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Measuring intra-industry trade and productivity in the South African pharmaceutical sector

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Background: The South African pharmaceutical sector is Africa's largest and most advanced but heavily depends on imported products and active pharmaceutical ingredients to meet its demands. The status quo is due to low intra-industry trade, which is necessary to induce innovation and technological progress essential for accelerating local production, export growth and reducing dependence on imports.

Aim: The primary objective of this article was to examine intra-industry trade in South Africa's pharmaceutical sector and subsequently, total factor productivity (TFP) as a key driver of intra-industry trade.

Setting: Intra-industry trade was measured using data obtained from the United Nations Conference on Trade and Development databases, while the TFP was measured using data from the South African Reserve Bank (SARB) covering 2001–2021.

Method: The marginal intra-industry trade index (MIIT) and unmatched changes in trade (UMCIT) were used to measure intra-industry trade, while the Malmquist total factor productivity (MTFP) index was used to analyse SARB data to determine TFP.

Results: The MIIT index and UMCIT revealed that trade is predominantly inter-industry with episodes of industry specialisation and significant intra-industry changes. The MTFP results showed that TFP is solely driven by technical changes.

Conclusion: The study recommends that South Africa should develop a coordinated and sustainable innovation system in the pharmaceutical sector. This will help prevent sporadic technological advancements and promote intra-industry trade.

Contribution: The article contributes to the empirical literature on intra-industry trade in developing countries by showing the correlation between an improvement in TFP and an increase in intra-industry trade necessary to stimulate domestic production to reduce high import demand.

Keywords: intra-industry trade; marginal intra-industry trade; pharmaceutical sector; South Africa; total factor productivity; Malmquist total factor productivity; import dependence.

Introduction

South Africa is Africa's largest and most advanced pharmaceutical producer, with an estimated market size of $3.9 billion, followed by Egypt at $2.6 bn (African Pharmaceutical Analysis Report 2021). It comprises about 128 companies, including local dominant players, multinational companies and retailers (Phillips 2023). The major players include Aspen Pharmacare, supplying over 150 countries and Adcock Ingram, which has a market share of 18% by value and 27% by volume (Veitch 2020). Aspen, Adcock Ingram, Cipla, Sanofi and Novartis (Table 1-A1) are the leading pharmaceutical firms in South Africa based on their supply of scheduled and non-scheduled medicines for prescribed and over-the-counter medication. These companies are involved in various stages of the pharmaceutical supply chain, including research and development (R&D), manufacturing, marketing and distribution. The South African pharmaceutical sector is an important contributor to the country's economy and significantly contributes to the region's healthcare landscape. However, the industry heavily depends on imports to meet some of its needs, particularly for high-tech and patented products. Local manufacturers of pharmaceutical products rely heavily on the imports of active pharmaceutical ingredients (APIs). Some studies that examined the South African pharmaceutical sector found that it largely depends on imported products (Maloney & Segal 2007; Rayment 2020; Te Naudé & Luiz 2013; Veitch 2020; Viviers et al. 2014). While imports may benefit the country by providing access to a wide variety of products among other things, heavy dependency on imports comes with a number of problems.

Firstly, the prices for medicines and other pharmaceutical products increase because most South African manufacturers depend on imported APIs and other raw materials to manufacture their products. Importing raw materials and the weaker Rand (local currency) lead to manufacturers selling at higher prices, which many people struggle to afford. The consumer price index (CPI) for medicinal products in South Africa was measured at 110.5 points. This is an increase of 6.5 points from the previous prices over a period of 4 years (Figure 1-A2) (Statistica 2023). The issue of unaffordable high-quality medicines does not only impact South Africa, but also other Southern African countries that rely on South Africa for their pharmaceutical supplies. A substantial percentage, ranging from 27.6% to 73.6%, of South Africa's pharmaceutical exports (Table 1-A2) are directed to the Southern African Development Community (SADC). As a result, healthcare affordability and access to high-quality medicines for all citizens have been a critical government priority in South Africa since the end of apartheid in 1994 (Moodley & Suleman 2019). However, this goal has not been achieved so far.

Secondly, the pharmaceutical sector constitutes a significant part of the economy (estimated at $3.9 bn). As such, the increasing pharmaceutical trade deficit (also shown in Table 1-A3) negatively affects the country's economy by draining foreign exchange reserves and stifling economic growth and the capacity to create jobs. Therefore, policymakers and industry stakeholders need to monitor and address the issue of import dependence to ensure sustainable growth and competitiveness in the industry. As such, local manufacturing of medicines is of strategic importance for the South African government (Veitch 2020:35).

Thirdly, depending on imported pharmaceuticals further exposes society to low-quality and counterfeit products as manufacturing standards and quality control measures vary from one country to another. Counterfeit products are often sold at a lower price than legitimate medicinal products, which attracts consumers who seek cheaper alternatives. As such, the South African Health Products Regulating Authority (SAHPRA) has recalled a number of medicines from May 2021 to August 2023 (Table 1-A4).

Fourthly, domestic firms struggle to compete with foreign firms, leading to declining domestic manufacturing. This trajectory is evident in South Africa, as an estimated nine plants closed down in the late 1990s because more companies opted to import rather than produce (Table 1-A5). On a global scale, the South African pharmaceutical sector is positioned as an end market for the sale of products produced elsewhere through the global value chain (GVC) rather than as a site of manufacturing (Horner 2021). As such, South Africa should carefully manage its trade relationships in this sector and strike a balance between imports and exports to maintain a certain level of domestic production and self-reliance.

To this end, this study contends that intra-industry trade is vital for the growth and sustainability of the South African pharmaceutical sector because such trade will spur innovation and technological progress, thereby fostering local production, boosting export expansion and lessening reliance on imports. Accordingly, the National Industrial Policy Framework (Strategic Program 3:9.6) acknowledges export promotion as vital for creating employment and reducing current account deficits while emphasising the need to identify and consider export constraints (National Industrial Policy Framework 2014). Moreover, the coronavirus disease 2019 (COVID-19) outbreak has emphasised the need for African countries to enhance local and regional production abilities for various manufactured goods, particularly in the pharmaceutical sector. This study primarily aims to examine the trade pattern between South Africa and its trading partners in the pharmaceutical industry and measure the level of intra-sectoral trade. The results will reveal the level of intra-industry trade and the direction of trade specialisation, which has implications for the flow of factors of production in the South African pharmaceutical sector.

Intra-industry trade has been a subject of contention for many years. Scholars acknowledge that such trade has become increasingly recognisable in international trade and is a significant part of trade. Nevertheless, intra-industry trade is primarily associated with high and middle-income countries, while African trade remains overwhelmingly inter-industry (Brülhart, Elliott & Lindley 2006). As a result, studies that examined intra-industry trade in the African context are limited. However, there is evidence that some trade in developing countries is also intra-industry (Manrique 1987). The few studies that investigated intra-industry trade in South Africa include the unpublished study by Simson (1987), Parr (2000), Isemonger (2000), Al-Mawali (2005), and Sichei, Harmse and Kanfer (2007). Noteworthy, these studies were carried out before economic crises such as the 2008 global financial crisis, the Eurozone financial crisis, the COVID-19 pandemic and recovery. Also, rapid technological advancement, numerous trade agreements, policy shifts and the rise of emerging markets such as China and India are all factors that may have reshaped trade relationships and are not captured by these studies, considering the time they were carried out. Furthermore, none of the studies analysed intra-industry trade within a specific industry. A more comprehensive understanding can be derived from a detailed examination of an individual industry, considering its distinctive institutional structures and global standing, directly affecting its trade performance.

If most of the trade growth is intra-industry (IIT), then industries benefit from lower adjustment costs as the disruption to factor markets is likely to be minimal during trade expansion because each industry produces differentiated varieties, which have similar factor requirements (Brülhart 1994; Greenaway et al. 1995; Hamilton & Kniest 1991; Helpman 1981; Helpman & Krugman 1985; Menon & Dixon 1997). Moreover, intra-industry trade may stimulate innovation, increase investment in knowledge-based capital, facilitate joint research and increase specialisation. All these benefits would further intra-industry trade, leading to increased productivity, industrial expansion and depth, and industrial performance. This implies that industries that engage in intra-industry trade are less prone to substantial adjustment costs such as retraining workers, upgrading technology or infrastructure, relocating to a new area or complying with new regulations. These costs may decrease profits for firms in the short run, potentially restricting new firms from entering the market. Consequently, the level of local manufacturing decreases while the appetite to source cheap imports increases. High adjustment costs perpetuate dependence on imported products and increase the industry's vulnerability to external shocks. Therefore, the South African pharmaceutical sector would benefit from intensifying intra-industry trade.

Based on the general view in the literature concerning the nature of trade in developing countries, the study expects trade in the South African pharmaceutical sector to be significantly inter-industry. Therefore, the second fold aims to investigate the factors that are key to improving intra-industry trade. The question then becomes, 'What factors play a pivotal role in enhancing intra-industry trade in the South African pharmaceutical industry?' The point of departure on this subject is that there are low pharmaceutical exports compared to imports in South Africa. As such, local pharmaceutical production and exports must improve to enhance intra-industry trade. Increased local production and exports can be achieved by improving productivity in the sector.

The nexus between productivity and export growth is well documented in the literature. One strand of the literature views outward-oriented trade regimes as a source of productivity gains (Benguria, Matsumoto & Saffie 2022; Chen & Tang 1990; Hatemi & Irandoust 2001). Another strand contends that high productivity increases the likelihood for firms to export if they are larger and if they benefit from foreign networks, domestic networks and communication networks (Aitken, Gordon & Harrison 1997; Bernard & Jensen 2004; Ricci & Trionfetti 2012; Roberts & Tybout 1997). Total factor productivity (TFP) is commonly used to measure firms' productivity. Furthermore, effective economic and business policy-making requires precise measurement of TFP change and its components (O'Donnell 2012). For this reason, this study will empirically analyse TFP to determine the factors that influence productivity in order to boost exports in the South African pharmaceutical sector. The aim is to see more pharmaceutical exports matching imports to increase intra-industry trade.

Lastly, this study aligns with the primary objective of the 15-year Pharmaceutical Manufacturing Plan for Africa (PMPA), spanning from 2013 to 2028. The plan aims to support local pharmaceutical manufacturing to enhance access to affordable, quality medicines and establish a sustainable supply chain for essential medicines (AUC-UNIDO 2012). Furthermore, this study's objectives also align with the Sustainable Development Goals 2030 (SDG 2030), which focus on boosting the share of global exports for developing nations. The rest of the article discusses the theoretical literature, methodology, analysis of results, policy-making implications and conclusion.

Theoretical literature review

Initial research on international trade sought to explain the economic benefits associated with countries that trade with one another. The theory of comparative advantage introduced by David Ricardo in 1821 was the primary reference for this purpose. The Ricardian theory emphasised the importance of having a different comparative advantage in trading countries for trade to be beneficial. As interpreted by Davis (1995:203), the Ricardian theory advances that technical differences become significant in trade patterns when the expansion of an individual sector does not lead to a rise in marginal opportunity costs. However, the theory of comparative advantage failed to explain why production conditions differ between countries, an issue that Heckscher (1919) and Ohlin (1933) attributed to differing factor endowments.

In contrast to the supply-side orientation of the Heckscher and Ohlin model, Linder (1961) predicted that trade is a product of 'overlapping demand'. This theory suggests that countries produce goods for their domestic market and export the surplus. As such, Linder concluded that countries interested in purchasing this surplus would have demand patterns similar to those of the exporting country. Linder's prediction that most trade in the world should occur between similarly endowed countries is no paradox; it is, instead, the natural result of a demand-driven trade.

To some extent, traditional trade theories still hold in today's world. However, it has been observed that trade between countries with similar economies has significantly increased over the years. Studies of international trade reached a consensus that trade has evolved from inter-industry to more intra-industry trade. Subsequently, scholars examined intra-industry trade to determine if its underpinnings align with the existing trade theories. Differing conclusions have been reached in this regard, with some maintaining that intra-industry trade can be viewed through the lenses of comparative advantage and factor endowment theories (Brülhart 2008; Davis 1995; Ddudovskiy 2012; Finger 1975; Helpman 1981; Ruffin 1999). In contrast, others criticised the traditional theories for inadequately explaining the new trade patterns (Falvey 1981; Gray 1976; Greenaway & Milner 1983; Kierzkowski 1987; Krugman 1981). The main criticism is that the comparative advantage and factor-endowment theories fail to explain significant volumes of trade between countries with similar factor endowments and technology and to capture the role of product differentiation and economies of scale. As such, Eaton and Kierzkowski (1984), Helpman (1981), Lancaster (1980) and Krugman (1979, 1981) pioneered the groundwork in the field of intra-industry trade.

Subsequently, large volumes of scholarly work have been produced to shed light on the importance, measurement and determinants of intra-industry trade. The literature highlights lower adjustment costs as the main benefit of intra-industry trade because an increase in intra-industry rather than inter-industry trade enables a simple adaptation to trade growth (Greenaway & Milner 1983; Menon & Dixon 1997:164). In terms of measurement, it is essential to measure intra-industry trade as accurately as possible to test any newly developed models of intra-industry trade. As such, the Grubel-Lloyd (1975) index has been widely used as a standard measure of intra-industry trade. However, the Grubel-Lloyd index has been met with severe criticisms, leading to the development of alternative models discussed in the 'Methodology' section.

As Lancaster (1980) introduced it, Paul Krugman's New Trade Theory revolutionised the field of international trade economics. Lancaster (1980) argued that under perfect monopolistic competition, firms have some market power and can produce various differentiated products, leading to intra-industry trade between countries. The central concepts in Lancaster's theory are 'product space' and 'product characteristics'. On the one hand, product space implies that products can be arranged in a multi-dimensional product space based on various characteristics such as quality, design and brand. Countries with similar preferences and abilities will trade products that are close in this space.

On the other hand, product characteristics within each category imply that products can be distinguished by their characteristics, and consumers may have preferences for specific attributes. For instance, automobiles can differ in size, fuel efficiency or safety features. These differences provide a premise for trade within the industry because it would not make sense for a country to import a good that is identical to what is produced domestically. Product differentiation and imperfect competition have been bases for repeatedly attesting and justifying intra-industry trade as a new approach to international (Fontagné, Gueriné & Jean 2005). For example, the South African pharmaceutical industry is characterised by a broad range of products, including branded drugs, generics and specialised treatments, each varying in formulation, efficacy and market targeting, driven by significant R&D investments and regulatory requirements that enforce product uniqueness. Furthermore, the South African pharmaceutical market is oligopolistic, dominated by a few firms with substantial market power, high entry barriers, and prevalent mergers and acquisitions, which all contribute to an imperfect competitive environment. These factors create a landscape where the exchange of differentiated products is common, such as South Africa importing innovative drugs while exporting generics. Therefore, it reasons that Lancaster (1980) provides a theoretical framework underpinning this study, just as Krugman (1979, 1980, 1984) used the same framework in his analysis of intra-industry trade.

Methodology

Measuring marginal intra-industry trade

The degree of intra-industry trade (IIT) in the South African pharmaceutical sector was measured using 1-digit SITC data from the United Nations Conference on Trade and Development (UNCTAD) databases from 2002 to 2021, available online at https://unctad.org. The period studied is critical for pharmaceutical trade because (1) it is when South Africa entered into deeper trade agreements with notable global pharmaceutical producers such as India and China; (2) South Africa implemented major policy changes in the Department of Health such as introducing the single exit price (SEP) and the massive rollout of antiretroviral therapy (ART) in 2003; (3) this period is characterised by the adoption of the Fourth Industrial Revolution (4IR), which saw the integration of automation into the manufacturing processes; and (4) pre- and post-COVID-19 pandemic also falls within this period. All these factors potentially affected the pattern of the pharmaceutical trade.

The Grubel-Lloyd Index (GL*i*) is the standard measure of intra-industry trade between countries. However, Lee (2004) criticised the index for being fundamentally flawed and lacking theoretical foundations. The GL*i* was criticised for neglecting the adjustment cost aspect. Hence, the introduction of the *marginal* intra-industry trade (MIIT), which measures the degree of IIT in *new* trade, became an alternative to the GL*i* (Brülhart 1994, 1999; Greenaway et al. 1995; Hamilton & Kniest 1991; Parr 2000).

Hamilton and Kniest (1991:360) proposed the original MIIT, which calculates the percentage rise in matched exports and imports. It has been found to have certain limitations, leading to a discussion on an appropriate measure (Cattaneo & Fryer 2002). Greenaway and Torstensson (1997:253) highlighted the primary drawbacks of the Hamilton-Kniest measure, represented by dX/dM if dM> dX> 0 and dM/dX if dX > dM > 0.32. Firstly, if there is a decrease in imports or exports, the MIIT index is undefined. Secondly, the measure is unscaled (also a major limitation of the Grubel-Lloyd index): It does not refer to the actual amount of new trade, nor to the initial level of trade or production within that specific sector. Lastly, the changes in trade were measured in nominal rather than absolute terms, and this criticism would apply to any MIIT index (Cattaneo & Fryer 2002).

Brülhart (1994) and Greenaway et al. (1994) developed many alternative measures of MIIT to correct the limitations of the Hamilton-Kniest measure. This study will use the MITT index proposed by Brülhart (1994) because it provides a more nuanced understanding of how trade patterns evolve. For example, it allows one to differentiate the adjustment in intra- or inter-industry trade that is taking place.

Brülhart's basic measure of matched changes is as follows (Equation 1):

$$\text{MIIT} = \frac{\left(dX_i - dM_i\right)}{\left(\left|dX_i\right| + \left|dM_i\right|\right)} \qquad \text{[Eqn 1]}$$

where dX_i is industry i's change in exports and dM_i is industry i's change in imports. Then (dX_i – dM_i) represents the net value of new trade and ($|dX_i|$ + $|dM_i|$) represents the absolute value of total new trade. The value ranges from -1 to 1. Matched (intra-industry) trade is indicated by MIIT = 0, which means that the new trade is dXi = dMi. Unmatched (inter-industry) trade is indicated by the value of MIIT between 0 and -1, which means that new trade is dXi < dMi and that the country has specialised out of the industry (Cattaneo & Fryer 2002). Lastly, if dXi > dMi, and MIIT is between 0 and 1, it implies that the new trade is more inter-industry or unmatched. However, the country has developed a specialisation in that industry (Parr 2000:302). The sign of the index is helpful to indicate the direction of specialisation in individual sectors (i.e. into or out of the sector). In contrast, its size signifies the degree to which new trade is matched or unmatched relative to the total change in trade. For instance, an MIIT value of -1 signifies that marginal trade is unmatched and the country is specialising out of that particular sector (Cattaneo & Fryer 2002).

While any deviation of MIIT from zero indicates some level of inter-industry specialisation, choosing a threshold between significant intra-industry changes and notable inter-industry specialisation into or out of the industry is important. Following Parr's approach, this study selects critical MIIT values of ±0.65 (Parr's 2000:302). This means that a value of MIIT ranging from -1 to -0.65 indicates specialisation out of the industry; MIIT from -0.65 to 0.65 indicates significant intra-industry changes have taken place; and MIIT from 0.65 to 1 indicates that there has been specialisation into that industry.

As Cattaneo and Fryer (2002) point out, it is important to incorporate a qualification when selecting a suitable index for examining adjustment costs concerning intra-industry trade. Menon and Dixon (1997:164) contend that the focal point should be measuring new inter-industry or unmatched trade, typically treated merely as a residual component. They propose utilising unmatched changes in trade (UMCIT) measures, asserting its greater suitability for research focussed on adjustment costs. Unlike MIIT, UMCIT can quantify the extent of trade changes necessitating inter-industry factor adjustments and is measured as follows (Equation 2):

$$UMCIT = |\Delta X_i - \Delta M_i| \quad \text{[Eqn 2]}$$

Despite the weak correlation that Menon and Dixon (1997) found between unmatched and matched measures of intra-industry trade, more evidence can be obtained by using both MIIT and UMCIT to analyse changing trade flows in the South African pharmaceutical sector.

Measuring total factor productivity

As mentioned earlier, the study anticipates that trade is predominantly inter-industry. Consequently, exploring strategies to strengthen intra-industry trade within the pharmaceutical sector is essential for increasing export potential, improving trade balance and reducing dependence on international supplies. One strategy is measuring productivity change in the pharmaceutical sector with a specific focus on factors that influence change in productivity using data from the South African Reserve Bank (2023) and UMCIT values (as explained in the 'Measuring marginal intra-industry trade' section) for the period 2002–2021. This article's fundamental premise is that individual firms operating in the pharmaceutical manufacturing sector aim to maximise their output. In this case, the output is represented by the value of finished pharmaceutical products ready for consumption and exporting. These products are assumed to be produced within the constraints of the firms' available inputs and production technology.

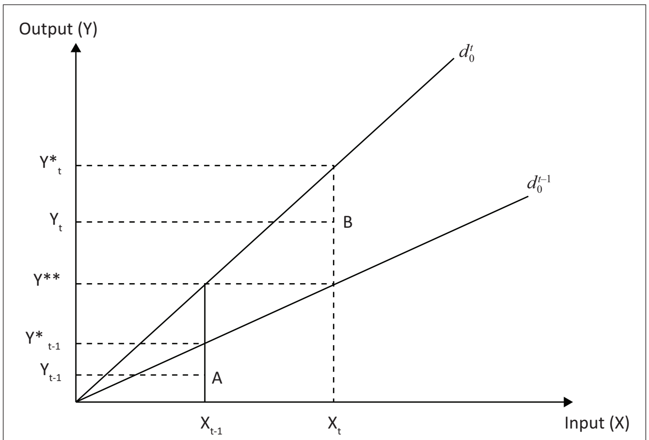
Based on the view that productive firms are more likely to export (Aitken et al. 1997; Bernard & Jensen 2004; Ricci & Trionfetti 2012; Roberts & Tybout 1997), the logic followed in this study is that if firms' productivity increases, exports will increase and more trade will be matched. On the contrary, if firms' productivity declines, exports will decrease, and more trade will be unmatched. This analogy makes the UMCIT eligible for use as an output variable in measuring productivity change. Research and development, foreign direct investment (FDI), real capital formation and labour were used as the input variables. Research and development drives productivity by fostering innovation, enhancing capabilities and providing competitive advantages. While there are challenges associated with R&D investments, the long-term benefits to productivity and economic growth are substantial (Blanco, Gu & Prieger 2016; Griliches 1979; Miguel Benavente 2006). Foreign direct investment drives economic growth, especially for developing nations, offering technological access and positive spillover effects (Li & Tanna 2019; Liu, Agbola & Dzator 2016; Liu et al. 2001). Adequate capital input boosts labour productivity and improvements in labour quality and utilisation lead to higher productivity and economic growth. Understanding and enhancing the role of labour is crucial for increasing TFP (Jajri & Ismail 2018; Li & Tanna 2019; Mate 2015). Therefore, this study employs an output-oriented approach to evaluate alterations in TFP, where TFP is defined as the ratio of total outputs to total inputs (Marire 2020:13). Notably, the primary concern of this article is not to measure the absolute level of productivity but the dynamic changes in productivity over time, which will then influence the intra-industry trade that the UMCIT also represents.

The study utilises a TFP index to quantify the shifts in TFP using the Malmquist index, which facilitates the comparison of TFP changes between consecutive periods while accounting for any shifts in the typical production technology (Balk 2013; Coelli et al. 2005). This framework enables us to assess how efficiently pharmaceutical manufacturing firms utilise their resources and how their productivity evolves.

The data envelopment analysis (DEA) has been widely used in the studies of productivity and efficiency studies to analyse changes in TFP. Cooper, Seiford and Zhu (2011) describe the DEA as a 'data-oriented' mathematical programming technique used for evaluating the performance of a set of peer entities called decision-making units (DMU). The DEA involves using linear programming methods to construct a non-parametric piecewise surface (or frontier) over the data to calculate efficiency in relation to this surface (Coelli et al. 2005). The DEA determines efficient levels of inputs and outputs for the organisation under evaluation by computing a scalar measure of efficiency. This study used the Malmquist total factor productivity (MTFP) index to examine the factors that influence TFP changes in the pharmaceutical industry because it allows us to assess how efficiency and production technology evolve. The MTFP index makes it possible to measure the improvement or decline in efficiency and the underlying production technology. This index provides a dynamic process for analysing changes in efficiency and productivity, and it determines the underlying factors driving these changes by decomposing the Malmquist TFP index. The key components of productivity change include technical change, technical efficiency change and scale efficiency change (O'Donnell 2012).

As in Marire (2020), Figure 1 offers a simplified representation of what production theory considers when assessing changes in productivity and efficiency. The graph assumes constant returns to scale, meaning that outputs increase proportionally to the increased inputs.

Figure 1 illustrates output distance functions and the measurement of productivity change. In this figure, d_0^{t-1} and d_0^t represent the production functions or technologies for periods *t*-1 and *t*, respectively. The decision-making unit operates below its technological frontier in both periods, situated at point A in period *t*-1 and point B in period *t*, indicating inefficiency. Performance measurement studies have identified various factors that contribute to improving TFP growth.



Source: Marire, J., 2020, 'Analysis of changes in Total Factor Productivity for academic departments of historically privileged small university in South Africa', *Progressive* 12(18), 10–24

FIGURE 1: Output distance functions and measurement of productivity change.

Firstly, technical change indicates a shift in production technology, such as an expansion or contraction of the maximal outputs or the production frontier (Coelli et al. 2005). In Figure 1, this is depicted as a transition from d_0^{t-1} to d_0^t or from d_0^t to d_0^{t-1}, and it is typically a product of innovation (Kaplan 1999). As Jakovljevic (2018) points out, innovative organisations consistently undergo cycles of technical change.

Secondly, there is technical efficiency change, where the producer either approaches or moves farther away from the existing production frontier (Coelli et al. 2005). Figure 1 illustrates this movement as a shift from point A towards d_0^{t-1} in period *t*-1 and from point B towards d_0^t in period *t*.

Thirdly, scale efficiency change occurs when the producer enhances productivity by adjusting the scale of operations to achieve a technologically optimal scale (Balk 2001). Figure 1 relates to the ability to produce the same or more output with fewer resources. For instance, producing Y** on d_0^t with input level X_{t-1}, which is less than X_t (the input level required on d_0^{t-1}), demonstrates scale efficiency change. Lastly, the output mix effect refers to improving productivity by altering the combination of outputs (Balk 2001; Coelli et al. 2005). This change in the output mix impacts scale efficiency. The conventional procedure combines these sources of productivity change to yield the Malmquist total factor productivity change (TFPC) (Coelli et al. 2005). The relationship can be stated as (Equation 3):

$$TFPC^{t-1,t}(X_{t-1}, X_t, Y_{t-1}, Y_t) = \text{technical change} * \text{technical efficiency change} * \text{scale efficiency change} * \text{output mix effect} \quad \text{[Eqn 3]}$$

X_{t-1} represents a set of input factors employed to generate a set of outputs Y_{t-1} during the preceding period (*t*-1), while X_t signifies the input vector employed in producing a set of outputs (Y_t) in the current period (*t*). Every element within Eqn (3) is derived from an index, and each of these elements was estimated by decompositions of Eqns (4) to (7) (Appendix 6). This measurement can take the form of 1 (indicating an increase in the output mix effect), less than 1 (suggesting a decrease in the output mix effect) or exactly 1 (indicating no change in the output mix). The article employed the decomposition framework represented in Eqns (4) to (7) to assess changes in TFP in the pharmaceutical manufacturing context.

Unmatched changes in trade were used as an output variable instead of the MIIT index because the DEA programme does not recognise ratios. The programme combines all the variables and categorises them into productive efficiency, scale efficiency, technical efficiency and total factor productivity changes. Total factor productivity is regarded as the output, while other variables are regarded as inputs that influence TFP changes.

Ethical considerations

Rhodes University Human Research Ethics Committee (RU-HREC) has reviewed and approved our ethics waiver request because our research involves a text-based analyses but does not involve interaction with human participants. Therefore, we were not required to go through the ethics approval process.

Analysis of results

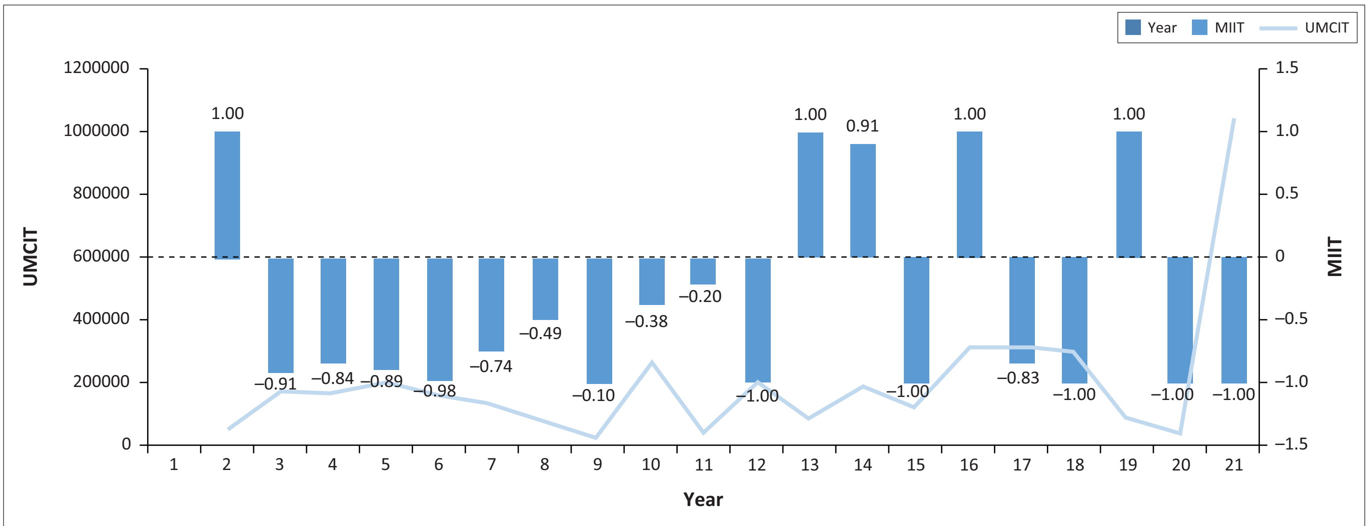
Intra-industry trade results

The results from analysing trade in the South African pharmaceutical sector suggest that new trade is largely inter-industry because MIIT values deviate from zero. This is consistent with early literature on intra-industry trade, which asserted that trade in Africa is overwhelmingly inter-industry (Brülhart et al. 2006, Havrylyshyn & Civan 1985). *Marginal* intra-industry trade index further reveals that a significant share of trade specialisation in South Africa is outside the pharmaceutical industry because MIIT values are mainly negative (Table 1-A7). Similarly, the UMCIT results (Table 1-A8) show significant volumes of unmatched new trade as shown by high UMCIT values, which supports the MIIT results and confirms the *a priori* expectation (that trade is inter-industry) of this study. This means that a wider range of products within the pharmaceutical industry is imported while a narrower range is exported. Specialising out of the industry also implies that resources will be allocated towards products with a more competitive edge than pharmaceuticals. Nevertheless, the results revealed some important nuances that could provide a basis for relevant interventions to help achieve a balanced pharmaceutical trade. Figure 2 provides the trend of the MIIT and UMCIT results provided in Table 1-A8.

The first finding is that although new trade is largely inter-industry, there are periods of specialisation in the industry shown by positive MIIT values (implying that new trade is more inter-industry; however, the country has developed a specialisation in that industry) for 2002, 2013, 2014, 2016 and 2019. Specialisation is associated with several benefits, which include increased efficiency, fostering innovation, cost-saving production (benefits from economies of scale) and skills development. It may also increase export opportunities and partnerships. Therefore, the industry should sustain the state of specialisation observed in 2002, 2013, 2014, 2016 and 2019 to enjoy the benefits associated with it.

The second finding is that there were periods of significant intra-industry trade (because MIIT values range from -0.65 to 0.65) changes despite trade specialisation being predominantly outside the industry (Table 1-A7 on comments considering critical values). Table 1-A7 shows significant intra-industry changes during 2008, 2010 and 2011 because the MIIT values fall between -0.65 and 0.65 for those years. Similarly, Kandogan (2003) found that intra-industry trade takes only a small portion of trade with developing countries. Although these changes occurred occasionally, they indicate that South Africa holds a certain level of competitive advantage in producing some pharmaceutical products. However, finding out which products are competitive will require further research in order to help the firms producing those products to strengthen their comparative advantage.

Several underlying factors contributed to the MIIT results presented in Figure 2. The following points attempt to shed light on possible underlying causes for the results. Firstly, the industry specialisation in 2002 (MIIT = 1) could be a product of the strategic plan for addressing HIV/AIDS in South Africa. The years 2000–2005 marked the first decade of implementing the ART programme in South Africa and Africa at large, making significant progress in providing life-saving treatment for HIV/AIDS patients. According to the report by the Joint Health and Treasury Task Team (2003), the cabinet reaffirmed its dedication to the strategic plan for addressing HIV/AIDS and STIs in South Africa, 2000–2005.



MIIT, *marginal* intra-industry trade; UMCIT, unmatched changes in trade.

FIGURE 2: Showing the trend of *marginal* intra-industry trade and unmatched changes in trade in the South African pharmaceutical sector.

South Africa's antiretroviral (ARV) programme is the largest globally, and the country is one of the world's major producers of radiopharmaceuticals (Veitch 2020). The massive rollout of the therapy started in 2003, suggesting that a bulk of the manufacturing activities occurred in the previous year as evidenced by industry specialisation in 2002.

Secondly, the extensive period of specialisation outside of the industry from 2003 to 2012 may be partially attributed to the implementation of the SEP. The introduction of SEP for medicines in South Africa was a significant regulation change aimed at price transparency of medicines and making them more affordable. However, implementing SEP had unintended consequences as pharmaceutical manufacturers experienced decreasing profits. Single exit price increases are insufficient to offset the effect of a weaker Rand (Local currency) and year-on-year inflation because most companies import APIs and other raw materials from overseas (Naidoo & Suleman 2021). The weakening of the Rand in a price-controlled environment increases the cost of production for goods sold (Ngozwana 2016; PMG 2017). Higher production costs decrease the products' global competitive edge and reduce the incentive to invest in local production. As a result, some pharmaceutical products were discontinued (Naidoo & Suleman 2021:445). Additionally, between 2002 and 2017, 37 plants closed down, which reduced local production and led to growing reliance on imports (PMG 2017).

Thirdly, the specialisation in the industry observed in 2013, 2014 and 2016 could be attributed to the injection of ZAR10.2 billion into the pharmaceutical sector. A tender of ZAR10.2 billion was awarded in 2013 for the local production of ARVs. The tender was split into four suppliers: three were locally formulating the product, and one was a global monopoly in producing a particular type of ARVs (PMG 2017).

Fourthly, the outward specialisation seen from 2017 to 2018 may be attributed to a sharp decline in South Africa's global competitiveness from 47 in 2016 to 67 out of 140 countries in 2018 (World Economic Forum 2018). The global competitiveness report shows South Africa's weaknesses in terms of competitive performance emanate from the health pillar, which ranks 125th; ICT adoption, which ranks 85th; and the skills pillar, which ranks 84th. These are all areas that are key in pharmaceutical production. Policy inertia and deterioration in the government and private sector relationship appear to be the major causes of reduced South Africa's global competitiveness index (World Economic Forum 2018).

Lastly, stringent global lockdowns to prevent the spread of COVID-19 could significantly explain the trade decline in 2020, which led to specialisation out of the industry. According to the global competitiveness fact sheet, imports and exports for 2020 declined by 25% and 9%, respectively, compared to 2019. Exports declined by 60% between March and April 2020 (DHET 2023). The results found in this study have important implications for the South African pharmaceutical industry in terms of adjustment costs and the movement of factors of production, which will be discussed in the discussion and policy-making implications section of this article.

Analysis of total factor productivity results

The MTFP results in Table 1 show the decomposition of TFP change (tfpch) into components such as technical change (techch), efficiency change (effch), scale efficiency change (sech) and pure (allocative) efficiency change (pech). From 2002 to 2021, TFP was only driven by technical change, as other components showed no changes in the output mix (output mix = 1). The results show significant technological changes in 2003, 2005, 2010, 2012, 2013, 2016 and 2021 because the index is greater than 1.

The technological changes led to an outward shift in the production possibilities frontier, denoting increased productivity. These results resonate with past empirical studies such as Dastane (2020), Lakhwani et al. (2020) and Fagerberg (2018), who found that adoption of technological changes positively impacts productivity in organisations. However, in this case, these outward shifts fluctuate over time, implying inconsistency in technological improvement. This indicates the need for an active and aggressive development policy to support and sustain higher productivity levels in the pharmaceutical sector. The 1996 White Paper on Science and Technology emphasises that the government is primarily responsible for establishing a conducive policy environment regarding regulatory and funding mechanisms. Furthermore, the National System of Innovation (NSI) provides a solid foundation for organising the country's collective efforts in science and technology in a much more integrated and holistic fashion (Manzini 2012).

TABLE 1: Data envelopment analysis results of total factor productivity changes in the South African pharmaceutical sector.

Year	effch	techch	pech	sech	tfpch
2003	1.000	10.331	1.000	1.000	10.331
2004	1.000	0.336	1.000	1.000	0.336
2005	1.000	1.238	1.000	1.000	1.238
2006	1.000	0.988	1.000	1.000	0.988
2007	1.000	0.616	1.000	1.000	0.616
2008	1.000	0.424	1.000	1.000	0.424
2009	1.000	0.468	1.000	1.000	0.468
2010	1.000	18.931	1.000	1.000	18.931
2011	1.000	0.098	1.000	1.000	0.098
2012	1.000	3.241	1.000	1.000	3.241
2013	1.000	1.208	1.000	1.000	1.208
2014	1.000	0.699	1.000	1.000	0.699
2015	1.000	0.673	1.000	1.000	0.673
2016	1.000	4.711	1.000	1.000	4.711
2017	1.000	0.708	1.000	1.000	0.708
2018	1.000	1.016	1.000	1.000	1.016
2019	1.000	0.593	1.000	1.000	0.593
2020	1.000	0.233	1.000	1.000	0.233
2021	1.000	23.267	1.000	1.000	23.267

tfpch, total factor productivity change; techch, technical change; effch, efficiency change; sech, scale efficiency change; pech, efficiency change.

In the quest to make the results more meaningful, the study examines the health sector to extract the factors that potentially improved technical changes, which led to the outward shift in the production possibilities curve during the period of study. One significant factor was the massive-scale rollout of the ART programme in 2003, which catalysed technological advancements in the healthcare sector. Like most developing countries, the National Department of Health in South Africa adopted technology applications to enhance health information management, as reflected in the *National Health Act (Act 61 of 2003*). For example, the expansion of the ART programme likely spurred increased adoption of electronic health records (EHRs), enabling healthcare providers to digitally capture and manage patient information, including human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS)-related data. Furthermore, technologies such as medication management, telemedicine and telepharmacy services were all implemented around this period to cater to the increased demand for ART treatment (PC4IR 2020). Other advanced instruments and technologies that pharmaceutical manufacturers adopted were to help ensure the quality and safety of their products and maintain quality control and compliance.

From 2010 to 2016, the notable technological changes that gained traction in the South African pharmaceutical space were primarily driven by the integration of automation into production as manufacturers embraced the Fourth Industrial Revolution (4IR) in manufacturing (PC4IR 2020). Manufacturers integrated automation across various stages of production such as formulation, filling and packaging. This period witnessed the adoption of advanced manufacturing techniques, such as continuous manufacturing, leading to a drastic improvement in the volume of products produced daily (PC4IR 2020). There was also a growing interest in the production of biopharmaceuticals during this period, which required biotechnology. For instance, in October 2016, Cipla BioTech and Dube Tradeport signed a memorandum of agreement to establish a facility for producing the first biosimilar drug, which was later launched in 2018. Cipla invested about $88m in the facility through its biotechnology subsidiary, Cipla BioTech (Cipla SA 2022).

Finally, in 2021, rapid technological improvements were needed to develop the pharmaceutical supply chain resilience because of COVID-19. In the wake of the pandemic, various sectors swiftly joined forces to mitigate the repercussions of the crisis. United Nations Industrial Development Organization (2021) reported that South African universities, in particular, collaborated closely with national and local governments and industry partners to manufacture essential personal protective equipment (PPE) and ventilators. For instance, the University of Johannesburg's engineering team designed and created portable 3D-printed mechanical ventilators featuring adaptable base plates to cater to many patients simultaneously.

On the contrary, the technical regressions observed in 2008 and 2009 that resulted in an inward shift of the production possibilities curve could be attributed to the global financial crisis, while the regression in 2020 could result from the countries' lockdown to prevent the spread of COVID-19. While the technological improvements discussed in this section are not the only factors that influenced changes in technological efficiencies in the pharmaceutical industry, they were identified as remarkable milestones achieved in the industry during the study period.

Interestingly, we note that instances of industry specialisation (2002, 2013, 2014 and 2016) and significant intra-industry changes (2008, 2010 and 2011) coincide with the period during which the industry experienced technological advancements. While the pattern may suggest a positive relationship between favourable trade activities and technology improvement, correlation does not imply causation. Understanding causation relationships requires further research.

Discussion and policy-making implications

The MIIT and UMCIT results showed that new trade is inter-industry and specialisation is often out of the industry. This finding confirmed the popular view in the literature that intra-industry trade is more prevalent in developed than developing countries. However, while trade was found to be largely inter-industry, there was evidence of significant intra-industry changes in 2008, 2010 and 2011 and periods of industry specialisation in 2002, 2013, 2014, 2016 and 2019. As highlighted in the 'Analysis of results' section, these two findings revealed three crucial insights about the South African pharmaceutical industry.

Firstly, conventional wisdom teaches that factors of production flow to economic segments with comparative advantage. In South Africa, the pharmaceutical industry's shift towards increased imports has led to a decline in manufacturing, resulting in reduced labour demand, lower returns on underutilised capital and potential misallocation of resources. This transition also undermines value-added manufacturing services by diminishing the entrepreneurial spirit essential for innovation and growth in the sector.

Secondly, inter-industry specialisation implies that adjustment costs are high because of the movement of production factors. If the movement of resources is limited, this can lead to short-term costs because of disruptions. Even when resources can move freely within a country, the neoclassical trade theory posits that resource prices are expected to adapt as countries gravitate towards their comparative advantages, potentially leading to some political ramifications. Either way, when trade expansion is inter-industry, the movement of resources is costly and may result in the industry not being flexible enough to swiftly respond to external shocks. Thirdly, periods of significant intra-industry changes and those of specialisation in the industry imply some level of competitiveness, which, if reinforced, would put the South African pharmaceutical industry in a better trade position than it is now. However, this article did not intend to determine specific competitive products or the type of intra-industry trade as it would require further research.

The DEA results showed that technological changes strongly influence the TFP. As such, policymakers must create an enabling environment for innovation, which may require some intervention strategies. These strategies should include promoting technology transfer and adoption, providing incentives for R&D activities, and fostering collaboration between academia, industry and government to spur technological advancement. In line with commitment 7 of the New Growth Path (2011), National Skills Accord 1, collaborating with academia will also help align education and training with the skill set needed in the pharmaceutical industry to achieve more productivity. Furthermore, the South African pharmaceutical industry is relatively small, lagging in technological advancement and faces fierce competition from global players. Therefore, investing in new technology is necessary to help the industry withstand the harsh global competition and drive efficiency and productivity improvement in the South African pharmaceutical industry.

Recommendations and conclusion

Despite its inherent high import demand, the South African pharmaceutical sector plays a vital role in supplying pharmaceuticals in Southern Africa. Therefore, ensuring a sustainable, productive capacity is essential because the industry serves as a launching site for firms to access other African pharmaceutical markets. This study identified intra-industry trade as a vehicle for building a resilient pharmaceutical sector in South Africa. As such, the MIIT Index was used to determine the type of new trade that is taking place. Knowing the type of trade helps to understand how the country is integrating into the global pharmaceutical value chain, which will then inform the segments of production that need to be strengthened to increase output and global presence.

Several factors contribute to high imports in the pharmaceutical industry and can only be combated if the government collaborates with private producers. South Africa is currently battling with infrastructure deterioration causing an additional strain to firms in South Africa across the sectors. This trajectory makes it even more difficult for local products to compete globally as infrastructure problems such as water shortages and frequent power cuts make production even more costly. The South African government should solve the infrastructure problems sooner rather than later and create an enabling environment for pharmaceutical firms to produce locally. Producers, on the other hand, need to take advantage of the existing opportunity of manufacturing generic medicines, which are in high demand in South Africa and in many other African countries but are mainly supplied by India.

Furthermore, the shared objective of the PMPA and the African Continental Free Trade Area (AfCFTA) of improving access to medicines and healthcare products across the African continent provides an opportunity for South Africa to establish and uphold a connection between trade and health within the continent. The trade facilitation provided by the AfCFTA's elimination of trade barriers has the potential for a larger market for pharmaceuticals produced under the PMPA, which can lead to increased exports of medicines originating from Africa (African Union 2018). Active engagement with PMPA and AfCFTA can help to achieve affordable medicines and improve healthcare access for South Africans and other African citizens. Hopefully, the recent commitment by the African Development Bank to establish the African Pharmaceutical Technology Foundation is a step in the right direction. Most importantly, South Africa needs a concerted and sustainable pharmaceutical sector innovation system to avoid episodic improvements in intra-industry trade and TFP changes. So far, significant gains are induced by major crises such as HIV and AIDS and COVID-19. It is time for African countries to mobilise resources to build a sustainable continental pharmaceutical supply chain and stop outsourcing their health security.

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Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article.

Authors' contributions

N.M. is the primary author of this article, and the manuscript is based on her PhD thesis. T.E.M. is the main supervisor, while J.M. is the co-supervisor. Both supervisors have contributed by reviewing this work from conceptualisation to the interpretation of results. In terms of methodology, the manuscript consists of two parts: measuring intra-industry trade and total factor productivity. The main supervisor contributed more to the international trade aspect, while the co-supervisor focussed more on measuring total factor productivity.

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Data availability

The data used in this manuscript are publicly available and can be accessed from UNCTAD databases at https://unctad.org and the South African Reserve Bank at https://www.resbank.co.za/en/home/what-we-do/statistics/releases/economic-and-financial-data-for-south-africa.

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Appendix 1

TABLE 1-A1: Pharmaceutical market leaders.

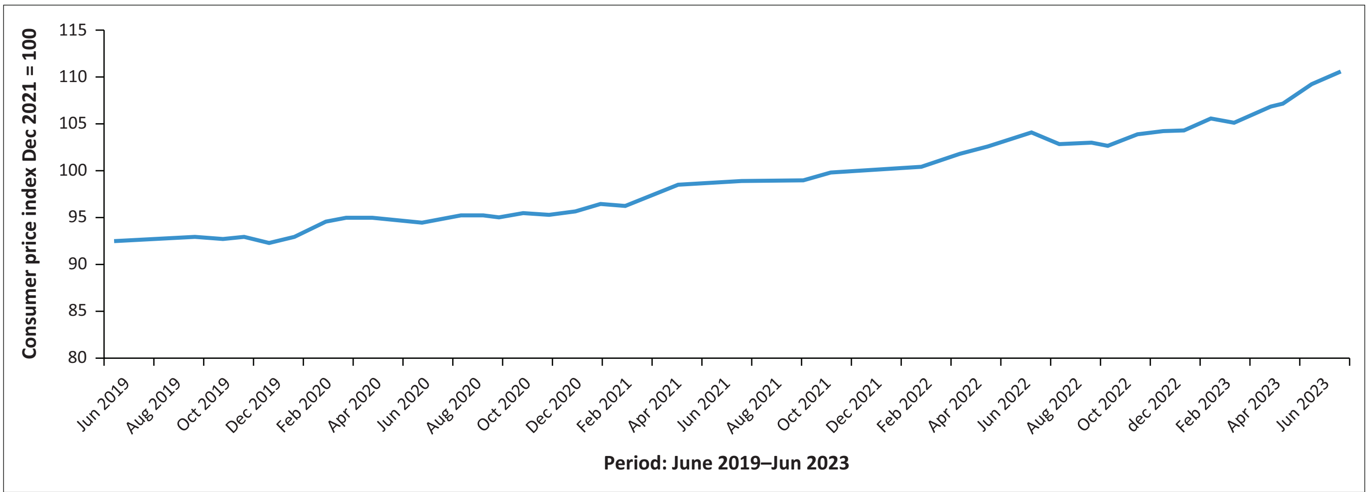
Rank	Overall	Rx	OTC	Non-schedule	State
	All schedules	Schedule 3 and above	Schedules 1 and 2 only	Scheduling not applicable	All schedules
1	ASPEN*	ASPEN*	ADCOCK INGRAM*	ADCOCK INGRAM*	MYLAN
2	ADCOCK INGRAM*	SANOFI	ASPEN*	ASCENDIS*	SANOFI
3	CIPLA	NOVARTIS	CIPLA	CIPLA	ASPEN*
4	SANOFI	CIPLA	JOHNSON &JOHNSON (Consumer)	ASPEN*	ADCOCK INGRAM*
5	NOVARTIS	ADCOCK INGRAM*	INOVA PHARMA	ABBOTT	PFIZER
Total	**722**	**144**	**95**	**647**	**371**

Source: Adcock Ingram, Iqvia (2020) adapted from Veitch, C., 2020, 'The pharmaceutical industry report. *Who Owns Whom*', *African Business Information*, December 2020, viewed 19 November 2022, from https://www.whoownswhom.co.za/

Rx, prescription medication; OTC, over-the-counter medicines.

*, Denotes local companies.

Appendix 2



Source: Statistica, 2023, *Consumer Price Index of medical products in South Africa*, viewed 10 December 2023, from https://www.statista.com/statistics/1122790/south-africa-monthly-cpi-medical-products/.

CPI, consumer price index.

FIGURE 1-A2: Consumer price index of medical products in South Africa from March 2019 to June 2023.

Appendix 3

TABLE 1-A3: South Africa's world trade in pharmaceuticals and % exports to Southern African Development Community. Unit: US$ thousand.

Year	Imports in USD from ROW US$ thousand	Exports in USD to ROW US$ thousand	Pharmaceutical trade balance US$ thousand	% share of pharm exports on total exports	% share of pharm import on total imports	% share of SA's pharm exports to SADC
2002	587 852	83 617	-504 235	0.36	2.55	27,6
2003	772 241	89 387	-682 854	0.28	2.44	27.71
2004	961 415	108 455	-852 960	0.27	2.39	33.58
2005	1 168 572	120 531	-1 048 041	0.26	2.49	28.95
2006	1 330 743	120 093	-1 210 650	0.23	2.53	26.41
2007	1 475 429	142 396	-1 333 033	0.22	2.30	28.76
2008	1 569 555	177 867	-1 391 688	0.24	2.12	33.76
2009	1 588 134	178 183	-1 409 951	0.33	2.95	37.19
2010	2 074 511	386 809	-1 687 702	0.47	2.51	73.24
2011	2 202 356	462 183	-1 740 173	0.43	2.04	73.69
2012	2 366 798	431 673	-1 935 125	0.44	2.39	68.42
2013	2 272 462	432 720	-1 839 742	0.46	2.39	65.86
2014	2 068 704	429 570	-1 639 134	0.46	2.23	63.85
2015	2 178 581	402 472	-1 776 109	0.50	2.71	63.89
2016	1 893 409	420 409	-1 473 000	0.55	2.49	54.57
2017	2 238 147	450 912	-1 787 235	0.51	2.54	61.54
2018	2 501 754	429 299	-2 072 455	0.46	2.67	67.78
2019	2 421 100	434 067	-1 987 033	0.49	2.71	62.28
2020	2 401 518	392 121	-2 009 397	0.46	2.82	59.36
2021	3 065 610	894 213	-2 171 397	0.73	2.50	30.98

SADC, Southern African Development Community.

Appendix 4

TABLE 1-A4: Examples of recalled medicine from May 2021 to August 2023.

Company name	Registration number	First distributed	Re-call classification	Re-call date
Pfizer Laboratories (Pty) Ltd	41/24/0432	12/04/19	Class III Type B	19/08/2021
Adcock Ingram limited	B/2.8/858	11/2020	Class II Type B	13/07/2021
	B/2.7/1404	12/2020	Class II Type B	
Sanofi-Aventis South Africa	40/7.1.3/0287	28/05/20	Class II Type B	27/10/2021
	40/7.1.3/0288	12/02/21	Class II Type B	27/10/2021
Cipla Medpro (Pty) Ltd	H1511 (Act 101/1965)	09/20	Class III Type C	24/01/2022
iNova Pharmaceuticals (Pty) Ltd	34/16.4/0391	13/12/2021	Class III Type C	28/01/2022
Pfizer Laboratories (Pty) Ltd	34/7.1.3/0230	19/10/19	Class II Type B	25/04/2022
Cipla Medpro (Pty) Ltd	W/16.3/58	04/02/2021	Class I Type A	15/06/22
Adcock Ingram Limited	B/2.8/1401	25/06/21	Class II Type B	23/06/22
Dr Reddy's Laboratories (Pty) Ltd	43/2.6.5/0432	24/02/23	Class III Type C	07/07/23
B.Braun Medical (Pty) Ltd	41/24/0432	03/05/21	Class II Type B	02/08/2023

Source: Adapted from South African Health Products Regulating Authority, 2023, *Product recalls*, viewed 18 September 2023, from https://www.sahpra.org.za

Appendix 5

TABLE 1-A5: Showing closures of domestic pharmaceutical plants in South Africa in the late 1990s.

Company	Location	Job losses	Reason
Searl	Johannesburg	77	Restructuring post-Monsanto merger
Pharmacia/Upjohn	Isando	75	Merger between the companies
Bristol Myers Squibb	Wadeville	50	Merger between the companies
Wellcome	Spartan	150	Restructuring-merger with Glaxo
Adcock Ingram	Various	1000	Merger with Prempharm
Boots	Isando	Unknown	Company bought out by Knoll
Noristan	Pretoria	Unknown	Company bought out by Hoechst
Wyeth	Isando	Unknown	Internal restructuring

Source: Horner, R., 2021, 'Global value chains, import orientation, and the state: South Africa's pharmaceutical industry', *Journal of International Business Policy* 5, 1–20. https://doi.org/10.1057/s42214-021-00103-y

Appendix 6

Decomposition of total factor productivity change.

The components of total factor productivity (Equation 3) are estimated as follows (see Equation 4):

$$\text{Technical change} = \left[\frac{d_0^t\left(X_{t-1},Y_{t-1}\right)}{d_0^{t-1}\left(X_{t-1},Y_{t-1}\right)} * \frac{d_0^t\left(X_t,Y_t\right)}{d_0^{t-1}\left(X_t,Y_t\right)}\right]^{\frac{1}{2}} \quad \text{[Eqn 4]}$$

Equation 4 means that if the productivity evaluated in the current period's production technology differs from the previous period's production technology, it indicates technical change – an inward or outward shift in the production function. If it exceeds one, it suggests technological progress. An index of unity indicates that the DMU remains on the frontier, indicating best practice or benchmarking (see Equation 5):

$$\text{Technical efficiency change} = \frac{d_0^t\left(X_t,Y_t\right)}{d_0^{t-1}\left(X_{t-1},Y_{t-1}\right)} \quad \text{[Eqn 5]}$$

In Equation 5, it is stated that the comparison of productivity levels in the current and previous periods, based on current and previous technologies, as shown in Figure 1, indicates a change in technical efficiency. This change occurs when the producer moves to or further away from their production frontier. For instance, this movement could involve transitioning from point A towards or away from d_0^{t-1} in period t-1 and from point B towards or away from d_0^t in period t (as depicted in Figure 1). This index can assume values greater than 1 (indicating an improvement in efficiency), less than 1 (indicating a decline in efficiency) or equal to 1 (indicating that the producer is operating at the frontier (see Equation 6):

$$\text{Scale efficiency change (SEC)} = \left[\frac{SEC_0^{t-1}\left(X_t,Y_{t-1}\right)}{SEC_0^{t-1}\left(X_{t-1},Y_{t-1}\right)} * \frac{SEC_0^t\left(X_t,Y_t\right)}{SEC_0^t\left(X_{t-1},Y_t\right)}\right]^{\frac{1}{2}} \quad \text{[Eqn 6]}$$

In the Malquist approach to analysing total factor productivity change, Equation 6 shows that scale efficiency change is determined by taking the geometric mean of two components: scale efficiency change concerning the previous period's production technology and output, and scale efficiency change concerning the current period's production technology and output (see Equation 7):

$$\text{Output mix effect} = \left[\frac{SE_0^{t-1}\left(X_{t-1},Y_t\right)}{SE_0^{t-1}\left(X_{t-1},Y_{t-1}\right)} * \frac{SE_0^t\left(X_t,Y_t\right)}{SE_0^t\left(X_t,Y_{t-1}\right)}\right]^{\frac{1}{2}} \quad \text{[Eqn 7]}$$

Equation 7 expresses that the alteration in the output mix effect is derived as a geometric mean of scale efficiency (SE) concerning the previous period's production technology and scale efficiency concerning the current period's production technology. The output mix effect quantifies the impact of a shift in the composition of output on the scale efficiency for the given period. This measurement can take the form of on (indicating an increase in the output mix effect), less than 1 (suggesting a decrease in the output mix effect), or exactly on (indicating no change in the output mix).

Appendix 7

TABLE 1-A7: Analysis of changes in South Africa's trade pharmaceutical sector (SICT1 digit).

Year	MIIT = (5)/(4)	Intra/inter	Matched/ unmatched	Direction of specialisation	Comments considering critical values
2002	1.00¶	*Inter*	*Unmatched*	*Into*	*Into*
2003	-0.91¶	*Inter*	*Unmatched*	*Out*	*Out*
2004	-0.84†	*Inter*	*Unmatched*	*Out*	*Out*
2005	-0.89†	*Inter*	*Unmatched*	*Out*	*Out*
2006	-0.98†	*Inter*	*Unmatched*	*Out*	*Out*
2007	-0.74†	*Inter*	*Unmatched*	*Out*	*Out*
2008	-0.49‡	*Inter*	*Unmatched*	*Out*	*Sig IIT changes*
2009	-1.00†	*Inter*	*Unmatched*	*Out*	*Out*
2010	-0.38‡	*Inter*	*Unmatched*	*Out*	*Sig IIT changes*
2011	-0.20‡	*Inter*	*Unmatched*	*Out*	*Sig IIT changes*
2012	-1.00†	*Inter*	*Unmatched*	*Out*	*Out*
2013	1.00¶	*Inter*	*Unmatched*	*Into*	*Into*
2014	0.91¶	*Inter*	*Unmatched*	*Into*	*Into*
2015	-1.00†	*Inter*	*Unmatched*	*Out*	*Out*
2016	1.00¶	*Inter*	*Unmatched*	*Into*	*Into*
2017	-0.83†	*Inter*	*Unmatched*	*Out*	*Out*
2018	-1.00†	*Inter*	*Unmatched*	*Out*	*Out*
2019	1.00¶	*Inter*	*Unmatched*	*Into*	*Into*
2020	-1.00†	*Inter*	*Unmatched*	*Out*	*Out*
2021	-1.00†	*Inter*	*Unmatched*	*Out*	*Out*

*a) Critical values of MIIT ARE ± 0.65.
†, MIIT from -1 to -0.65 means there has been specialisation out of the industry.
‡, MIIT from - 0.65 to 0.65 means significant intra-industry changes have taken place.
¶, MIIT from 0.65 to 1 means there has been specialisation in the industry.

Appendix 8

TABLE 1-A8: *Marginal* intra-industry trade index in the South African pharmaceutical sector from 2002 to 2021.

Year	Pharm. exports (1)	Pharm. imports (2)	d(Exports) (3)	d(Imports) (4)	dXi – dMi (5)	|dXi| + |dMi| (6)	MIIT= (5) /(6)	UMCIT = |dXi - dMi|
2002	95 642.277	647 975.703	18 498.651	-38 649.221	57 147.87	57 147.87	1.00	57 147.87
2003	104 505.567	833 007.067	8 863.29	185 031.364	-176 168.07	193 894.65	-0.91	176 168.07
2004	121 000.308	1 016 895.36	16 494.741	183 888.293	-167 393.55	200 383.03	-0.84	167 393.55
2005	133 384.023	1235268.569	12 383.715	218 373.209	-205 989.49	230 756.92	-0.89	205 989.49
2006	134 874.145	1 398 677.962	1 490.122	163 409.393	-161 919.27	164 899.52	-0.98	161 919.27
2007	157 478.288	1 552 439.565	22 604.143	153 761.603	-131 157.46	176 365.75	-0.74	131 157.46
2008	196 208.479	1 665 208.606	38 730.191	112 769.041	-74 038.85	151 499.23	-0.49	74 038.85
2009	193 723.207	1 687 242.761	-2 485.272	22 034.155	-24 519.43	24 519.43	-1.00	24 519.43
2010	411 476.306	2 175 307.014	217 753.099	488 064.253	-270 311.15	705 817.35	-0.38	270311,15
2011	488716.651	2 291 160.67	77 240.345	115 853.656	-38 613.31	193 094.00	-0.20	38 613.31
2012	456 701.615	2 463 760.452	-32 015.036	172 599.782	-204 614.82	204 614.82	-1.00	204 614.82
2013	457 654.836	2 380 659.581	953.221	-831 00.871	84 054.09	84 054.09	1.00	84 054.09
2014	448 143.921	2 178 622.682	-9 510.915	-202 036.899	192 525.98	211 547.81	0.91	192 525.98
2015	427 723.191	2 284 156.833	-20 420.73	105 534.151	-125 954.88	125 954.88	-1.00	125 954.88
2016	449 777.635	1 990 205.043	22 054.444	-29 3951.79	316 006.23	316 006.23	1.00	316 006.23
2017	483 161.578	2 339 082.46	33 383.943	348 877.417	-315 493.47	382 261.36	-0.83	315 493.47
2018	448 133.8	2 603 328.093	-35 027.778	264 245.633	-299 273.41	299 273.41	-1.00	299 273.41
2019	455 216.06	252 6605.457	7 082.26	-76 722 636	83 804.90	83 804.90	1.00	83 804.90
2020	423 472.629	2 530 405.377	-31 743.431	3 799 92	-35 543.35	35 543.35	-1.00	35 543.35
2021	284 200.953	344 0341.28	-139 271.676	909 935.903	-104 9207.58	104 9207.58	-1.00	104 9207.58

MIIT, marginal intra-industry trade; UMCIT, unmatched changes in trade.