they have achieved a post-secondary qualification.

However, when considered in conjunction with the downstream industries, there is potential for employment should South Africa develop a nonwoven and technical-use textiles industry, since this industry feeds into the automotive, construction and architectural industries, which all require physical labour at some point along their value chain. This suggests that the best way to realise employment gains from expanding the nonwoven and technical-use textiles industry is to facilitate its integration into the broader value chain.

This section has outlined the potential for nonwoven and technical-use textiles as a potential industry to adopt fibrous plants as an input into production. For the most part, although there exist significant challenges in supply continuity, market perception of natural fibres, high capital outlay, skills constraints, high transport costs, and product certification, there seems to be a real possibility of utilising fibrous plants as inputs to production. This has been corroborated by firms in the industry who have indicated that they are currently expanding production to make use of natural fibres in their production processes. One of the most important findings resulting from interviews with firms was the potential for integrating the nonwoven textiles into the value chain for other highly complex industries, such as motor vehicle parts. Of key importance is the accumulation of the capabilities needed to cultivate and process natural fibres according to downstream application. This requires further R&D across the value chain. Firms that locate themselves as part of a value chain feeding into high-complexity downstream industries may find themselves able to expand production as well as compete in international markets, providing employment opportunities that were not available before.

7.3.2 Motor Vehicle Parts

Motor vehicle parts covers a wide set of heterogeneous products that feature in the final assembly of a motor vehicle.[37] Our focus is centred on products that could potentially be manufactured using fibrous materials. These include door panels, spare tyre lining, noise insulation panels, door trim, interior door panelling, windshield, dashboard, back cushions, insulation, spare wheel compartment cover, seat backs, passenger rear decks, parcel shelves, trunk linings and pillars (Fogorasi & Barbu, 2017; Broadhurst, Chimbganda & Hangone, 2019). Diversification toward this set of products will go a long way toward building economic complexity, since motor vehicle parts is the second most complex fibrous frontier product.[38]

The products of interest are known as fibre reinforced composites. Firms that manufacture nonwoven textiles (see Section 7.3.1), produce a fibre mat that is typically made of glass. The fibre mat is supplied to firms that manufacture composites. These manufacturers place the fibre mat into a mould and infuse it with a synthetic resin, such as phenolic resin, to produce a synthetic fibre reinforced polymer composite. Natural fibres, such as hemp or kenaf, can be substituted in the place of synthetic fibres, such as glass.

The use of natural fibre reinforced polymer composites in place of conventional synthetic fibre reinforced polymer composites is not new to the motor vehicle industry. For example, industrial hemp has been used for automotive composites in Germany and Austria since 1996. The main factors driving the use of natural fibres include: reduction in greenhouse gas emissions; competitive pricing; natural fibres are renewable resources; light weight; and socio-economic benefits resulting from jobs created in agriculture (Fogorasi & Barbu, 2017). In South Africa, the project at Winterton aimed to cultivate and process kenaf fibres for the purpose of manufacturing composites for the South African automotive industry. This does seem to suggest that there is economic potential in the use of natural fibres in reinforced polymer composites for the automotive industry. Taking the South African context into consideration, we explore this economic potential further in the next section.

37 For example, engines, leather trims and upholstery for seats, dashboards, engine parts and catalytic converters.

38 The engineering grouping of the CoP note that the motor vehicle parts applications made from fibrous polymer composites are high-end products (Broadhurst, Chimbganda & Hangone, 2019). This is consistent with our classification of these products as complex.

Potential to Use Fibrous Plant Materials in the Manufacture of Motor Vehicle Parts[39]

The shift in regulatory emphasis toward increasing the recyclability and biodegradability of motor vehicle components is a key factor in establishing the economic case for manufacturing natural fibre reinforced polymer composites. Most notably, the *European Union End of Life Vehicle Directive* imposes that 80 percent of a waste vehicle has to be reused, recovered or recycled.[40] As such, synthetic materials, such as glass fibres, which are non-recyclable and -biodegradable, are likely to be phased out in the future as manufactures shift toward natural fibres.

This is important for the economic potential of using natural fibres in automotive applications because Original Equipment Manufacturers (OEM) determine the design specifications for motor vehicles. Primarily an assembler of motor vehicles, the South African automotive industry fits within the global automotive value chain and is thus subject to these design specifications. A respondent involved in the manufacture of composites for various OEMs noted that most component and material development is done by first tier international suppliers. Design innovations and material selections take place at these firms with the purpose of meeting OEM performance, design scope criteria and specifications such as impact strength, odour, chemical emissions, dimensional stability, heat ageing, colour-fastness, durability, and vibration. Component suppliers across the global value chain then work with these firms to develop manufacturing processes and tooling to supply local OEMs.[41]

Therefore, the economic potential for the incorporation of natural fibres into motor vehicle components in the South African context is closely tied to developments in the global automotive industry. Regulatory shifts, such as the European Union End of Life Vehicle Directive, indicate that the use of natural fibres is set to become increasingly prevalent. This offers South African firms the opportunity to develop the requisite capabilities needed to take advantage of this shift.

However, the accumulation of these capabilities and productive knowhow act as a constraint to the potential use of natural fibres in the manufacture of motor vehicle components in South Africa. In particular, for natural fibres to feature as an input into these components, cultivation and processing of kenaf fibres needs to be learnt. This lack of productive knowhow, as mentioned by numerous respondents, was most evident in the Winterton kenaf project. In the mid-2000s, kenaf was cultivated in Winterton, KZN, to supply natural fibres that could be used in the manufacture of interior trim

39 It is worth noting that biocomposite applications are not restricted to motor vehicle components. Respondents noted the potential to manufacture biocomposites for the aerospace industry and the construction industry (cladding on buildings).
40 See https://ec.europa.eu/environment/waste/pdf/guidance_doc.pdf
41 Respondents noted that current machinery is interchangeable between synthetic and natural fibres, and thus should not constrain a shift to natural fibre applications.

structures for motor vehicles.[42] However, respondents noted that the project failed due to the poor quality of the fibres emerging from the retting process. They noted that the crop was not harvested at the correct time, and the retting process was done incorrectly. This is a function of the various elements of the production process not having the requisite productive capabilities.

Relatedly, it has been noted by respondents that there is not enough R&D taking place within the sector. R&D would allow for the accumulation of these productive capabilities. There are a number of scientific and engineering challenges associated with the cultivation and processing of natural fibres. For example, there is a challenge in designing predictable components for the industry because there is inconsistency in the properties of natural fibres depending on time of harvest, climatic history, soil characteristics, and fibre processing technology. Further technical challenges include the dimensional stability of natural fibres under different climatic conditions, the moisture absorption characteristics of the fibres, and their mechanical properties. As such, these challenges need to be researched, understood, and addressed. Arguably, the public sector can play a key role in facilitating this process. For example, one respondent noted that in India there is substantial government support for the jute industry. Regulatory bodies, such as the National Jute Board, facilitate the growth of the industry by, amongst other things, undertaking R&D into new and innovative uses of Jute.

Finally, to link into global automotive value chains, continuity of supply would need to be ensured. OEMs manufacture a certain number of units per day and thus need the requisite volume of components on hand to ensure that production is not delayed. Components manufacturers thus require a stable supply of nonwoven mats from nonwoven manufacturers, who in turn require a stable supply of fibre from the decortication plant, that in turn needs a stable supply of fibrous material from farmers. As such, the volume of fibrous material must be such that the entire value chain can function so as to meet the demands of the OEM. When dealing with such large volumes of fibrous material there are additional concerns relating to the safe storage and transport of the fibrous material. For example, to ensure a consistent supply of fibrous material along the value chain, a sufficient volume of crop needs to be harvested during the single annual harvest season. This mass of fibrous material needs to be stored in a dry environment to prevent further degradation of the fibre, which then presents a fire hazard. Further, the transportation of fibrous material is costly since it is characterised

42 The Winterton project was a joint venture between the Industrial Development Corporation and the Seardal Group. Farmers within the Winterton area were involved in the cultivation of kenaf, which would then be supplied to and processed at a newly built decortication plant in Winterton. The processed fibre would then be processed into nonwoven mats and combined with polypropylene in moulds to manufacture motor vehicle components for export to Germany and to supply the local automotive industry.

by low bulk density. Therefore, to ensure continuity of supply, the entire value chain needs to develop and harmonise.

General Constraints Facing the Industry

This subsection expands on the discussion above, by providing insights into the opportunities and constraints faced by the industry in general, which could affect the development of the industry, irrespective of whether natural fibres are used as a feedstock.[43]

A key factor that constrains the industry, more generally, is the supply of technical skills specific to the manufacture of composites. These technical skills include material science knowledge, fibre chemistry, polymer processing, and polymer characterisation. It was noted by another respondent that skills in metrology and engineering skills related to process, design, mechatronics, robotics and industrial systems were hard to find.

A key factor acting as an opportunity for the manufacture of composite components for the automotive industry relates to its alignment with current industrial policy. The automotive sector is a priority sector, with the flagship policy being the Motor Industry Development Programme (MIDP) that was in place between 1995 and 2012, and currently the Automotive Production Development Programme (APDP), which is in place until 2020. While the MIDP focused on incentivising the assembly of motor vehicles, and thus did not actively attempt to build complexity through increased value addition, the APDP aims to promote both production volumes and value addition in the automotive component industry. The latter element – increasing the local content of assembled vehicles – which has the potential to build economic complexity, has become increasingly important. The revised APDP is set to target a local content requirement of 60 percent for light commercial vehicles and small passenger vehicles, and 50 percent for high-technology vehicles. Thus, the policy environment has the potential to facilitate the development of automotive component manufacturers.

Employment Potential of the Industry

It was noted by respondents that much of the employment potential resides at the primary production level. The cultivation of fibrous plants is likely to generate a substantial number of jobs. Importantly, the skills requirements of these jobs in the agricultural sector are low, thus aligning with the country's labour endowment.

43 Further information on constraints facing motor vehicle components manufacturers can be found in Bhorat et al. (2019a) provide.

On the processing side, the employment potential is somewhat lower, especially in firms directly involved in the manufacture of automotive components. Respondents noted that OEMs push components suppliers toward the automation of their production processes in order to reduce the labour content of production. Thus, production has become increasingly capital-intensive. One respondent stated that, in the case of composites manufacturers servicing OEMs, the job creation potential lies in post-moulding activities, such as painting, assembly and welding. Jobs in this part of the value chain require at least a matric education. It was, however, noted that firms involved in the processing of the natural fibres – retting and decortication – can employ unskilled workers. This element of the value chain thus offers employment opportunities more in line with the skill supply in South Africa.

This section has outlined the potential for automotive component manufacturers to adopt fibrous plants as an input into production. The extent to which this potential can be realised is constrained by challenges to the continuity of supply, inputs costs, such as safety costs, skills constraints, and a lack of R&D needed to accumulate the relevant capabilities required to cultivate and process natural fibres. Potential lies in the fact that the policy environment is shifting toward increased local content and value addition and should trends in the global automotive value chain continue to shift toward greener components, the industry is well placed to exploit this shift.

7.3.3 Paper and Pulp

The paper and pulp industry in South Africa is responsible for the production of a wide variety of products, from standard reams of paper to dissolving wood pulp (DWP) used as a filler in products such as yoghurts and pharmaceutical fillers (SAPPI, 2019). Paper and pulp products would fall more generally into the "Wood and wood products" community, which accounted for 29 of the 50 identified fibrous frontier products. In fact, 23 of these 29 products fall under the paper and pulp industry, making this industry the single largest entry point to grow a fibrous plant economy.

According to the Paper Manufacturers Association of South Africa [PAMSA] (2017), the paper and pulp industry contributed approximately 0.48% to overall South African GDP, or 4.06% of manufacturing GDP.[44] Furthermore, South Africa currently ranks among the top 20 pulp producers in the world (PAMSA, 2019a). The majority of paper production is concentrated in corrugated materials and containerboard, followed by printing and writing paper and tissue paper (PAMSA, 2017), and these products have seen a large upswing in exports since the onset of the global financial crisis – the only

44 This contribution was estimated to be approximately R4.5 billion by the Fibre Processing and Manufacturing Sector Education and Training Authority [FP&M SETA] (2018)

subsector under the FP&M SETA sectors to do so (FP&M SETA, 2018). Pulp production levels, on the other hand, have remained static over the same time period (FP&M SETA, 2018).

The South African paper and pulp industry is relatively concentrated, with approximately 5 firms being responsible for the majority of paper and pulp production in South Africa (FP&M SETA, 2014a). These firms are, for the most part, located in KwaZulu-Natal and Gauteng, with a few manufacturers in the Western Cape (FP&M SETA, 2014a).[45] In their production processes, these firms mostly use eucalyptus and pine trees, which are harvested on a rotational basis from local plantations (PAMSA, 2019b).

The process for manufacturing paper requires the fibres and cellulose stored in the tree to be prepared through the use of chemicals and specialised paper starches in order to form various pulps that are used to produce the different paper grades required by end users (PAMSA, 2019b). Following global trends, South African firms opt to use pine and eucalyptus fibres in their production processes (PAMSA, 2019b). Respondents indicated that pine and eucalyptus fibres were best suited to the final product grade required by customers, with eucalyptus fibres being better suited to office-grade and tissue paper, and pine fibres being better suited to newsprint. Respondents further indicated that at the time of the interview, hemp, kenaf and bamboo were not being considered as inputs in the paper and pulp production process.

<u>The Potential to Use Fibrous Plants in the Manufacture of Paper and Pulp Products</u>

Hemp, kenaf and bamboo can all produce fibres that can be used in paper- and pulp-making activities. As a result, these fibrous plants can theoretically all be used to produce paper, and respondents have indicated that there are aspects of using fibrous plants which are desirable to the production process. For example, hemp has a high alpha-cellulose content, which acts as a stabilising molecule in paper and pulp products, resulting in more durable products (Launer, 1937). However, there are many challenges that are faced in the adoption of fibrous plants in the paper and pulp industry which make this industry ill-placed to drive an expansion of the fibrous plant economy.

Inception costs for fibrous plants as a source of fibre are significantly higher than that of existing pine and eucalyptus forests, particularly where water use is concerned. Respondents indicated that when setting up a tree-based forest, one can plant approximately 1600 saplings per hectare, and each sapling requires between one and two litres of water initially. However, hereafter, the forests are maintained purely through rainfall and groundwater sources, and do not require any irrigation (PAMSA, 2019c). This

45 In 2014, 86% of the paper and pulp industry was located in KwaZulu-Natal, with the remaining 14% located in Gauteng (FP&M SETA, 2014).

is in contrast to hemp and kenaf, where respondents stated that irrigation would be necessary to grow the crop in a way suitable to meet the demands of their companies.

Secondly, the quality of the fibre recovered from a fibrous plant is ill-suited to current market needs, whereas pine or eucalyptus fibres are a global standard. To begin, the fibre lengths are much longer in hemp, kenaf or bamboo plants, meaning that the paper produced with these plants will have a markedly different finish to current industry standards. If the resulting grade of paper is not comparable to current industry norms due to, for example, the bleeding of ink on pages, then this could raise concerns over the marketability of the final product.

Moreover, fibres are also not as densely packaged in fibrous plants as in a tree trunk. As a result, transport of the raw fibrous input to paper and pulp mills suffers from a bulk-density problem: respondents indicated that transporting fibrous plant stems would significantly increase costs due to the input being volumetrically adverse in fibre. This is corroborated by da Silva Vieira et al. (2010) who present a comparative study of hemp and eucalyptus paper manufacturing. In their paper, they emphasise that hemp would need to be dried before transporting in order to reduce transport costs. One manufacturer indicated that their mill uses approximately 8 000 to 9 000 tons of wood per day, indicating even a slight increase in transport costs per ton of input could lead to large changes in total costs.

The volume of fibrous plants also interacts with the seasonality of their harvesting to create further challenges to using fibrous plants as an input in this industry. Respondents indicated that there are very short windows available for the harvesting of our suggested fibrous plants each year. As a result, it becomes necessary to stockpile the raw material so as to ensure there is sufficient input available for a year’s worth of production. Given the volumetrically adverse properties of these fibrous plants, this becomes infeasible, especially when compared to current practice, which involves harvesting trees on a rotational basis throughout the year (PAMSA, 2019b).

Soil conditions around South Africa are also detrimental to the growth of the fibrous plants as a source of fibre for the paper and pulp industry. Although the majority of South African soil has a pH of between 6.5 and 8.4, indicating relatively neutral soil, the soil in KwaZulu-Natal is significantly more acidic, with soil pH often below 5.5 (Courtman, van Ryssen & Oelofse, 2012). Given that the majority of the paper and pulp industry is located in KwaZulu-Natal, and due to higher transport costs for fibrous plants, industry players would need the source of fibre close to their mills. Although, Harrison et al. (2019) indicate that kenaf and bamboo could potentially grow in these conditions, it is unclear whether this constitutes an ideal growing environment, and as such, whether the fibre yields from these plants would be sufficient for paper manufacturers to meet existing market demand.

Growing the fibrous plants close to manufacturers will also be challenging due to a lack of availability of land. Through academic research conducted on hemp (da Silva Vieira et al., 2010) and from answers provided by interview respondents, it is clear that the growing and harvesting of fibrous plants requires more specialised machinery than the growing and felling of trees. The use of machinery in the harvesting process requires land that can accommodate the harvesters – namely, flat land as would be used for agriculture. Current forests owned by paper and pulp mills are located on land that is unsuitable for agriculture, primarily due to its unlevel gradient. As a result, a move to the production of paper using fibrous plants would require the use of agricultural land, which is unfeasible due to cost and food security concerns. If, on the other hand, the plants were to be grown on the mine lands in the north of South Africa and transported, different concerns are raised due to the potential accumulation of heavy metals in the plant itself, which may violate global health and safety requirements.

Assuming that all these constraints could be overcome, there is still the difficulty of actually producing the paper from an alternative fibre source. At present, respondents indicate that the machinery is optimised for pulping wood, and as a result, a change in input to fibrous plants could require investment in new machinery, as well as research into creating the correct mix of chemicals for the 'liquor' used to prepare fibres before pulping.[46] Although this would be a significant capital outlay, it was noted that not all machinery would need replacing – some machinery would be transferable to the new production process.

General Constraints to the Industry

South Africa's paper and pulp industry faces a number of constraints to growth that are unrelated to using fibrous plants as an input, although these constraints may well add to the difficulty in diversifying the industry as a whole. Low demand in the South African market has meant that the local industry has experienced slowdowns, which have impacted the long-term growth forecasts of the industry overall (FP&M, 2018). These challenges faced by the industry naturally filter through into the feasibility of adopting fibrous plants as an input in the production process.

Currently, paper producers face legislative barriers to growing their business because of a lack of water-use permits available for purchase. Respondents indicated that due to streamflow reduction concerns, it is difficult to obtain new water permits for forestry activities. Although the cultivation of fibrous plants is not considered a streamflow reduction activity at this time, respondents indicated that this may

46 da Silva Vieira et al. (2010) note in their study of hemp paper in Portugal that the chemical composition of the liquor required for hemp is more environmentally damaging than that required for standard eucalyptus paper. As a result, the movement to fibrous plant-based paper could raise environmental concerns as well.

simply be due to the scale of operations, and this would likely change if fibrous plants were to be planted *en masse*. Furthermore, even though water within the paper mill is completely recycled and reused (PAMSA, 2019c), this is not taken into account for the growing of crops. Thus, the application for and granting of a water permit is a significant barrier to expansion for firms at the current time.

A second hurdle experienced by firms wishing to expand production is the high cost of capital expansion. According to the Energy Technology Systems Analysis Programme [ETSAP] (2015), a large-scale chemical pulp mill could cost up to USD 2.5 billion to build. This was corroborated by respondents, who indicated that a paper mill that was recently erected in Indonesia was a multi-investor capital venture costing approximately USD 1 billion to set up. Respondents further indicated that this was their major barrier to expansion, as it was not easy to acquire this amount of equity to expand production.

Another concern regarding the expansion of plants was the lack of skills present to set up a paper mill. Even if firms could acquire the equity to set up a new mill, it was noted by respondents that South Africa currently does not have the required professionals to oversee the setting up of such a facility. In fact, experts are often brought in from overseas to oversee the construction of the plant. These experts will then train management and workers in the correct running of the plant before leaving, as we currently do not have the required expertise to do so within South Africa.

Skilled labour is not only a problem in the setting up of the plant, but also in the day-to-day running of the paper and pulp industry. Respondents indicated a lack of industry-specific skills in workers, and as a result, they have to invest heavily in on-the-job training. This training is extensive and can take anywhere from a couple of months to a few years, according to one respondent. However, an entry-level worker in a paper mill already needs to have a minimum of a matric education, and preferably a technical diploma, further limiting the scope for finding labourers to operate the mills in South Africa.

On the forestry side, there is a severe shortage of forestry-trained individuals in the industry. In general, it was indicated that forestry researchers need to have a postgraduate qualification or a doctorate in biogenetics or forestry to be hired for research work at a paper mill. This is a concern as there are very few formal qualifications available in South Africa that train workers in this field, with only three tertiary institutions in the country offering an undergraduate-level qualification in forestry (Forestry South Africa, 2019). As a result, the lack of skills on both the operational and research side of the industry curtail growth and expansion of the industry.

A final constraint faced by respondents was the lack of phytosanitary standards at South African border posts. This lack of standards, and a general lack of training of border officials, means that products infected with pests and diseases enter South African borders, the likes of which can severely impact the growth of local forests. This problem is exacerbated by the lack of trained bio-geneticists in the industry as they are unable to assist in breeding trees and plants that are resistant to these diseases and pests. As a result, the lack of appropriate border control and phytosanitary standards have severe impacts on the potential for expansion in the paper and pulp industry.

Employment Potential in the Industry

The paper and pulp industry, just like many other industries, is mechanising production. Although the planting of saplings is a relatively labour-intensive process, many other points down the production line are shifting towards greater capital-intensity. As indicated by respondents, the felling of trees is becoming more capital-intensive, and it would remain just as capital-heavy, if not more so, if production were to move to fibrous plants. As a result, it is not clear that the shifting of production to fibrous plants would provide any net gain to employment in South Africa.

On the other hand, in the paper mill itself, although labour is needed to operate machinery, pulping and producing paper is itself a highly capital-intensive process. As a result, it is unlikely that there would be much opportunity for job creation in the paper mill itself. Furthermore, as discussed above, the employment in the paper mill is relatively skilled labour, and as a result, even if jobs were created, it would generally be the creation of skilled employment for those individuals who hold degrees or technical diplomas.

Overall, the paper and pulp industry does not seem to be well situated to address South Africa's fibrous complexity gap. General constraints to the industry include difficulties in obtaining water permits, high start-up costs, and a need for highly skilled employment – all of which pose severe barriers to growth even before one considers expanding into production using fibrous plants. The use of fibrous plants poses many issues of its own, most notably higher variable costs as a result of the bulk-density problem feeding into transport and storage costs. Further challenges arise because of a lack of available land, the acidity of the soil in the areas surrounding current paper mills, and the quality of the fibre obtained from fibrous plants feeding through into different paper qualities. Finally, although of slightly lesser concern to the overall economic outlook, where pulp is used for other products such as rayon, nylon, or fillers for foodstuffs and medicaments, it is not clear that fibrous plants grown on contaminated mine lands would meet the health and safety conditions required for these products.

7.3.4 Bioethanol

As discussed in Section 6, there are a number of downstream applications using fibrous plants that fall within the chemicals sector. In the discussion to follow, we focus on the economic potential of bioethanol in the South African context. Relatedly, we consider the potential for bioethanol to feature as an input in bio-fuel production.

In South Africa, four companies – Glendale, Illovo, NCP Alcohols and Sasol – produce ethanol, with a total installed capacity of 405 000 million litres (Ethanol Producers Association of Southern Africa [EPASA], 2019a). The production of bioethanol in South Africa is closely tied to the sugar industry. The first three companies use molasses – a by-product of sugarcane production – as the main input into bioethanol production. Sasol produces an ethanol alcohol – "ethylol 95" – as a by-product of its synthetic fuel process.

It is important to note that ethanol features as an input into a wide range of products that span the food, beverage, pharmaceutical and chemical industries. The beverage industry is the biggest user of fermented alcohol, where it features as an input into brandy, vodka, cane spirit and whisky (EPASA, 2019b). In the food industry, alcohol is used in the production of vinegar. Another use is in the pharmaceutical industry, such as in cough mixtures (EPASA, 2019b). In the chemicals industry, synthetic ethanol is used to produce ethyl acrylate and ethyl acetate (EPASA, 2019b). Finally, ethanol is used to produce fuel ethanol, which, internationally, is the fastest-growing application of ethanol (EPASA, 2019b).

Fibrous plants can be used as a feedstock (or input) into the production of ethanol. In terms of bamboo, Littlewood et al. (2013) show that by using Liquid Hot Water (LHW) pre-treatment, sugar release from bamboo light cellulose could be enhanced, making bamboo ethanol technically feasible. Further they note that this process is economically feasible in China – the largest bamboo producer in the world. Indian companies have invested in bamboo-to-ethanol plants further demonstrating the feasibility of using bamboo as the primary input for ethanol (Chakrabory and Pandya, 2018).

With regards to hemp, the whole plant can be used to produce ethanol (Hemp Gazette, 2019). As with bamboo, the hemp requires pre-treatment in order to make the cellulose suitable for hydrolysis, which converts cellulose into glucose. In terms of kenaf, the stalk contains a high percentage of cellulose (42 percent), which makes it a suitable feedstock into the production of ethanol (Qicheng et al., 2012).

The Potential of Fibrous Plants in the Manufacture of Bioethanol and Biofuel

Bioethanol

No firm in the South Africa currently uses fibrous plants, such as bamboo, hemp and kenaf, in the production of bioethanol. Furthermore, respondents noted that there are no plans to use fibrous plants in the future. It is worth contextualising this response. Bioethanol is a by-product that emerges from the sugar industry in South Africa. As such, the production of bioethanol is not the primary activity of the firms that manufacture it. Put differently, given that sugarcane is the main feedstock into their primary activity, there is little incentive to divert resources away from sugarcane toward fibrous plants.

Further, there are two main constraints to the use of fibrous plants in the production of bioethanol in the South African context: firstly, the technological capabilities needed to convert fibrous plants into bioethanol are not available in a commercial quality in South Africa. Further, the substantial investment required to obtain and set up this technology constrains its future use. The type of technology that is utilised is dependent on the crop that is used as the input (Pradhan and Mbohwa, 2014). The production of ethanol from sugar requires the fermentation of lower quality sugar using yeast, while the production of cellulosic ethanol – the type that is generated from fibrous plants – requires the use of a hydrolysis process (Pradhan and Mbohwa, 2014).

Relatedly, and given this technological constraint, the economic case for shifting feedstocks to fibrous plants is weak in the face of alternative feedstocks that are simpler to use. As mentioned above, bioethanol production is a by-product that emerges from the sugar industry in South Africa, and thus there is little incentive, certainly amongst these firms, to change feedstock. Furthermore, there is a wide range of competing inputs that do not require these technological capabilities. These alternative feedstocks, due to their high sugar content, include sugar beet, maize, sorghum and cassava (Adelekan, 2010).[47] Most of these inputs are – unlike the three fibrous plants – readily available in South Africa. For instance, sorghum alone is cultivated on between 13 000 and 15000 ha of land, which is around seven times greater than the *total* production for all three fibrous plants combined (Agricultural Research Council, 2013). In sum, there are easier crops to use as a feedstock.

The final constraint relates to the complementarities between production processes, and how incorporating fibrous plants into existing production processes – such as sugar production – may not be economically viable. There is a good economic case for the production of bioethanol as a by-product in the manufacture of sugar. Respondents noted three key reasons for this: first, large volumes of biomass are needed to make these capital- and scale-intensive production process economically viable. The large volumes of molasses left over after sugar production makes the production of bioethanol economically viable. Hence, sugar production and bioethanol production complement one another. Second, the transport of the biomass feedstock, be it sugar or hemp, is very expensive since the bulk density of biomass is low. As a result, sugar mills, and associated bioethanol distilleries, are located in the vicinity

47 The technology to ferment sugar into ethanol is widely used globally and these capabilities are well established in South Africa.

of the sugar cane farms. Relatedly, the greater the distance between the feedstock and the factory, the longer the cut-to-crush period. This opens up the possibility of the biomass rotting, which in turn affects its chemical make-up, and thus reduces the propensity to extract quality output. Third, the production technology used to make bioethanol from molasses cannot be used to make ethanol from fibrous plants such as hemp.

To be precise, the established linkages between the sugar industry and the bioethanol industry make the incorporation of fibrous plants as a feedstock unlikely. As such, the use of fibrous plants in the production of bioethanol, assuming the technological capabilities are acquired, would necessitate new entrants and investment. New investment is unlikely since it would require a strong commercial case – which does not exist at present – to overcome the scale and transport constraints associated with the production process.

Biofuel

As mentioned above, the fastest growing application of bioethanol, internationally, is the production of biofuel. As such, we consider the potential for fibrous plants to feature as a feedstock in the production of biofuel. It is worth noting upfront that the constraints listed above pertaining to bioethanol naturally apply to biofuel, since bioethanol is the key input into the production of biofuel. However, the current policy framework regarding biofuel production in South Africa acts as the key factor constraining the use of fibrous plant feedstock, and, arguably, biofuel production in general.

In 2007, the Department of Minerals and Energy released the Biofuels Industrial Strategy. The document aimed to achieve a 2 percent penetration (equivalent to 400 million litres a year) of national fuel supply by 2013 (i.e. 2 parts bioethanol and 98 parts petrol). This target was not achieved, due to a number of problems in the policy that are explained below.

Firstly, it is noted that the state would only support biofuel projects that were located in the former Bantustans, thereby entirely excluding the Northern and Western Cape provinces (Letete and Blottnitz, 2012). These conditions hamstrung investment because emerging farmers located in those areas were not aware of biofuels (Letete, 2009). Furthermore, these farmers were unwilling to engage in growing crops in which they were unfamiliar (Letete, 2009).

A second issue was the lack of clarity regarding the definition of specific terms. The government was only willing to support new ventures on land which was “currently under-utilised”. However, there was no guidance on what this term meant. Letete (2009) found that three types of land could be classified as “currently under-utilised”: land owned by emerging black farmers, communal, and state-owned land.

However, without further clarification by the government, the meaning of the term remains uncertain, resulting in interested parties not becoming involved in the development of the industry.

A third issue with the policy is that the only feedstock that is allowed to be used in producing bioethanol is sugarcane and sugar beet (Letete and Blottniz, 2012). The exclusion of maize was based on food security concerns as it is a staple food for many South Africans. This decision forced Ethanol Africa – a company that had secured USD 110 million in funding to build a bioethanol plant in South Africa's maize heartland of Bothaville, Free State – to abandon its planned investment (Letete and Blottniz, 2012).

Besides the poor design of the policy document, three further factors constrain the biofuel sector. Firstly, there is a lack of financing provided by the government. Currently, the subsidy amounts to around 6c per litre, or R6 for a 60L tank – an amount that is too small for consumers to notice. Furthermore, it was estimated that even with the small subsidy, the government could not afford the R2 billion a year in subsidies that it would be required to pay to producers if the 2 percent penetration level was reached.

Secondly, transport costs increase the price of biofuels, which are already expensive to produce in comparison to petrol and diesel. Currently, bioethanol production facilities are located in rural areas, such as Craddock in the Eastern Cape. However, the biggest consumption of fuel is in the urban areas, resulting in the ethanol fuel being transported over long distances. Not only does this add a time constraint, but it also, more importantly, adds significantly to the overall cost of the ethanol fuel. As the production cost of ethanol is already above that of petroleum and diesel, transport costs act as a further constraint to expanding the market share of bioethanol.

A further issue relates to the octane level of biofuel and thus the integration of biofuel into the domestic fuel industry. In the process of blending the bioethanol with petrol, refineries are concerned with getting the fuel to a 93-octane level. At 2 percent penetration, there is no major impact on the octane rating after blending the bioethanol (98 octane) with the petrol, and thus refineries are not concerned. However, at a 5 to 10 percent penetration, the blending would push up the octane level and refineries would need to modify their production processes to start off with a lower octane petrol before blending with the bioethanol to achieve a 93-octane fuel. It was noted by a respondent that refineries would not be prepared to modify their production processes unless the supply of bioethanol could be guaranteed. Issues such as drought in South Africa impact on the certainty of supply.

General Constraints Facing the Industry

As mentioned above, bioethanol production is closely tied to sugar production since ethanol is processed from molasses – a by-product of sugar production. As such, factors that affect the sugar industry also impact on the bioethanol industry.

Respondents noted that a key constraint facing the sugar industry is the lack of tariff protection from sugar imports. The South African Sugar Association has consistently argued for tariff protection based on the highly distorted world sugar price and the extensive government support and subsidies that are provided to other country's sugar industries (South African Sugar Association [SASA], 2018). SASA asked for a Dollar Based Reference Price (DBRP) of $856 to be applied to imports but the International Trade Commission of South African only granted a DBRP of $680. As a result, imported sugar would remain around 15 percent cheaper than locally produced sugar, leading to a further shrinkage of the industry (SASA, 2018).

A further constraint relates to the sugar tax, which was implemented on 1 April 2018. The sugar tax is fixed at 2.1 cents per gram that exceeds 4g per 100ml (Arthur, 2018)[48]. In response, Coca-Cola, South Africa's largest sweet beverage manufacturer, reduced the sugar content of its drink by 26 percent (Pilane and Green, 2019). This had a knock-on effect on sugar producers, who claimed they had lost R925 million in revenue in the 2018-19 financial year, as well as costing the economy 1 000 jobs (Pilane and Green, 2019).

Land reform is also an issue facing the sugar industry. Farmers who previously supplied Illovo sold their land to land claimants. The new owners have either stopped producing sugar or have not been able to achieve the same yields as done previously. As a result, the supply of sugar cane has fallen. A respondent noted that before land reform was undertaken, they could expect around 2 million tons of sugar cane per annum. This has reduced to 1.4 million tons. Related to land reform is the issue of expropriation without compensation. The uncertainty resulting from this policy issue has resulted in farms supplying the sugar mill at a reduced rate, since they have not undertaken productivity enhancing investment.

A national minimum wage was implemented on the 1st of January 2019, specifying that farming and agricultural workers must be paid R18 per hour. A respondent noted that this has had a negative effect on hiring decisions involving workers involved in the harvesting of the sugar cane. In addition, the sugar industry has strikes every four to five years, which typically reach impasse, affecting productivity.

48 The first 4g per 100ml is exempt from the tax.

The volatility of the exchange rate acts as a constraint since the by-products linked to sugar production – bioethanol and furfural – are exported, and thus subject to global commodity pricing. These by-products are high-value chemical commodities and thus even small variations in the exchange rate can have large knock-on effects.

A further constraint facing the ethanol industry relates to water scarcity. South Africa is regarded as a 'water stressed' country (Department of Minerals and Energy, 2007). Approximately 60 percent of South Africa's available water resources are used by irrigated agriculture (Department of Minerals and Energy, 2007). As a result, water allocations would have to be re-allocated from other crops, or ethanol crops would have to compete with other crops when new water sources came online. The water scarcity, combined with the increasing frequency of droughts in South Africa, has drastically affected the amount of crop that can be harvested, and consequently, the volume of ethanol produced.[49] This uncertainty acts as a disincentive for businesses who might want to purchase ethanol fuel.

<u>Employment Potential in the Industry</u>

Silalertruksa et al. (2012) estimate that between 112 and 121 jobs are created for every million litres of ethanol produced in Thailand. Based on these estimates, they conclude that the Thai ethanol industry could employ between 238 000 and 382 400 workers by 2022. These numbers do not apply to South Africa, since the agro-chemicals sector, of which bioethanol manufacturers are a sub-sector, only accounted for 11 250 jobs in 2014. The small number of jobs generated from the ethanol industry is indicative of the capital-intensive nature of the industry. Respondents noted that the major source of employment in the bioethanol industry is found in the agricultural component of the value chain, while the processing of sugar and its by-products remains highly capital-intensive. This is confirmed by Hartley et al. (2017, p.14) who state that the large majority of jobs generated from the bioethanol industry "are created largely through the crop activity, as the processing of ethanol is relatively capital intensive".

In terms of the type of jobs generated, there is good potential for low-skilled workers. The bioethanol sector is strongly linked to the agriculture sector, which tends to have many low-skilled workers. This was confirmed by a respondent who stated that workers involved in the harvesting of sugar cane do not have a Grade 12 school-leaving certificate.

Respondents note that at by-product facilities, the skilled artisans and operators who operate the machinery typically have a matric. In addition, there is a skilled managerial cohort who would be expected to have obtained an undergraduate degree. Further, there are chemical and mechanical

49 See Kalaba (2019).

engineers required at the by-product facilities. An industry expert felt that were no issues with obtaining the requisite engineering skills as South African engineering degrees are internationally accredited and there is a sufficient supply of graduates from the nation's universities.

Overall, the bioethanol industry does not seem to be well situated to address South Africa's fibrous complexity gap. There are a number of constraints that preclude the use of fibrous plants in the manufacture of bioethanol. These include: not having the technological capabilities to convert fibrous plants into ethanol; the manufacture of bioethanol being structured around the sugar industry and the related continuity of supply issues; high capital costs; high transport costs; and water scarcity. With respect to biofuel, the biggest stumbling block is the existing policy environment, which, for instance, prohibits the use of feedstocks other than sugar cane.

7.3.5 Wood Products

In this section we focus on a set of frontier products falling within the wood and wood-related products community. These products include particle boards, wood fibreboards, and wood flooring (labelled carpentry and joinery in HS coding), which represent a subset of frontier products characterised by lower complexity levels.[50] They are primarily used in the construction industry. For example, particle boards and fibreboards are used in bedroom and kitchen cabinetry, while wood carpentry and joinery products can be used in flooring applications.

<u>Potential to Use Fibrous Plant Materials in the Manufacture of Wood Products</u>

Respondents noted that there is potential to use bamboo as an input into the manufacture of flooring, and hemp or kenaf in the manufacture of particle and fibreboards. The discussion proceeds by focusing on the former and then moving to the latter.

It was stated that a key constraint to the development of a bamboo industry in South Africa is the competition it faces from China, which in turn limits the downstream bamboo applications that South African manufacturers can viably produce. China has cultivated bamboo for 7000 years and has thus accumulated the productive capabilities and knowledge to manufacture a wide range of bamboo products. The Chinese market is well developed and highly specialised. Chinese firms typically specialise in a single product and are thus able to achieve scale economies. Since bamboo cultivation in South Africa is marginal, local manufacturers have to import most of the raw material and then

50 In Broadhurst, Chimbganda & Hangone (2019), these types of products are classified as lower value-add products.

process. Respondents noted that South African manufacturers that import and then process cannot compete with Chinese final product imports because they are not able to produce on the same scale.

As such, respondents noted that for the potential of the bamboo industry to be realised, two things need to occur: first, South African manufacturers need to focus on simple niche products and avoid competing directly with the Chinese. These products include raw poles, fencing, furniture, laminated beams, boards, and notably, flooring. Second, respondents noted that the industry needs to cultivate locally, and thus generate a domestic supply of bamboo. It is argued that this will lower the cost of production for manufacturers since bamboo in raw form is costly to transport.

Related to the previous point, a key factor constraining the development of a bamboo industry and the realisation of these frontier products is establishing the continuity of supply of bamboo feedstock. Respondents noted that to establish a continuity of supply, cultivation needs to take place at a substantial scale in order to generate sufficient volumes of feedstock for downstream applications.[51] Further, given the high cost of transporting a low bulk density raw material, cultivation and processing needs to take place in relatively close proximity.

It was further noted by industry experts that there is not enough R&D into bamboo cultivation and processing. R&D is key to the accumulation of productive capabilities in cultivation and processing that would allow the industry to expand and diversify into more complex downstream applications. Respondents stated that, while the industry should focus on producing simple low complexity products, as detailed above, it should concurrently increase its investment in R&D and learn how to develop more complex bamboo applications as the industry develops over time.

With respect to the manufacture of fibreboards and particle boards using kenaf or hemp, respondents noted that while it is technically possible to adjust production processes to use these fibres, there needs to be a strong commercial case to warrant such a shift. In particular, the primary constraint to the economic viability of shifting to another feedstock input relates to the continuity of supply. The supply chain for this industry is well established. Manufacturers obtain eucalyptus or pine logs from either their own forests or from outside suppliers, and then process these inputs once transported to the factory. The scale of production is substantial and thus firms need a reliable supply of the feedstock material.[52] As such, it was noted that a shift to an alternative feedstock would require getting the fibre, at the right time, at the right volumes, and at a price that warrants such a shift. Such a shift would thus require massive investment into the upstream elements of the supply chain. Furthermore, shifting to

51 One respondent noted that the establishment of a 100ha farm would kick-start the industry in South Africa.
52 For example, a 1000 cubic metre plant consumes approximately 400-450 thousand tons of raw material per annum.

a new feedstock also needs to be considered in light of the massive capital costs of setting up a factory that is able to manufacture these downstream products.[53] In order to ensure a return on investment it is vital that the commercial case is strong, and this is closely linked to the continuity and cost of supply.

General Constraints Facing the Industry

It was noted that South Africa's present macroeconomic climate, characterised by subdued demand, is acting as a major constraint to growth in the sector. Since these products fall within the construction industry, the demand for these products is derived from consumer demand and is thus sensitive to the broader macroeconomic climate. In the case of bamboo, this aggregate demand effect is felt more strongly, since bamboo is perceived to be a luxury high-end product, and such products are the first to be affected by household budget tightening.

A further constraint to the sector is the high costs associated with investment in plant and machinery. Respondents involved in the manufacture of fibreboard and particle board noted that a 1000 cubic metre factory costs between R1.5 - 2 billion. Respondents involved in the manufacture of basic bamboo products noted that machinery can cost upward of R50 000, which is high given the relative size of the market. As such, these large capital outlays act as a barrier to entry for future entrants, and as a constraint to incumbents looking to diversify and expand.

Employment Potential of the Industry

With respect to the manufacture of basic bamboo products, such as flooring, the skill demands are relatively low. Entry level positions do not require a complete secondary education. Much of the training can be done on-the-job. Given the basic nature of the products, the manufacturing process is relatively labour-intensive, which suggests that should this industry grow, a number of low-skill entry-level jobs can be created. It is worth noting that the skill demands rise as the complexity of the products increases. The manufacture of fibreboards and particle boards is more skill-intensive, with entry-level positions requiring a complete secondary education or more. Given the magnitude of capital investment into the production plant, the production process is also more capital-intensive.

Across both these wood-based products, it was noted that while firms are able to find individuals with technical skills, such as fitters and electricians, they require additional training to be able to work proficiently with the machinery. This can take as long as a year in some instances. Even in the more basic

53 For example, a 1000 cubic metre plant costs approximately R1.5 - 2 billion.

bamboo operations, it was noted that there is a need for a SETA skills programme for machine operators.

In summary, the potential in bamboo products lies in simple products, such as flooring, so as to avoid competing with China and allowing for a period of sustained R&D that would enable the industry to accumulate capabilities and later shift to a more complex set of bamboo products. Further, bamboo cultivation needs to expand to ensure the continuity of supply to downstream manufacturers. In the case of fibre and particle boards, there is potential to shift feedstock. However, for this to materialise, the continuity of supply would need to be ensured, and the cost of ensuring this is potentially prohibitive. Across both sets of products, the large capital outlays required for machinery constrain growth and diversification.

8 POLICY RECOMMENDATIONS

The previous section outlined the constraints/capabilities that hinder/enable the development of downstream fibrous diversification opportunities in South Africa. Drawing on the firm and industry expert responses, it is clear that the challenges facing the development of these fibrous frontier products cannot be overcome in isolation. Rather, policy intervention is required to make diversification into these fibrous products commercially and practically viable. In this section, we present a set of product-level policy recommendations that would assist in the development of the requisite capabilities needed to facilitate diversification into these fibrous products.

8.1 General Policy Interventions in the Fibrous Plant Economy

Although the aim of micro-industrial policy is to provide product-level interventions, there are certain challenges that are common across all the product communities detailed in Section 7.3. These challenges are high input costs due to storage, transport and safety, as well as ensuring the continuity and scale of supply of the feedstock material.

The continuity of supply of the fibrous feedstock to downstream fibrous product applications is important along two metrics: first, in terms of the quality of fibre supplied to processing plants, and second, in terms of the requisite scale. A consistent and reliable supply of the correct quality feedstock material is vital in order to ensure that downstream manufacturers are able to produce sufficient products that meet industrial standard. Failure to provide continuity of supply has had crippling effects on previous attempts to diversify into fibrous products. This is evidenced by the failure of the Winterton kenaf processing plant, discussed earlier, which was unable to process the low-quality fibre supplied by farmers (PMG, 2015).

In order to combat low-quality feedstock, government and/or agricultural research units could intervene by undertaking research to determine best farming practice for these fibrous plants and then provide training to farmers. This training would detail the correct methods of cultivating and harvesting the fibrous crops in order to provide the requisite quality fibre demanded by downstream applications. This could be done in the form of presenting agricultural research in the form of crop-specific farming manuals, or else through the presentation of practical farming workshops, which would educate farmers in a more hands-on way. These interventions are consistent with the goals set out in the National Development Plan (NDP), which speak specifically towards developing key capabilities surrounding labour-absorbing growth (National Planning Commission [NPC], 2012). Since South Africa has a strong agricultural sector, and the sector is relatively labour-intensive, educating farmers on what is required by their end-users would build a resilient and labour-absorbing sub-industry in South Africa.

The seasonality of hemp, kenaf and bamboo is a second concern which transcends industries: since these crops are only available for harvest for a short window during the year, and not perennially, issues of storage arise. Since downstream industries require a consistent supply of fibrous feedstock, it is necessary to grow and stockpile raw materials in large quantities. Due to low bulk density, this becomes practically challenging from both a transport and storage perspective, since stockpiling sufficient raw material for a year's supply to industry will require extremely large volumes. Furthermore, in order to prevent rotting, the fibrous plants will have to be dried out after harvesting, presenting a fire hazard wherever the material is stored.

In order to assist in growing the scale of feedstock material needed, government could institute subsidies to assist farmers in setting up the size of farm required to meet industry demand. By entering a type of joint venture with government, farmers would be able to set up their business more efficiently and be able to establish themselves more reliably as suppliers to downstream industries. Furthermore, to ensure the continuity of supply it is necessary to provide a common biomass storage facility, which is carefully monitored for safety and security concerns. The feedstock material from a community of farmers can be stored at such facility in order to allow for sufficient scale of supply.

A second issue arising from the low bulk density of fibrous crops is the high transport costs, particularly for industries that use large volumes of fibrous biomass, such as the paper and pulp industry. A potential means of lowering these transport costs would be the setting up of the processing, storage, and cultivation activities in close proximity to one another on degraded mine land. The use of abandoned mine land for cultivation and processing speaks directly to the NDPs goal of rural and informal development (NPC, 2012). By reinvigorating mining towns and providing employment opportunities to those individuals situated in rural areas close to these abandoned mines, one can kickstart economic growth and development in these localities.

8.2 Product-Specific Policy Interventions in the Fibrous Economy

There are also a number of challenges specific to certain fibrous frontier products. Thus, different products may require tailored interventions needed to support and encourage their development. The remainder of this section focuses on product-specific policy interventions.

High capital outlay stands as a barrier to entry across a number of the fibrous frontier products, namely: paper and pulp, bioethanol, nonwoven and technical-use textiles, and fibreboard wood products. In the case of paper and pulp and fibreboard, setting up a factory with the required machinery is prohibitively expensive, and is, in general, not financially viable without a significant level of external financial support. In order to assist firms in acquiring the necessary equity to purchase machinery and set up new processing plants, government could attempt to subsidise industry through the strengthening of their incentive schemes administered through the DTI. For example, the promotion of the Clothing and Textile Competitiveness Programme (CTCP) for the textiles industry may assist in alleviating the high capital costs for the nonwoven textiles sub-industry. If similar programmes that aim to subsidise the procurement of competitiveness-enhancing machinery can be promoted across these fibrous product communities, then this could open up opportunities for the development of the relevant fibrous frontier products.

A lack of capacity at the relevant standards authority is a further challenge faced by nonwoven textile manufacturers. This lack of institutional capacity at the standards authority stifles product innovation. It acts as a barrier to introducing fibrous feedstocks into the production process and thus the manufacturing of fibrous products. Given that the nonwoven industry feeds into the motor vehicle components industry, which supplies the automotive sector, this is a constraint that should be addressed carefully.

In order to assist firms in the innovation of fibrous products, the capacity of the standards authority should be enhanced. By increasing the capacity and efficacy of the standards authority, firms in the nonwoven textiles industry may feel it is worthwhile to invest in fibrous product development, and thereby kickstart the fibrous plant economy.

A lack of skilled labour was identified in the product communities specific to paper and pulp, nonwoven textiles and motor vehicle components. For example, it was noted that the closing of a nonwovens institute specifically geared towards training individuals in the skills needed to work in this industry left an industry-specific skills deficit. In the motor vehicle parts industry, a lack of technical skills, such as material sciences, was indicated, while a lack of postgraduate and industry-specific skills was noted in the paper and pulp industry. In order to assist firms in combatting this skill gap present in the workforce, government could redirect funds towards support of Technical and Vocational Education and Training (TVET) colleges, or similar technical training institutions.

In an attempt to summarise the various constraints faced by different industries and the level of policy intervention required in each case, a type of policy intervention heat map is presented in Table 10. Product communities for fibrous frontier products run across the columns, and constraints identified in the fibrous economy run down the rows. Cells are highlighted according to the severity of the policy intervention required in order to overcome existing constraints in the industry: red cells indicate areas where policy intervention is a high priority, and where the constraint stands as a barrier to entry that would preclude diversification into that product. Orange cells indicate a medium priority for policy intervention, where the industry will not be functional without some form of assistance in this regard, but the lack of intervention in the short-term does not preclude this industry from diversifying. Yellow cells indicate a low priority for policy intervention, which means that firms are able to overcome the challenge with little to no assistance in the short term, although attention should be paid to these areas in the long term. Green cells indicate that there is no policy intervention required for diversification to occur.

Table 10: Constraints by Fibrous Frontier Product

	Bioethanol	Paper & pulp products	Textiles: Non-woven	Textiles: Technical use	Wood products: Fibre & particle boards	Wood products: Carpentry (flooring)	Motor vehicle parts
Input costs (e.g. transport, safety, storage, water)	Red	Red	Red	Red	Red	Red	Red
Continuity of supply & scale	Red	Red	Red	Red	Red	Red	Red
High capital outlay	Red	Red	Orange	Orange	Red	Yellow	Green
Transferability of machinery	Red	Orange	Green	Orange	Green	Green	Green
Skills constraints	Green	Red	Orange	Green	Green	Green	Yellow
Water permits & scarcity	Red	Red	Green	Green	Green	Green	Green
Research & Development	Green	Green	Orange	Orange	Green	Green	Yellow
Macroeconomic constraints (e.g. exchange rate, demand)	Orange	Green	Green	Green	Orange	Yellow	Green
Fibre not suited to the application	Green	Orange	Green	Orange	Green	Green	Green
Certification	Green	Green	Red	Green	Green	Green	Green
Policy constraints	Red	Green	Green	Green	Green	Green	Green

Key: Red – High Priority; Orange – Medium Priority; Yellow – Low Priority; Green – No Intervention Needed

Table 10 acts as a high-level summary of the area and level of policy intervention required in order to create a viable fibrous plant economy for fibrous frontier products. Although not all instances have been discussed at length, this section has provided suggestions on how to tackle some of the more pressing concerns for the fibrous products identified as viable options for South Africa: nonwoven textiles, motor vehicle parts and bamboo flooring.

9 Concluding Remarks

South Africa's economic development path has been shaped by its substantial natural resource endowment, particularly its abundance of mineral deposits. However, over the past twenty years approximately 6000 mines have been abandoned and a large number are expected to close in the coming decade. Mine closure leads to an economic vacuum in mining localities, which has dire socio-economic consequences, such as increased unemployment and poverty. This paper explored the potential to develop a diversity of fibrous downstream activities – or fibrous frontier products – that stem from fibrous plant production on degraded mining land. In essence, the paper explored whether the remediation of abandoned mining land can act as an industrial catalyst and thus potentially mitigate the socio-economic consequences of mine closure through the generation of sustained and inclusive economic growth in these marginalised localities.

Applying an intensely cross-disciplinary approach, we explored the potential to develop a diversity of fibrous downstream activities using economic complexity and network analytics. We developed the *fibrous complexity index*, a contribution to the literature, which allows us to measure the economic complexity of a country's fibrous plant economy. Using network analytics, we developed the *fibrous product space* – to our knowledge the first of its kind – which allows one to visualise a country's fibrous plant economy and determine its future fibrous diversification opportunities. Informed by semi-structured firm and industry expert surveys, we identify capabilities/constraints that enable/hinder the development of these fibrous diversification opportunities.

There is a strong positive relationship between the *economic complexity index* and the *fibrous complexity index*. This suggests that a country can build economic complexity, and thus reap the associated economic development and growth benefits, by growing the complexity of its fibrous plant economy. However, the analysis shows that South Africa has a fibrous complexity gap – a disparity in the level of overall economic complexity and the level of fibrous complexity present in the economy. This suggests that South Africa has relatively under-invested in the development of its fibrous plant economy, and that there are potential fibrous product diversification opportunities that are easily achievable. This is confirmed in the network analytics which show that South Africa is well positioned within the core of the *fibrous product space*. South Africa thus has sufficient capabilities to allow it to diversify into other proximate and more complex fibrous products, which will allow it to grow the complexity of its fibrous economy, and in turn build economic complexity

Using economic complexity analytics, product-level diversification opportunities – or *fibrous frontier products* – were identified. These products included nonwoven and technical-use textiles; motor vehicle parts; paper and pulp products; bioethanol; and various wood products, such as flooring and fibreboards. Semi-structured firm and industry expert surveys provided insight into the economic feasibility of developing these fibrous diversification opportunities, and the factors that constrain this process. A number of insights emerged: first, a potential two-part development path has materialised from the analysis. It is feasible to follow both a low-complexity path, featuring wood products, such as flooring; and a high-complexity path, featuring motor vehicle components and the nonwoven textiles that serve as intermediates to these components. While the former represents a relatively more labour-intensive path, the latter represents a less labour-intensive path, but one that is characterised by employment opportunities along an integrated value chain.

Second, the cultivation and the processing of the natural fibres needs to occur in close proximity in order to ensure continuity of supply. This is necessitated by the fact that natural fibres are characterised by low bulk density and are thus costly to transport. In order to viably diversify into the various fibrous diversification opportunities, it is vital that there is a reliable supply of feedstock material. Therefore, to ensure the reliable supply of the correct fibre, the requisite cultivation capabilities need to be accumulated.

Third, the positioning of the cultivation and processing activities in close proximity to one another is best achieved through utilising degraded mining land, since the cultivation and processing of industrial crops should not compete with food production on fertile land. It is worth noting that the positioning of the cultivation and processing activities in close proximity to one another on degraded mining land would assist in driving rural development, since abandoned mining land is typically located in rural localities. However, the supply of suitable skills needed for the processing of natural fibres would need to be overcome in these rural localities.

Fourth, and relatedly, it is important that the processing plant is a multi-product plant that produces a primary product as well as various by-products. This will ultimately increase its economic viability. The key advantage of fibrous plants is the flexibility that they offer as industrial crops, since the various components of the plant can be used for various downstream applications. As such, the processing plant needs to adopt an integrated approach, whereby a diversity of products can be produced using these plant components. This would ultimately facilitate the building of economic complexity and the resultant inclusive economic growth.

References

Adelekan, B. A. 2010. Investigation of ethanol productivity of cassava crop as a sustainable source of biofuel in tropical countries. *African Journal of Biotechnology*. 9(35): 5643 – 5650.

Agriculture Research Council [ARC]. 2013. Sorghum production. Available: http://www.arc.agric.za/arc-gci/Fact%20Sheets%20Library/Sorghum%20Production.pdf [2019, 9 September].

Agriculture Research Council [ARC]. 2014. Hemp. Available: http://www.arc.agric.za/arc-iic/Pages/Hemp.aspx [2019, 10 September]

Agricultural Research Council [ARC]. 2018. *The Agricultural Research Council conducts a research program to cultivate hemp for medicinal purpose*. Available: http://www.arc.agric.za/MEDIA%20STATEMENT/The%20Agricultural%20Research%20Council%20conducts%20a%20research%20program%20to%20cultivate%20hemp%20for%20medicinal%20purpose.pdf [2019, August 30].

Arockiam, N.J., Jawaid, M. & Saba, N. 2018. Sustainable bio composites for aircraft components. In *Sustainable composites for aerospace applications.* Jawaid, M. & Thariq, M. Eds. Cambridge, United Kingdom: Woodhead Publishing. 109-123.

Arthur, R. 2018. South Africa introduces sugar tax. Available: https://www.beveragedaily.com/Article/2018/04/03/South-Africa-introduces-sugar-tax [2019, 10 September].

Balassa, B. 1965. Trade Liberalisation and "Revealed" Comparative Advantage. The Manchester School. 33(2):99-123.

Bhorat, H., Ewinyu, A., Lilenstein, L. Rooney, C., Steenkamp, F. and Thornton, A. 2019a. Economic Complexity and Employment Expansion: The Case of South Africa. IDRC/DPRU Country Report, 2019.

Bhorat, H., Kanbur, R., Rooney, C. & Steenkamp, F. 2019b. Chapter 8: Sub-Saharan Africa's Manufacturing Sector: Building Economic Complexity. In *The Quality of Growth in Africa*. R. Kanbur, A. Noman & J.E. Stiglitz Eds. Columbia University Press.

Blouw, S. & Sotana, M. 2005. *Performance of four European hemp cultivars cultivated under different agronomic experimental conditions in the Eastern Cape Province, South Africa.* Port Elizabeth: Council of Scientific and Industrial Research.

Broadhurst, J., Chimbganda, T. & Hangone, G. 2019. Identification and review of downstream options for the recovery of value from fibre producing plants: Hemp, kenaf and bamboo. Unpublished. University of Cape Town.

Bureau for Food and Agricultural Policy. 2018. BFAP Baseline: Agricultural Outlook 2018 – 2027. Available: http://www.bfap.co.za/wp-content/uploads/2018/08/BFAPBaseline-2018.pdf [2019, 10 September].

Business Report. 2007. Seardel-IDC venture to build first kenaf plant. *Business Report*. 19 April. Available: https://www.iol.co.za/business-report/companies/seardel-idc-venture-to-build-first-kenaf-plant-729441 [2019, 10 September].

Bustos, S. and Yildirim, M. 2016. Ecomplexity. Stata user-written software. Available: https://github.com/cid-harvard/ecomplexity [2019, June 18]

Caldarelli, G., Cristelli, M., Gabrielli, A., Pietronero, L., Scala, A. and Tacchella, A., 2012. A Network Analysis of Countries' Export Flows: Firm Grounds for the Building Blocks of the Economy. PLOS ONE, 7(10): e47278. Available: https://journals.plos.org/plosone/article?id=10.1371/ journal.pone.0047278 [2019, August 23]

Cheng, W.Y., Akanda, J.M.H. & Nyam, K.L. 2016. Kenaf seed oil: a potential new source of edible oil. *Trends in Food Science & Technology*. 52(2016). 57-65.

Center for International Development at Harvard University (CID). 2019. The Atlas of Economic Complexity. Available: http://www.atlas.cid.harvard.edu. [2019, June 03].

Chakraborty, D. & Pandya, D. 2018. Bamboo to ethanol, India's biofuel industry to explode into a $15 bn market. *Business Standard*. April 3. Available: https://www.business-standard.com/article/companies/bamboo-to-ethanol-india-s-biofuel-industry-to-explode-into-a-15-bn-market-118040300588_1.html [2019, 5 September].

Coogan, C. 2016. The South African hemp story: saviour crop or business as usual? Masters Dissertation. Stellenbosch University.

Courtman, C., van Ryssen, J.B.J. and Oelofse, A. 2012. Selenium Concentration of Maize Grain in South Africa and Possible Factors Influencing the Concentration. South African Journal of Animal Science. Vol 42(5)-1.

Cristelli, M., Gabrielli, A., Tacchella, A., Caldarelli, G. and Pietronero, L. 2013. Measuring the Intangibles: A Metrics for the Economic Complexity of Countries and Products. PLOS ONE, 8(8): e70726. Available: https://doi.org/10.1371/journal.pone.0070726. [2019, August 23]

da Silva Vieira, R., Canaveira, P., Da Simões, A. and Domingos, T. 2010. Industrial hemp or eucalyptus paper? The International Journal of Life Cycle Assessment, 15(4), pp.368-375.

Dempsey, J.M. 1975. *Fibre crops*. Gainesville: The University Press of Florida.

Department of Agriculture, Fishing, and Forestry [DAFF]. 2011. A Profile of the South African Hemp Market Value Chain. *Government Report.* Pretoria: DAFF.

Department of Minerals and Energy. 2007. Biofuels Industrial Strategy of the Republic of South Africa. Pretoria: Department of Minerals and Energy.

Department of Trade and Industry [DTI]. 2015. *Progress report on implementation of the industrial policy action plan (IPAP) for the financial year April 2014 to March 2015 to the Trade and Industry Portfolio Committee of the National Assembly*. Pretoria: DTI.

De Vos, S. 2017. Should I Use the 93 or 95 Version of Unleaded Petrol? Available: https://compareguru.co.za/news/should-i-use-the-93-or-95-version-of-unleaded-petrol [2019, 12 September].

DTI. 2019a. *Industrial Policy Action Plan: economic sectors and employment cluster, 2014/15 - 2016/17.* Pretoria: DTI.

DTI. 2019b. *Industrial Development. Incentives: Clothing and Textiles Competitiveness Programme.* Available: https://www.thedti.gov.za/industrial_development/industrial_incentive.jsp?id=35&subthemeid=25 [2019, September 19]

Discover Natural Fibres Initiative [DNFI]. 2019. *Natural fibres and the world economy: July 2019.* Available: https://dnfi.org/coir/natural-fibres-and-the-world-economy-july-2019_18043/ [2019, 10 September].

Duvall, C.S. 2016. Drug laws, bioprospecting and the agricultural heritage of Cannabis in Africa. *Space and Polity*. 20(1). 10-25.

Energy Technology Systems Analysis Programme [ETSAP]. 2015. Pulp and Paper Industry: Highlights. Technology Brief – May 2015. Available: https://iea-etsap.org/E-TechDS/PDF/I07_Pulp &Paper_May2015OK.pdf [2019, September 09]

Enterprise Opportunities Limited. 2006. Mekong bamboo sector feasibility study. *Final report, 1st edition.* Enterprise Opportunities Limited.

Ethanol Producers Association of Southern Africa. 2019a. About Us. Available: http://www.epasa.org.za/about-us.html [2019, 5 September].

Ethanol Producers of Southern Africa. 2019b. Applications. Available: http://www.epasa.org.za/ethanol/applications.html [2019, 5 September].

Fibre Processing and Manufacturing Sector Education and Training Authority (FP&M SETA). 2014a. A Profile of the Paper and Pulp Sector: December 2014. Available: https://www.fpmseta.org.za/downloads/FPM_sub-sector_paper%20and%20pulp_final.pdf [2019, September 09]

FP&M SETA. 2014b. A Profile of the Clothing, Textiles, Leather and Footwear sector: December 2014. Available: https://fpmseta.org.za/downloads/FPM_sub-sector_clothing_textiles_footwear_leather_final.pdf [2019, September 09]

FP&M SETA. 2018. FP&M SETA Sector Skills Plan: 2018 – 2022. Available: https://www.fpmseta.org.za /downloads/FPM%20SETA%20Sector_Skills_Plan_2018-22.pdf [2019, September 09]

Fogorasi, M.S. and Barbu, I. 2017. The potential of natural fibres for automotive sector-review. *IOP Conference Series: Materials Science and Engineering*. 252(1): 012044.

Food and Agricultural Organisation [FAO]. 2017. Jute, kenaf, sisal, abaca, coir and allied fibres. *Statistical Bulletin, No. CCP: JU/HF/ ST / 2016/1*. FAO.

Forestry South Africa. 2019. Forestry Education. Available: https://forestry.co. za/forestry-education/ [2019, September 10]

Fu, J., Li, X., Gao, W., Wang, H., Cavaco-Paulo, A. & Silva, C. 2012. Bio-processing of bamboo fibres for textile applications: a mini review*. Biocatalysis and Biotransformation.* 30(1). 141-153.

Harrison, S. T. L., Rumjeet, S., Mabasa, X. & Verster, B. 2019. Towards Resilient Futures: Can fibre-rich plants serve the joint role of remediation of degraded mine and fuelling of a multi-product value chain? Unpublished. University of Cape Town.

Hartley, F., van Seventer, D., Samboko, P. & Arndt, C. 2017. Economy-wide implications of biofuel production in Zambia. *UNU-Wider Working Paper 2017/27*. UNU-WIDER: Helsinki, Finland.

Hausmann, R. and Chauvin, J. 2015. Moving to the adjacent possible: Discovering paths for export diversification in Rwanda. CID Working Paper No. 294. Cambridge, MA: Centre for International Development at Harvard University.

Hausmann, R. and Klinger, B. 2007. The structure of the product space and evolution of comparative advantage. CID Working Paper No. 146. Cambridge, MA: Centre for International Development at Harvard University.

Hausmann, R., Hialdo, C.A., Bustos, S. Coscia, M., Chung, S., Jimenez, J., Simoes, A. and Yildirim, M.A. 2014. The Atlas of Economic Complexity: Mapping Paths to Prosperity. Puritan Press: Cambridge MA.

Hemp Gazette. 2019. Industrial Hemp's Energy Potential – Biofuels. Available: https://hempgazette.com/industrial-hemp/biofuel-hemp-energy/ [2019, 5 September].

Hemporium. 2019. *Cultivate.* Available: https://hemporium.com/cultivate/ [2019, 29 August].

Hidalgo, C.A., Klinger, B., Barabási, A.L. and Hausmann, R. 2007. The product space conditions the development of nations. Science, 317(5837), pp.482-487.

Huberty, M. & Zachmann, G. 2011. Green exports and the global product space: Prospects for the EU industrial policy. *Bruegel Working Paper No. 2011/07*. Bruegel: Brussels.

International Jute Study Group. 2013. Raw jute price movement in India and Bangladesh. *Jute Matters: A Monthly Publication*. 1(5). 1-4.

Isdardi, E.F., van Schalkwyk, H.D. & Viviers, W. 2015. The agricultural product space: Prospects for South Africa. *International Conference of Agricultural Economists*. Milan: Italy.

Johnson, R. 2018. *Hemp as an agricultural commodity*. Washington, DC: Library of Congress Washington DC Congressional Research Service.

Junayed, M. & Mehtaj, M. 2017. Export performance of Bangladesh: a study on selected products. *Asian Business Review*. 7(2). 51-54.

Kalaba, M. 2019. How droughts will affect South Africa's broader economy. Available: https://theconversation.com/how-droughts-will-affect-south-africas-broader-economy-111378 [2019, 12 September]

Kamal, I.B. 2014. Kenaf for biocomposite: an overview. *Journal of Science and Technology*. 6(2). 41-66.

Khamsi, M.A. and Kirk, W.A. 2001. An introduction to metric spaces and fixed point theory (Vol. 53). John Wiley & Sons, Inc: Toronto.

Kayembe, P. 2015. Kenaf (Hibiscus cannabinus L.) fibre yield and quality as effected by water, nitrogen, plant population and row spacing. *MSc. (Agric) Agronomy dissertation*. University of Pretoria.

Kaytech. 2015. Soil Saver: The Natural Solution for Soil Erosion Problems. Available: http://kaytech.co.za/wp-content/uploads/2015/11/SoilSaver-brochure-BR-ERSN-0651-06_2015.pdf [2019, September 19]

La Rosa, A.D., Cozzo, G., Latteri, A., Recca, A., Björklund, A., Parrinello, E. & Cicala, G. 2013. Life cycle assessment of a novel hybrid glass-hemp/thermoset composite. *Journal of Cleaner Production*. 44(2013). 69-76.

Lash, R. 2002. Industrial hemp: the crop for the seventh generation. *American Indian Law Review.* 27(1): 313-356.

Launer, H.F. 1937. Simplified volumetric determination of alpha, beta, and gamma cellulose in pulps and papers. US Government Printing Office.

Lee, H.J. and Cassill, N., 2006. Analysis of world nonwovens market. *Journal of Textile and Apparel, Technology and Management*. 5(3): 1-19.

Letete, T.C.M. 2009. Multiobjective modelling of biofuel supply systems. *M.Eng. Dissertation*. University of Cape Town.

Letete, T.C.M & von Blottnitz, H. 2012. Biofuel policies in South Africa: A critical analysis. In: R. Jannssen and D. Rutz (eds). *Bioenergy for Sustainable Development in Africa*. Springer. South Africa.

Lin, J., Gupta, S., Loos, T.K. & Birner, R. 2019. Opportunities and challenges in the Ethiopian bamboo sector: a market analysis of the bamboo-based value web. *Sustainability*.11(6). 1644.

Littlewood, J., Wang, L., Turnbull C., & Murphy, R. J. 2013. Techno-economic potential of bioethanol from bamboo in China. *Biotechnol Biofuels*. 6: 173 – 186.

Macaskill, C. 2017. *Forestry and industrial crops: fibre crops*. Available: http://www.agribook.co.za/index.php/book/forestry-industrial-crops/fibre-crops [2018, 19 September].

Mandela Bay Composites Cluster. 2017. *Mandela Bay Composites Cluster says accelerated growth in composites expected*. Available: http://www.mandelabaycompositescluster.co.za/mandela-bay-composites-cluster-says-accelerated-growth-composites-expected/ [2019, 10 September].

Mealy, P., Farmer, J.D. and Teytelboym, A. 2019. Interpreting Economic Complexity. Science Advances 5(1): eaau1705.

Mealy, P. and Teytelboym, A. 2018. Economic Complexity and the Green Economy. INET Oxford Working Paper No. 2018-03.

Minister of Justice and Constitutional Development and Others v Prince, 2018, CCT 108/17 (C).

Mostert, H., Paterson, A., Young, C. & van Schalkwyk, L. 2019. From Tailings to Tillings: Designing the legal framework for mine waste land rehabilitation through bio-remediation. Unpublished. University of Cape Town.

National Conference of State Legislators. 2019. State industrial hemp statuses. Available: http://www.ncsl.org/research/agriculture-and-rural-development/state-industrial-hemp-statutes.aspx

[2 October, 2019].

National Planning Commission (NPC). 2012. *National Development Plan 2030: Our Future – Make it Work*. Pretoria: Department of the Presidency.

Paper Manufacturers Association of South Africa [PAMSA]. 2017. South African Pulp and Paper Industry: Summary Findings on 2017 Production, Import and Export Statistics. Available: https://www.thepaperstory.co.za/wp-content/uploads/2018/10/PAMSA-stats-report-2017-final.pdf [2019, September 10]

PAMSA. 2019a. About PAMSA. Available: https://www.thepaperstory.co.za/about-pamsa/ [2019, September 10]

PAMSA. 2019b. How Paper is Made. Available: https://www.thepaperstory.co.za/how-paper-is-made/ [2019, September 10]

PAMSA. 2019c. The Sustainability Story: Water. Available: https://www.thepaperstory. co.za/the-sustainability-story/water/ [2019, September 10]

Parliamentary Monitoring Group [PMG]. 2015. *Questions and replies: Economic Development B.* Pretoria: PMG.

Phillips, L. 2018. Hemp production could soon be legal. Available: https://www.farmersweekly.co.za/agri-news/south-africa/hemp-production-soon-legal/ [2019, 10 September].

Pilane, P. & Green, A. 2019. Sugary drinks turns one – amid opposition. Available: https://health-e.org.za/2019/04/01/sugary-drinks-tax-turns-one-amid-opposition/ [2019, 10 September].

Pil, L. Bensadoun, F. Pariset, J. & Verpoest, I. 2016. Why are designers fascinated by flax and hemp fibre composites?. *Composites Part A: Applied Science and Manufacturing.* 83(2016). 193-205.

Piotrowski, S. & Carus, M. 2011. Ecological benefits of hemp and flax cultivation and products. *Nova institute* 5(2011).1-6.

Pradhan, A. & Mbohwa, C. 2014. Development of biofuels in South Africa: challenges and opportunities. *Renewable and Sustainable Energy Reviews*. 39: 1089 – 1100.

Qicheng, R., Jianmin, Q., Kaihui, H., Xiuhua, C., Guorong, L. & Dian, W. 2012. Bioconversion of fuel ethanol from kenaf stalk. *Journal of Fujian Agriculture and Forestry University (Natural Science Edition*). 41: 78-82.

Raymer, P.L., 2002. Canola: an emerging oilseed crop. Trends in new crops and new uses. Vol. 1, pp.122-126.

Roseberg, R.J. 1996. Underexploited temperate industrial and fibre crops. In *Progress in new crops*. Janick, J. Ed. Alexandria, Australia: ASHS Press. 60-84.

SAPPI. 2019. Dissolving Wood Pulp. Sustainability FAQs. Available: https://cdn-s3.sappi.com/s3fs-public/Sappi-FAQs-Dissolving-wood-pulp.pdf [2019, September 10]

Scheba, A., Mayeki, S. & Blanchard, R. 2017. *Bamboo for green development? The opportunities and challenges of commercialising bamboo in South Africa*. Cape Town: Human Research Sciences Council.

Silalertruksa, T., Gheewala, S.H., Hünecke, K. and Fritsche, U.R. 2012. Biofuels and employment effects: Implications for socio-economic development in Thailand. *Biomass and bioenergy*. 46:409-418.

Small, E. & Marcus, D. 2003. Tetrahydrocannabinol levels in hemp (Cannabis sativa) germplasm resources. *Economic Botany*. 57(4). 545-558.

South African Sugar Association. 2018. SASA Position on the new sugar tariff. Available: http://www.dti.gov.za/parliament/2018/SASA_Tariff.pdf [2019, 9 September].

Textile Innovation Knowledge Platform (TIKP). 2019. Manufacturing: Nonwovens Manufacturing. Available: http://www.tikp.co.uk/knowledge/technology/nonwovens/under-construction/ [2019, September 18]

Truong, A.H. & Le, T.M.A. 2014. Overview of bamboo biomass for energy production. *HA Archives, No. halshs-01100209*. HAL.

van der Lugt, P. & Lobovikov, M. 2008. Markets for bamboo products in the West. *Bois Et Forêts Des Tropiques, No. 295(1).* Netherlands: Delft University of Technology

Van der Werf, H.M. 2004. Life cycle analysis of field production of fibre hemp, the effect of production practices on environmental impacts. *Euphytica*. 140(1-2).13-23.

Wang, G., Innes, J., Dai, S. & He, G. 2008. Achieving sustainable rural development in Southern China: the contribution of bamboo forestry. *International Journal of Sustainable Development and World Ecology*. 15(5).484-495.

Webber, C.L., III. & Bledsoe, R.E. 1993. Kenaf: production, harvesting, and products. In *New crops*. J. Janick, J & Simon, J.E. Eds. New York: Wiley. 416–421.

Welsh, D.J.A. 1968. Kruskal's theorem for matroids. In Mathematical Proceedings of the Cambridge Philosophical Society. Vol. 64, No. 1, pp. 3-4. Cambridge University Press.

Wood, I. M. & de Jong, S. 1997. Plant fibre crops. In *The new rural industries: a handbook for farmers and investors*. Hyde, K.W. Ed. Canberra, Australia: Rural Industries Research and Development Corporation. 453-463.

World Bank. 2019. World Bank GNI per capita operational guidelines and analytical classifications. Dataset. Available: https://datahelpdesk.worldbank.org/knowledgebase/articles/378834-how-does-the-world-bank-classify-countries [2019, June 05]

APPENDIX I: SUPPLEMENTARY TABLES AND FIGURES

Table A. 1: Top- and bottom-ranked fibrous products by PCI, 2016

Ranking	HS4 Code	Product Name	PCI	Product Community
1	3403	Lubricants	3.922	Chemicals & allied industries
2	9205	Musical instruments, wind	3.639	Miscellaneous
3	5911	Textile articles for technical use	3.359	Textiles/clothing
4	3912	Cellulose N.E.C.	3.052	Plastics/rubbers
5	3816	Refractory cements	2.943	Chemicals & allied industries
6	8708	Parts of motor vehicles	2.925	Transportation
7	2930	Organo-sulphur compounds	2.839	Chemicals & allied industries
8	9003	Frames for spectacles, goggles	2.818	Miscellaneous
9	5603	Nonwoven textiles	2.771	Textiles/clothing
10	5905	Textile wall coverings	2.763	Textiles/clothing
⋮	⋮	⋮	⋮	⋮
166	1211	Plants used in perfumery, pharmacy or insecticide	-2.493	Vegetable products
167	6103	Men's suits, knit	-2.520	Textiles/clothing
168	6305	Bags for packing goods	-2.610	Textiles/clothing
169	4601	Products of plaiting materials	-2.634	Wood & wood products
170	1521	Vegetable waxes and beeswax	-2.794	Vegetable products
171	5305	Vegetable textile fibres	-2.908	Textiles/clothing
172	5307	Yarn of textile bast fibres	-3.380	Textiles/clothing
173	6505	Hats, knit	-3.571	Footwear/headgear
174	5310	Woven fabrics of jute or of other textile bast fibres	-3.583	Textiles/clothing
175	5303	Textile bast fibres	-5.015	Textiles/clothing

Source: Authors' calculations from CID (2019)

Table A. 2: Fibrous Products in South Africa's Export Basket, 2016

HS4 Code	Community	Product Name	PCI
6502	Footwear/headgear	Hat shapes	-2.260
6217	Textiles/clothing	Other clothing accessories	-1.377
3301	Chemicals & allied industries	Essential oils	-1.372
3401	Chemicals & allied industries	Soap	-1.319
4402	Wood & wood products	Wood charcoal	-1.301
1209	Vegetable products	Seeds used for sowing	-1.203
6405	Footwear/headgear	Other footwear	-1.037
1208	Vegetable products	Flours of oil seeds	-0.866
1512	Vegetable products	Sunflower seed oil	-0.784
0604	Vegetable products	Other parts of plants	-0.769
2207	Foodstuffs	Ethyl alcohol > 80%	-0.751
1517	Vegetable products	Margarine	-0.667
4820	Wood & wood products	Notebooks	-0.607
2001	Foodstuffs	Pickled fruits and vegetables	-0.601
3101	Chemicals & allied industries	Animal or vegetable fertilizers	0.021
4404	Wood & wood products	Strips and other pieces of wood	0.634
4804	Wood & wood products	Uncoated craft paper and paperboard	1.077
3405	Chemicals & allied industries	Polishes and creams	1.290
2206	Foodstuffs	Other fermented beverages	1.420
6808	Stone/glass	Panels of vegetable fibres	1.574
4808	Wood & wood products	Corrugated paper and paperboard	1.949
3803	Chemicals & allied industries	Tall oil	2.024
4702	Wood & wood products	Chemical wood pulp, dissolving grade	2.161

Source: Authors' calculations from CID (2019)

Note: 1. Fibrous products listed here were those for which RCA≥1for South Africa in 2016. 2. While these products can be produced using fibrous plant materials as an input, there is no manner of knowing whether this is the case.

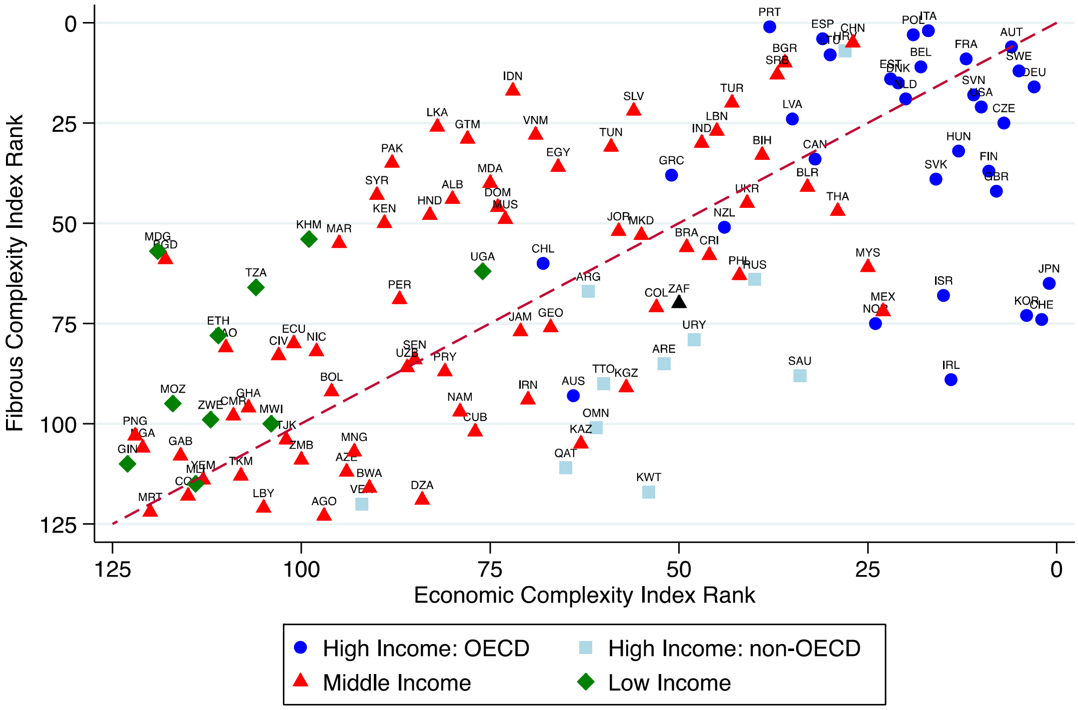


Figure A. 1: Relationship Between ECI Rank and FCI Rank, 2016

Source: Authors' calculations from CID (2019)
Note: Red dashed line is a 1:1 reference line.

Table A. 3: South Africa's Fibrous Frontier Products, 2016

HS4 Code	Community	Product Name	PCI
2209	Foodstuffs	Vinegars	0.182
4417	Wood & wood products	Wooden tools	0.239
1108	Vegetable products	Starches	0.342
4411	Wood & wood products	Fibreboard of wood	0.622
4821	Wood & wood products	Paper labels	0.650
2309	Foodstuffs	Animal feed	0.736
1518	Vegetable products	Animal or vegetable fats and oils, processed	0.740
5601	Textiles/clothing	Wadding of textile materials	0.767
3305	Chemicals & allied industries	Hair products	0.924
3402	Chemicals & allied industries	Cleaning products	0.996
9403	Miscellaneous	Other furniture and parts	1.027
4818	Wood & wood products	Toilet paper	1.036
2106	Foodstuffs	Food preparations N.E.C.	1.046
4817	Wood & wood products	Letterstock	1.063
4703	Wood & wood products	Chemical wood pulp, soda or sulphate	1.147
4410	Wood & wood products	Particle board and similar board	1.152
9401	Miscellaneous	Seats	1.168
4905	Wood & wood products	Maps	1.190
4705	Wood & wood products	Semi-chemical wood pulp	1.219
4706	Wood & wood products	Pulps of recovered paper fibres	1.343
2909	Chemicals & allied industries	Ethers	1.370
2303	Foodstuffs	Starch residues	1.408
4418	Wood & wood products	Wood carpentry for construction	1.408
4813	Wood & wood products	Cigarette paper	1.416
4901	Wood & wood products	Books, brochures etc.	1.473
3304	Chemicals & allied industries	Make-up preparations	1.497
4823	Wood & wood products	Other paper cut to size	1.508
4807	Wood & wood products	Uncoated composite paper	1.547
5602	Textiles/clothing	Felt	1.550
4415	Wood & wood products	Packing boxes	1.563
4811	Wood & wood products	Cellulose wadding, coated	1.564
4805	Wood & wood products	Other uncoated paper and paperboard	1.630
4822	Wood & wood products	Bobbins, spools, cops of paper	1.714
4416	Wood & wood products	Casks, barrels, etc. of wood	1.820
4911	Wood & wood products	Other printed matter	1.897
4808	Wood & wood products	Corrugated paper and paperboard	1.949
3208	Chemicals & allied industries	Paints and varnishes, nonaqueous	1.961
4814	Wood & wood products	Wallpaper	2.038
3003	Chemicals & allied industries	Medicaments, not packaged	2.047
4906	Wood & wood products	Architectural, engineering, etc. drawings	2.065

HS4 Code	Community	Product Name	PCI
3004	Chemicals & allied industries	Medicaments, packaged	2.112
4704	Wood & wood products	Chemical wood pulp, sulphite	2.220
4802	Wood & wood products	Paper used for graphic purposes	2.397
4902	Wood & wood products	Newspapers, journals and periodicals	2.432
4701	Wood & wood products	Mechanical wood pulp	2.454
4801	Wood & wood products	Newsprint	2.510
5603	Textiles/clothing	Nonwoven textiles	2.771
8708	Transportation	Parts of motor vehicles	2.925
3816	Chemicals & allied industries	Refractory cements	2.943
5911	Textiles/clothing	Textile articles for technical use	3.359

Source: Authors' calculations from CID (2019)

Appendix II: Fibrous Frontier Products versus Frontier Fibrous Products

It should also be noted that amongst the set of frontier products identified in Section 6.1, there are a fair number of fibrous products. It is important at this point to understand the distinction between, what we term, 'fibrous frontier products' and 'frontier fibrous products'. Frontier products are the non-RCA products that meet the criteria outlined in Section 6.1. Fibrous frontier products are then the subset of those frontier products that can be produced using the fibrous plants as their feedstock material. Frontier fibrous products, on the other hand, would be those products identified by applying the four-step methodology, detailed in Section 6.1, to only fibrous products that have RCA$<$1. In other words, frontier fibrous products would aim to develop fibrous complexity and the fibrous economy specifically but would not necessarily increase complexity in the economy as a whole.

Although the identification of frontier fibrous products is possible, it is hard to make an economic case for why one would focus here. The power of the economic complexity framework lies of course in being able to identify paths of diversification which develop the economy as a whole (Hausmann et al., 2014; Hausmann and Chauvin, 2015). By focusing purely on the fibrous economy then, opportunities for aggregate economic development may be missed.

Data restrictions make it impossible to determine whether the occupation of a particular node in the *fibrous product space* (i.e. exporting a fibrous product with RCA$\geq$1) actually means that a country is producing that product with fibrous plants. As an example, margarine is a fibrous product produced by South Africa with RCA$\geq$1 in 2016. The trade data does not distinguish as to whether the margarine produced in South Africa is made using the oils from hemp, bamboo and kenaf, or whether it is made using oils from other plants, such as sunflowers, or rapeseed.[1] As a result, the data is not well suited to limiting analysis to only those frontier products within the fibrous plant industry as there is no guarantee that the capabilities for producing products out of our chosen fibrous plants exist at this point.

1 Rapeseed oil that has less than 2% erucic acid produces canola oil, which is used in the production of margarine (Raymer, 2002).

Appendix III: Research Approach – Firm Surveys

The method used to sample firms in this research project is based primarily on the process undertaken by Bhorat et al. (2019a). Their method included a stratified sampling design, whereby a number of predetermined product communities were identified, and a sample was chosen within each of these product communities. The communities in question for this paper were identified broadly as those communities into which fibrous frontier products fall. Stratification of the sample across product communities ensured that the resultant findings covered sufficiently many of the available fibrous frontier products so as to be inclusive in scope.

In this paper, stratification was carried out at three levels: firstly, industry experts for each of the identified product communities were identified. Secondly, where possible, firms using each of the fibrous plants as an input to their production process were selected, whether or not they were currently producing products within the fibrous frontier product groupings. Finally, firms identified as key players in the market for each of the identified fibrous frontier product communities were identified and interviewed, regardless of whether they used fibrous feedstock in their production process. Only by stratifying across all three of these levels would we be able to truly interrogate the possibilities for growing the fibrous economy. Industry experts provide valuable insight into the existing value chain in the country, while speaking to the productive capabilities that South Africa currently possesses. Firms using fibrous plants as an input would provide insight into the challenges of setting up a fibrous plant industry in South Africa, as well as where they have identified available markets for fibrous products. Finally, speaking to those firms who produce fibrous products, but are using alternative inputs, would inform potential barriers to entry for transitioning into production using fibrous plants as an input. Together, these insights provide a holistic picture of the opportunities and challenges faced in growing a fibrous plant industry in South Africa.

Interviews began with industry experts in order to ensure that a full understanding of the relevant product value chain was established. Hereafter, through a combination of desktop research and referrals by industry experts, a sample of firms suitable for interviewing was identified. After conducting interviews with the selected firms, if a referral for another firm was provided by the interviewee, this linked firm was included in the sample of potential interviewees.

In total, 25 semi-structured firm and industry expert interviews were conducted. Table A. 4 shows the product communities of interest and the fibrous frontier products that fall within these communities. The interviews focused on the following product communities: wood, paper and pulp products, chemicals and allied industries, textiles and clothing, and transportation. The number of interviews detailed in the table do not aggregate to 25 because interviews with certain respondents covered multiple product communities and fibrous frontier products.

The survey instrument used to conduct the interviews was a mixture of short-answer and open-ended questions. The survey instrument was designed to determine, among other things: the potential for fibrous plant material to act as a feedstock to the processing and production of fibrous frontier products, the factors that may constrain this use of fibrous plant material as a feedstock, general factors that constrain or enable the development of these products, and the employment potential of these products.

Interviews, in general, lasted between 60 and 90 minutes. Where answers were brief in nature, such as average educational attainment of the workforce, or whether a fibrous plant is used in the production process, short-answer questions were used. However, when interrogating the challenges firms may face in shifting production to a new input, or the constraints and opportunities to growing the current industry, more open-ended questions were used. This mix of questions provides a more nuanced understanding of the workings of the industry than a purely short-answer survey instrument, and as a result, provides richer conclusions to translate to policymakers.

Although every attempt was made to ensure that the sample of firms provided generalisable results, this was impossible to guarantee. Firstly, the small sample size precludes the sample from being representative of the industry as a whole. Secondly, by identifying key players in the industry and then acting on referrals provided by these players, there is an element of selection bias present in the sample. Bhorat et al. (2019a) noted similar challenges in their research but note that by restricting comparisons between firms to a narrowly defined, relatively homogenous product, it is possible to mitigate some of this bias and still obtain useful insights. Furthermore, where necessary, information provided by respondents was corroborated and supplemented with desktop research. This was done in order to ensure that information gathered during the interview process was somewhat representative of the industry view, and not simply an outlying opinion of one firm.

Table A. 4: Survey Interviews by Fibrous Frontier Product Community

Product Community	Frontier Products	No. Interviews
Wood, paper and pulp products	Wood products: Fibreboard; Wooden tools; Particle board; Wood carpentry; Casks, barrels etc. of wood; Paper products: Paper labels; Toilet paper; Letterstock; Maps; Cigarette paper; Books brochures etc.; Other paper cut to size; Uncoated composite paper; Packing boxes; Other uncoated paper and paperboard; Bobbins, spools, cops of paper; Other printed matter; Corrugated paper and paperboard; Wallpaper; Architectural, engineering, etc. drawings; Paper for graphic purposes; Newspapers, journals and periodicals; Newsprint Pulp products: Chemical woodpulp, soda or sulphate; Semi-chemical woodpulp; Pulps of recovered paper fibres; Cellulose wadding; Chemical woodpulp, sulphite; Mechanical woodpulp	8 firms 2 industry experts
Chemical and allied industries	Hair products; Cleaning products; Ethers; Make-up preparations; Paints and varnishes, non-aqueous; Medicaments, not packaged; Medicaments, packaged; Refractory cements	4 firms 2 industry experts
Textiles and clothing	Wadding of textile materials; Felt; Nonwoven textiles; Textile articles for technical use	4 firms 2 industry experts
Transportation	Parts of motor vehicles	4 firms 2 industry experts

Although the above steps were taken to mitigate bias in the sample, this bias is not wholly eradicated. However, even with a biased sample, the results obtained are valuable in that they provide an insight into the workings of various industries in the South African context. This brief insight, coupled with desktop research, can provide a strong foundation from which micro-industrial policy can be developed.