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# MEASURING TOTAL FACTOR PRODUCTIVITY IN THE SOUTH AFRICAN AGRICULTURAL SECTOR USING A GROWTH ACCOUNTING FRAMEWORK

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***Abstract***

*In this study, we measure the total factor productivity (TFP) in the South African agricultural sector using annual time series data from 1980 to 2019. First, a Cobb-Douglas production function is estimated recursively to determine the time-varying factor contributions of labour, capital and land to agricultural output. Second, a growth accounting framework is used to measure TFP growth, which is then converted to a measure for TFP. The results show that TFP growth recorded an average growth of 2.2% between 1980 and 1989, followed by a decline to 0.04% between 1990 and 1999, a period characterised by major policy reforms and economic structural changes in the agricultural sector, such as the removal of agricultural subsidies and the introduction of competition with the deregulation of markets in 1996. A recovery in TFP with a growth rate of 2.3% was recorded between 2000 and 2009, attributed to the precipitation of new technology and skills improvement underpinned by export growth fuelled by foreign-demand induced agricultural production growth in industries like fruits, wine, cotton and grains. The TFP growth was slow between 2010 and 2019 compared to the previous period, attributed to stagnation in policy reforms and rising incidence of drought, labour challenges and increasing cost of production. The study recommends a carefully designed policy mix of land and water reform, complemented by a comprehensive farmer support programme that addresses skills, markets, drought-resistant varieties and affordable production loans to enhance TFP.*

Keywords: Total factor productivity, growth accounting framework, South African agriculture.
JEL codes: Q10, D24, C51.

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## 1 INTRODUCTION

South Africa is a developing nation that has undergone major policy and structural changes since the dawn of democracy in 1994. The most notable changes are the removal of state subsidies and control in many economic sectors coupled with ratification and simplification of trade policy, resulting in strong growth performance in the exportation of agriculture and non-agricultural commodities over the past 28 years. Today, more than 55% of agriculture value-added is generated from export earnings (DALRRD, 2022). Moreover, agricultural production, measured in quantities, has doubled in size, fuelled by rising international food demand, the adoption of new technologies such as better yielding cultivars and mechanisation. The introduction of the land reform programme and other transformative initiatives contribute to the inclusion of previously disadvantaged individuals (PDIs) in the agricultural economy, that is, small-scale and subsistence farmers. Despite the positive effects of policy reforms from the mid-1990s, the country is still constrained by rising poverty levels, unemployment and inequality; therefore, it still has a long way towards successfully addressing the challenges of inclusive growth and employment to enhance social cohesion and nation building.

This study focuses on the agricultural sector, measuring total factor productivity and assessing the factors that impact productivity. The agricultural share to Gross Domestic Production (GDP) has gradually declined over time, dropping from 9% in 1960 to 3.4% in 1994 and a further decline to 2.5% in 2021 (World Bank, 2023; Stats SA, 2023). This decline in the agricultural sector's contribution is consistent with Economic Development theory, which posits that the share of the primary industry diminishes as the economy develops, shifting towards secondary and tertiary sectors – industry and the services sector contributed 24.5% and 63.02% of the total value added in 2021, respectively (Stata SA, 2023). Despite the falling share in GDP, agriculture plays a major role in the country's rural development, foreign earnings and employment creation agenda (Bennett et al., 2003; Fuglie & Rada, 2013). The importance and resilience of the agricultural sector were also evident during the Covid-19 period, where it was the sole economic sector that recorded positive growth in 2020, registering 13.1% compared to the previous year. This expansion was attributed to the good rains and the agility of farmers to quickly adapt to the Covid-19 restrained environment (BFAP, 2021).

However, the persisting duality and perpetual exclusion of small-scale and subsistence farmers in the formal agricultural economy remains challenging for the agricultural sector. This has also prevailed during the Covid-19 period (i.e., 2020 to 2021) when the share of small-scale and subsistence farmers reduces to less than 10% of total agricultural output (NAMC, 2021). Most scholars identify the limited access to land, water rights, markets and skills development as critical constraints impeding the participation of PDIs in the sector (Binswanger-Mkhize, Deininger & Feder, 1995; Commey, 2013; Greyling & Pardey, 2019; Gwiriri et al., 2019; Lahiff, 2016; Khapayi & Celliers, 2016; Magingxa et al., 2009). The findings of the scholars, as mentioned above, are supported by the land audit conducted by then the Department of Rural Development and Land Reform (DRDLR, 2017), which found that 72% of agricultural land is still owned and operated by white farmers. Furthermore, the agricultural sector uses over 65% of total water in the country for irrigation purposes; however, 95% of allocated irrigation water rights are allocated to white farmers constraining the viability and contribution of small-scale and subsistence farmers in the country (DRDLR, 2017; NAMC, 2021). The issue of land and water is expected to impact the total factor productivity in the agricultural sector.

Acknowledging that equitable land redistribution remains a pressing issue (for example, see Kirsten & Sihlobo, 2021; Mosoma et al., 2023), this paper assesses the agricultural production process to determine factor contributions and measure total factor productivity. To measure total factor productivity, we unpack the production structure of the agricultural sector in South Africa using a growth accounting exercise – consisting of the determination of the time-varying contributions of primary input factors (i.e., labour, capital and land) in the agricultural production process, using a Cobb-Douglass production function specification. The factor elasticities, together with the annual growth rates of the output (gross value added) and input factors (labour, capital and land), are then used to obtain a measure for total factor productivity (TFP) growth, which in turn allows for the construction of a TFP index. A standard production function specification, augmented with human capital and land, is recursively estimated using time series data from 1980 to 2019 to ascertain the time-varying contributions of individual production factors and TFP to agricultural output.

The principal contribution of this paper is to provide an updated TFP measure for the South African agricultural sector, building upon existing yet older studies. Most importantly, since the previous studies on TFP in agriculture were conducted, there has been a series of policy and farmer support programmes implemented coupled with exogenous factors like climate change, drought, the introduction of minimum wages, land reform, and biosecurity outbreaks that have collectively impacted the TFP of the sector either positively or negatively. It is, therefore, important for policymakers to understand the South African agricultural sector's production structure and the factors that boost or constrain the growth and sustainability of agriculture output in the country. Unpacking and assessing these underlying macroeconomic factors contributing to TFP will assist in formulating practical and effective recommendations to policymakers and farmers to allow for collective improvement in the productivity of the South African agricultural sector.

This paper is organised as follows: section 2 reviews the literature on measuring TFP in the South African agriculture sector. Section 3 discusses the data and methods used in this study. Section 4 presents the empirical results, while section 5 concludes the paper and presents policy implications from this study.

## 2 REVIEW OF SELECTED STUDIES ON AGRICULTURAL PRODUCTIVITY

Agricultural productivity is measured as a ratio of agricultural output to inputs and reveals the sector's performance. According to Fuglie (2018), measuring agricultural productivity indicates the country's ability to produce and ensure food security, income generation and stimulation of economic development. In most studies reviewed, single-factor productivity (SFP) and total factor productivity (TFP) are used to measure agricultural productivity. SFP measures the units of outputs produced per unit of a given input and only considers a single input in the ratio (Solow, 1956 and 1957). TFP is a commonly used empirical tool to assess the sustainability of a specific agricultural production system as it measures the total conventional resource cost of producing economic outputs. This measure considers the joint effect of multiple factors in the agricultural sector (Ortega & Lederman, 2004; Kumar et al., 2010; Olomola & Osinubi, 2018; Degu & Bekele, 2019).

Approaches used to measure TFP includes parametric and nonparametric estimation. Parametric approaches include analysis through the specification of a production function and stochastic frontier analysis. The empirical estimation of a production function characterises the underlying technology and is used to estimate the factor elasticities or contributions to output (Aden et al., 2014). Nonparametric analysis entails data envelope analysis (DEA) and growth accounting to construct a TFP index for the agricultural sector (Saikia, 2014; Sheng et al., 2017; Giang et al., 2019). Poonyth and Van Zyl (2001) employ a translog cost function method and suggest that research conducted in the past should be interpreted with care as earlier studies likely did not test the characteristics of the underlying production function and technology. Aden et al. (2014) used the translog production function to obtain TFP growth rates for Tunisia, which specification was chosen as a preferred framework for analysing the input reaction to price changes.

The challenge for many developing economies in measuring TFP growth is a lack of input and output data, especially at the disaggregated level (Fuglie, 2015; Sheng et al., 2017). South Africa is classified as a developing country, and accurate input data remains challenging, hence the limited number of studies in measuring TFP. The study by Ramaila et al. (2011) also highlights the government's limited involvement in setting up a database on productivity estimates as a major concern. Calculating capital stock poses a challenge when analysing developing economies, resulting in several studies using capital formation rather than capital stock (Balcha, 2011; Khatun & Afroze, 2016). Furthermore, Gandidzanwa and Liebenberg (2016) note that using a constant capital ratio over an extended period is inappropriate due to the inability to demonstrate the changing nature of mechanisation, thus resulting in incorrect estimates. The authors generated a new capital formation series for machinery in South African agriculture as an essential input for measuring agricultural productivity.

A study by Liebenberg and Pardey (2012) recorded an annual average multi-factor productivity (MFP) growth rate of 1.5% over the 1945 to 2010 period. According to Arndt and Pratt (2020), the agricultural sector in South Africa is practically productive in terms of TFP, although they report a decline in productivity growth since 2005. A stagnant growth path between 1998 and 2010 was attributed to a decline in the output growth rate, whilst an increase in the input rate used in agriculture was recorded over the same period. The deregulation phase in agriculture (agricultural marketing Act[3], Water Act[4], land reform, labour market reform, amongst others) was also cited as a cause of the slacking in TFP growth during the 1990s (Van Zyl et al., 2000).

Fuglie (2015) reported higher agricultural TFP growth rates in South Africa compared to Van Zyl et al. (2000), which alluded to the adjustments for input quality changes, particularly labour. Saikia (2014) reported similar TFP growth trends for Indian agriculture TFP growth that was very low during the pre-Green Revolution period that began in the 1960s and marginally improved in the 1980s, followed by further declines during the 1990s. Sheng et al. (2017) measured the Australian agricultural TFP growth rate and found it to be, on average, 2.1% per year between 1949 and 2012. The productivity growth was attributed to a substantial output expansion, moderate input growth, and changes in the output mix.

In another related study, Conradie et al. (2009) measured the TFP growth by district in the Western Cape. This study demonstrates the benefits of disaggregation compared to determining national TFP growth. Different districts producing different commodities demonstrated different TFP growth rates due to the levels of technological change (e.g., infrastructure like irrigation systems). The study has proven the importance of disaggregated TFP measurements at the district level to provide district-specific advisory services to farmers and inform policy-making, resulting in relevant interventions by public and private stakeholders participating in agriculture. Bulagi and Kaseeram (2020) underscore the importance of proper allocation of inputs to maintain optimal production and further suggest that the productivity and efficiency growth of the sugarcane growers in KwaZulu Natal may be improved without altering the size of the plots. The study proposed investment in improved technology, optimal application of inputs and sustainability of the sugarcane growers through focused input subsidies.

The study by Aden et al. (2014) affirms that investment in irrigated production systems and using new production technologies in the agricultural sector is crucial for TFP growth. Saikia (2014) argues that for the government to sustain TFP growth in agriculture, investment in technology development, infrastructure and extension programmes should be increased significantly. A study by Ramaila et al. (2011) reports an increase in agricultural productivity in developed countries, compared to developing countries over time, attributed to higher levels of investment in land, labour and capital in the developed countries in contrast to developing countries. These factors are crucial in improving productivity in the agricultural sector.

[3] This refers to the promulgation of the Marketing of Agricultural Products Act, No 47 of 1996.
[4] The promulgation of a new Water Act, No 36 of 1998.

The review of the studies above shows that South African agricultural productivity has varied over time, influenced by multiple factors. Some studies argue the importance of assessing productivity at a district level to provide regionalised policy advisory. More importantly, the studies in South Africa apply comparable methodologies to international studies focusing on countries like India, Tunisia and Australia, amongst others. What is evident, recent studies which measure agricultural TFP are extremely limited, which justifies the need to re-evaluate the TFP for the agricultural sector to capture recent events such as drought, biosecurity outbreaks and land reform initiatives, amongst others. Furthermore, taking a long-term view of agricultural TFP and segmenting different periods to illustrate the impact of policy reforms and structural changes on agricultural performance is crucial; hence the current analysis measures TFP from 1980 to 2019, stratified over four decades, that is, 1980 to 1989, 1990 to 1999, 2000 to 2009 and 2010 to 2019. This study's outcomes are anticipated to contribute to the empirical literature by using the most recent data spanning 40 years.

## 3 METHODOLOGY AND MODEL SPECIFICATION

This study uses a growth accounting framework introduced by Robert Solow (Solow, 1957) in conjunction with a production function specification to determine total factor productivity (TFP) in the agricultural sector. Growth accounting is intended to gain an understanding of the extent of output variation and growth that can be produced through input variation and input growth while attributing the remaining proportion to TFP (sometimes also referred to as technological progress). In this study, the output variable is represented by the gross production value (gross value added), including the main three sub-sectors: horticulture, livestock and field crops.

A Cobb-Douglas production structure is assumed, where capital and labour (employment) are augmented with human capital and land. A recursive approach is followed to establish the time-varying nature of the factor contributions of capital, labour (augmented with skills development equivalent to human capital), and land (augmented with rainfall). Total factor productivity (or technological progress) is indirectly derived in the process. This concept is also referred to as the Solow residual.

Through recursive estimation of the Cobb-Douglas production function, the input factor elasticities are obtained, which subsequently serve as factor weights in the growth accounting equation. In order to determine the factor elasticities through regression analysis, we start by evaluating the univariate properties of the data series and testing for cointegration between the variables in the specification. Once cointegration has been established, and factor contributions have been determined, we can solve the growth accounting equation to derive TFP for the period (detailed in section 4.5).

The Augmented Dickey-Fuller (ADF) unit root test (Dickey & Fuller, 1979 and 1981) and the Elliot-Rotenberg-Stock (ERS) point optimal unit root test (Elliot, Rotenberg & Stock, 1996) are used to study the univariate properties and determine the order of integration of individual time series used in the analysis. Where appropriate, a breakpoint unit root test is also employed. The Johansen (1988, 1991) multivariate cointegration test is used to establish whether the series, as per model specification in equation (3) below, constitute a cointegrated relationship (refer to Appendix A, section A.2).

### 3.1 Model specification

In order to employ growth accounting to approximate total factor productivity, we need to obtain factor contributions in the production process. A Cobb-Douglas production function, augmented with land and constant returns to scale in the production process, is assumed:

$$gva = Ak^{\beta_1}(l \cdot hc)^{\beta_2}(land \cdot rain)^{(1-\beta_1-\beta_2)}e^{u} \quad (1)$$

where $gva$ is agricultural real gross value added, $k$ is real fixed capital stock employed in the agricultural sector, and $l$ is employment in the sector. Employment is augmented (interacted) with $hc$, a measure of human capital to account for labour input quality improvements (as per Fuglie, 2015). The production function is further augmented with agricultural land area ($land$), interacted with rainfall ($rain$) – two vital input factors in the agricultural production process.

Equation (1) can be log-linearised as follows:

$$lngva_t = lnA + \beta_1 lnk_t + \beta_2(ln(l * hc))_t + (1 - \beta_1 - \beta_2)(ln(land * rain))_t + u_t, \quad (2)$$

equivalently expressed as:

$$lngva_t = lnA + \beta_1 lnk_t + \beta_2(lnl + lnhc)_t + (1 - \beta_1 - \beta_2)(lnland + lnrain)_t + u_t \quad (3)$$

The above model specification is estimated for the full sample period of 1980 to 2019 to obtain capital, human capital and land elasticities for agricultural output. Recursive estimation, starting with an initial sample of 1980 to 1990 and incrementing the sample size with one period at a time, is performed to observe potential changes in factor elasticities over time. Further robustness checks include testing for structural breaks in the relationship due to economic sanctions (1985 to 1994), the global financial crisis (2008-2009), and years of drought that could have negatively influenced agricultural output.

### 3.2 Selected variables and data sources

This analysis uses time series data for the period 1980 to 2019 to determine TFP. Data was sourced from Statistics South Africa (Stats SA), the Department of Agriculture, Land Reform and Rural Development (DALRRD), the South African Reserve Bank (SARB), the Food and Agricultural Organization of the United Nations (FAO), the Department of Higher Education (DHE) as well as the South African Weather Service (SAWS). The variable selection for the agricultural productivity analysis is informed by the chosen methodology and model specification. Table 1 presents a list of variables used, the description of each variable selected, and the data source.

**Table 1: Variable description**

| Variable | Variable description | Data source |
|---|---|---|
| *gva* | Gross value added: agriculture, forestry and fishing, constant 2010 prices (R million) | SARB |
| *k* | Fixed capital stock: agriculture, forestry and fishing, constant 2010 prices (R million) | SARB |
| *l* | Employment in the agricultural sector | Stats SA and DALRRD |
| *hc* | Human capital, proxied by the number of graduates in agriculture, agricultural operations and related sciences | DHE |
| *land* | Agricultural land (square km) | FAO |
| *rain* | Rainfall (mm) | SAWS |
| *dum_gfc* | 1 for 2008 to 2009; 0 otherwise | |
| *dum_sanctions* | 1 for 1986 to 1993, 0.5 for 1985 and 1994; 0 otherwise | |
| *dum_drought*[5] | 1 for 1981, 1982, 1986, 1991, 1992, 1994, 1997, 1998, 2002, 2003, 2004, 2006, 2011 and 2014 to 2017; 0 otherwise | |

Figure A.1 in Appendix A contains a graphical depiction of the variables used in the analysis (using natural log transformation). While the real gross value added has increased over the sample period, the real capital stock has declined since 1982, with mostly a side-ways movement from the mid-nineties onwards. The decline follows a consistent increase from as far back as 1946 up to 1982. As published by the SARB, the capital stock series is constructed through the accumulation of gross fixed capital formation and a depreciation rate of approximately 5 per cent. Labour (employment), augmented with human capital (Senhadji, 2000, Sultana et al., 2019), displays an increasing trend. This contrasts with employment, which shows a contraction between 1987 and 1995 and another decline between 2000 and 2011. It is, however, important to account for quality improvements in input factors (Fuglie, 2015), hence the augmentation of employment with human capital, proxied by the number of graduates in agriculture, agricultural operations and related sciences. The agricultural land area has declined post-2000 due to a diversion and rezoning of land use towards non-agricultural purposes such as

[5] According to SAWS, average rainfall is 500 mm per annum. Dum_drought was assigned by allocating 1 for all years where average rainfall was below 500 mm and 0 for all the years that have rainfall above 500 mm. Further modificiations were made using reports from DALRD and BFAP.

urbanisation, industrial development, residential housing and roads (DAFF, 2014). In the analysis, *land* is multiplied (or interacted) by *rainfall* to represent land productivity (similar to Fuglie, 2015).

Table 2 presents descriptive statistics for the variables used in the analysis in levels. An average gross value added of R55 billion in constant 2010 prices is recorded, translating to an average growth rate over the sample period of 1.3%. South Africa's agriculture contributed a maximum of R78 billion to the country's GDP in 2017, while the average real fixed capital stock amounts to R3 billion, expressed in constant 2010 prices.

**Table 2: Descriptive statistics, 1980 - 2019**

| Variable | Mean | Median | Maximum | Minimum | Std. Dev. |
|---|---|---|---|---|---|
| *gva* | 54 583 | 52 950 | 77 857 | 31 188 | 11 847 |
| *k* | 292 295 | 285 911 | 327 1991 | 281 805 | 13 911 |
| *l* | 1 073 890 | 1 091 600 | 1 845 000 | 653 100 | 264 272 |
| *hc* | 2 010 | 1 481 | 4 991 | 737 | 1 277 |
| *land* | 963.5 | 963.5 | 981 | 940 | 13.5 |
| *rain* | 517.6 | 507.5 | 726 | 366 | 84.8 |

On average, a million workers are employed in the agricultural sector, with a maximum value of 1.8 million recorded in 2000. Over the reviewed period, agricultural employment has fluctuated between 1.845 million and 0.653 million workers due to weather, biosecurity breaches such as the outbreak of bird flu (i.e., Avian Influenza), Foot and Mouth Disease in cattle, goats and sheep and African Swine Fever in pigs as well as market dynamics like the introduction of minimum wages and rising farm evictions and redistribution of land to PDIs. However, the expansion of agricultural exports and investment in high-value products such as fruit, nuts and wine have maintained agricultural jobs at around 865 000 per annum during the past five years.

Following the era of economic sanctions in the country, the early 1990s witnessed significant structural and policy shifts in agriculture. It moved from a sector characterised by segregation, protectionism and exclusion to one which strives for inclusivity, modernisation and trade openness, ascribing to the principles of a free and competitive market. Further analysis of selected agricultural trends shows that the sector has doubled in size, underpinned by growing exports, technology adoption and market-friendly policy reforms.

Some of the notable policy reforms in the country are the joining of the World Trade Organisation (WTO) in 1995 which led to the ratification and simplification of the tariff structure, thus removing state subsidies to farmers and reducing tariffs on imported agriculture and quantitative import controls. This was followed by the deregulation of agricultural markets with the promulgation of the Marketing of Agricultural Products Act of 1996. The same year, the government introduced a Land Reform Programme through a White Paper on Land Reform of 1996. The Land Bank Act was amended in 2001 to include the developmental and transformative mandate in support of an inclusive and competitive agricultural sector that promotes the co-existence of large commercial farmers and small-scale farmers as well as subsistence farmers in the rural areas of the country.

Investment in education and learning increases human capital levels that enable the exploitation of technologies and innovation, thus influencing productivity and economic growth (Ortega & Lederman, 2004; Asghar et al., 2012; Anik et al., 2017; Habib et al., 2019). According to Davis et al. (2021), less than 3% of the global agriculture development finance was invested in skilling and capacitating farmers between 2015 and 2018. The Agricultural Sector Education Training Authority (AgriSETA) in South Africa facilitates skills development of the agricultural workforce, including training, learnerships, apprenticeships, bursaries and mentorships. In 2020/21, AgriSETA spent R275,5 million on total grant and project expenditures compared to R372 million in 2019/20. According to NAMC transformation guidelines, at least 20% of statutory levies collected by industries should be allocated to transformation NAMC (2018). The transformation funds increased from R47,4 million in 2014 reaching R124,4 million in 2020. The NAMC's transformation guidelines also prescribe that 18% of the transformation funds be allocated to skills development (including training, bursaries and mentorship). All these investments are expected to positively impact human capital development in agriculture, consequently enhancing total factor productivity in the sector.

South Africa is relatively arid to semi-arid, with an average of 517 mm of rain annually, unevenly distributed (FAO, 2005). The country is a summer rainfall region, although the Western Cape province receives most of its rainfall in winter. According to Liebenberg and Pardey (2012), around 80% of South Africa's total land receives around 750 mm of average annual rainfall, whilst less than 30% of the total area receives less than 250 mm per annum. Agricultural production and productivity are affected mainly by the changing weather phenomena of high temperatures and changing rainfall cycles that eventually result in drought, flooding, and pest and disease outbreak (Clements et al., 2011). The most severe drought periods in South Africa were recorded in 1981, 1982, 2003, 2015, 2016 and 2017 (BFAP, 2020).

## 4 RESULTS AND ANALYSIS

### 4.1 Unit root test results

Table 3 contains unit root test results for the Augmented Dickey-Fuller (ADF), and Elliot-Rotenberg-Stock (ERS) point optimal tests, respectively. In both instances, the assumption that series have non-zero means and a stochastic drift is accommodated by including an intercept term in the test regression. The null hypothesis for both tests, namely that of a unit root, is tested against the alternative of stationarity.

**Table 2.3: Unit root test results**

| Variable | ADF | ERS | Breakpoint URT (break date = 1994) |
|---|---|---|---|
| *lngva* | -0.671 | 29.788 | |
| *lnk* | -4.672*** | 93.945 | -2.467 |
| *lnl_hc* | -0.850 | 23.571 | |
| *lnland_rain* | -5.088*** | 1.697*** | |
| | | | |
| *Δlngva* | -6.989*** | 0.662*** | |
| *Δlnk* | -4.577*** | 25.111 | -6.871*** |
| *Δlnl_hc* | -7.058*** | 1.369*** | |
| *Δlnland_rain* | -7.613*** | 1.122*** | |

**(**)[***] indicates rejection of the null hypothesis of a unit root at the 10(5)[1]% level of significance*

According to the ADF and ERS unit root tests, real gross value added (*lngva*) is non-stationary in levels but becomes stationary when differenced once, hence is integrated of order 1, I(1). Given the linear trajectory of the gross value-added series, there is also evidence that the series may be trend-stationary when allowing for a deterministic trend in the test regression (not shown in the table). Given that capital stock in real terms (*lnk*) remained relatively constant beyond 1994, it is not surprising that the ADF unit root test finds the series to be stationary in levels. However, when accounting for the structural break around 1994, the series is found to be non-stationary in levels and stationary in first-differenced form, hence non-stationary and integrated of order 1, I(1). Even though employment numbers have been declining in the agricultural sector for a large part of the sample period, when combined with increasing human capital in the sector, the series (*lnl_hc*) tests non-stationary, I(1).

The variable constructed for productive farmland, namely land combined with annual rainfall (*lnland_rain*), is stationary in levels, given that rainfall appears to be a mean-reverting process. In contrast, available agricultural land increased in the first part of the sample but declined due to re-appropriating farmland for other uses since 2000.

In summary, both *lngva* and *lnl_hc* can be considered non-stationary I(1) in levels, *lnland_rain* is stationary in levels, while ADF and ERS produced mixed results for *lnk*. However, accounting for the structural break around 1994 in the latter series, the series may also be considered non-stationary, I(1). What is important is that when combining all input factors in the production function and output (real gross value added), we can prove that the relationship constitutes a cointegrating relationship.

### 4.2 Production function estimation for the full sample, 1980 to 2019

In this section, results for the estimation of the model specified in Section 3.1 is reported. Model (1) in Table 4 is the model without accounting for structural breaks. Model (2) includes a dummy for years of drought (*dum_drought*). Model (3) isolates the impact of the global financial crisis by only including *dum_gfc*. Model (4) accounts for the impact of drought (*dum_drought*) and the impact of the global financial crisis in 2008 and 2009 (*dum_gfc*), whilst the final model (5), in addition to the global financial crisis and drought, also controls for the effect the debt standstill and economic sanctions (*dum_sanctions*) may have had on the agricultural sector. The dummy variables (*dum_drought*, *dum_gfc* and *dum_sanctions*) were lagged by one period for models 2 to 5. Given that constant returns to scale in the production process are assumed, no standard errors for the coefficients of *lnland_rain* are reported, as its contribution in the production process is derived as one minus the contributions of capital and labour.

Table 4 illustrates that the estimated coefficient of determination (Adjusted $R^2$) of the production functions for models (1) to (5) ranges between a minimum of 0.57 and 0.69, being the highest, indicating that all models present a moderate fit. Models (2), (3), (4) and (5) are cointegrated at the conventional levels of significance, while model (1) is cointegrated in the margin with the probability for the cointegration test for model (1) falling marginally outside the 10% significance level.

According to Butzer et al. (2012), the agricultural sector continues to grow by adopting productive technologies and building physical and human capital. The estimated results show that a 1% increase in fixed capital stock increases the gross value added by between 0.45% and 0.56%, ceteris paribus. A 1% increase in human capital increases the gross value added by between 0.42% and 0.47%, holding all other factors constant. A 1% increase in land augmented with rainfall increases the gross value added by between 0.02% and 0.10%, ceteris paribus. These variables accord with *a priori* expectation.

**Table 4: Estimation results**

Dependent variable: *lngva*

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *lnk* | 0.487*** | 0.450*** | 0.556*** | 0.519*** | 0.504*** |
| | (0.142) | (0.137) | (0.130) | (0.128) | (0.124) |
| *lnl_hc* | 0.431*** | 0.451*** | 0.415*** | 0.432*** | 0.473*** |
| | (0.047) | (0.047) | (0.044) | (0.044) | (0.048) |
| *land_rain* | 0.082 | 0.099 | 0.029 | 0.049 | 0.023 |
| *dum_drought* | | -0.107** | | -0.078* | -0.077* |
| | | (0.046) | | (0.043) | (0.042) |
| *dum_gfc* | | | 0.272*** | 0.234*** | 0.264*** |
| | | | (0.086) | (0.087) | (0.084) |
| *dum_sanctions* | | | | | 0.105* |
| | | | | | (0.056) |
| *Constant* | -5.495*** | -5.628*** | -5.350*** | -5.473*** | -5.844*** |
| | (0.417) | (0.415) | (0.391) | (0.386) | (0.422) |
| Adj. $R^2$ | 0.571 | 0.605 | 0.646 | 0.667 | 0.690 |
| Akaike info criterion | -0.949 | -1.014 | -1.123 | -1.162 | -1.212 |
| E.G. coint test [a)] | -3.87 | -4.17* | -5.341*** | -5.290*** | -5.235*** |
| | [0.1317] | [0.0780] | [0.0064] | [0.0072] | [0.0082] |

**(**) [***] indicates 10 (5) [1] % level of significance.*
*Standard errors are in parentheses.*
*a) $H_0$: No cointegration (p-values in square brackets).*

Models (2) to (5) control for periods of droughts and the impact of exogenous shocks like the global financial crisis and economic sanctions. The coefficients on *dum_drought* in models (2), (4) and (5) are -0.107, -0.078 and -0.077, respectively, implying that during years of drought, gross value added is negatively impacted. In the case of model (2), for example, the impact of the drought translates to an

11.2% decrease in agricultural output.[6] These results are consistent with Kang et al. (2009) and Hlalele et al. (2016). Kang et al. (2009) further propose expanding irrigated areas to increase crop production, whilst Hlalele et al. (2016) further indicate that the economies of Sub-Saharan African countries are most vulnerable to the effects of drought due to their dependency on rain-fed agriculture.

On the other hand, the global financial crisis did not harm agricultural output; models (3), (4) and (5) show that, during the period 2008 and 2009, the dependent variable, *lngva*, was higher on average by 0.272, 0.234 and 0.264, respectively. Model (5) depicts the impact of economic sanctions (0.105). During the period of economic sanctions (1985 to 1994), the dependent variable, *lngva*, increased on average by 0.105, ceteris paribus. This equals an average increase of 11% in real gross value added. The positive sign on the dummy variables (*dum_gfc* and *dum_sanctions*) illustrates that the demand for food is relatively insensitive to exogenous shocks compared to other commodities.

### 4.3 Cointegration results

Given that in the case of *N* variables in the relationship, the possibility exists that there may be *N-1* unique cointegrating vectors amongst the set of variables, we also subject the model to a multivariate (Johansen, 1988, 1989) test for cointegration. Table 5 presents the Johansen unrestricted rank test results for model (1), based on a VAR of order 1 (refer to Table A.1 in Appendix A for the lag selection test result) and allowing for a linear trend in the data, as well as a constant in the cointegration equation and test VAR. Testing for cointegration is done through the Trace and Maximum Eigenvalue tests statistics. Both tests reject the null hypothesis of no cointegrating vector in favour of one or more cointegrating vectors to exist. However, both tests fail to reject the null hypothesis of one cointegrating relationship ($r = 1$), against the alternative of two or more cointegrating vectors, at the 1 and 5 per cent significance level, for the Trace and Maximum Eigenvalue tests, respectively. Conclusively, the two tests provide ample evidence that the chosen variables have a long-run relationship amongst them, with a single unique cointegrating vector.[7]

[6] The percentage negative impact on output is calculated as 100[exp (0.107)-1] = 11.2%.

[7] Similarly, when controlling for exogenous factors through inclusion of dummy variables for drought, economic sanctions and the global financial crisis, the Johansen cointegration test provides evidence of cointegration amongst the set of variables.

**Table 5: Multivariate unrestricted cointegration rank test**

Series: *lngva, lnk, lnl_hc lnland_rain*

Unrestricted Cointegration Rank Test (Trace)

| $H_0$: No cointegration | $H_A$: Cointegration | Eigenvalue | Trace Statistic | 0.05 Critical Value | Prob.[a)] |
|---|---|---|---|---|---|
| r=0 | r≥ 1 | 0.5635 | 56.58*** | 47.87 | 0.0061 |
| r ≤ 1 | r≥ 2 | 0.3349 | 25.08 | 29.80 | 0.1588 |
| r ≤ 2 | r≥ 3 | 0.2189 | 9.57 | 15.49 | 0.3149 |
| r ≤ 3 | r≥ 4 | 0.0048 | 0.19 | 3.84 | 0.6665 |

[a)] *MacKinnon-Haug-Michelis (1999) p-values.*

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

| Hypothesised No. of CE(s) | | Eigenvalue | Max-Eigen Statistic | 0.05 Critical Value | Prob.[a)] |
|---|---|---|---|---|---|
| r=0 | r=1 | 0.5635 | 31.50** | 27.58 | 0.0150 |
| r ≤ 1 | r=2 | 0.3350 | 15.50 | 21.13 | 0.2554 |
| r ≤ 2 | r=3 | 0.2189 | 9.39 | 14.26 | 0.2552 |
| r ≤ 3 | r=4 | 0.0049 | 0.19 | 3.84 | 0.6665 |

[a)] *MacKinnon-Haug-Michelis (1999) p-values.*
**(**) [***] indicates rejection of the null hypothesis of no cointegration at a 10 (5) [1] % level.*

### 4.4 Recursive estimation of the production function

Based on the long-run cointegration result for gross value added, physical and human capital and productive land, and the premise that factor contributions, in reality, may be time-varying, this section presents results for model (1) estimated recursively. Even though models (3), (4) and (5) exhibit a higher degree of explanatory power based on Adjusted $R^2$ values and Akaike model selection criteria, the fact that the global financial crisis occurred only in 2008 and 2009 does not allow for recursive estimation due to perfect multicollinearity of *dum_gfc* and the constant in the estimation for sub-samples ending prior to 2008. For this reason, the model specification in (1) is used to determine factor contributions recursively.

The first estimation is performed for the sub-sample period 1980 to 1990, after which the sample is expanded by one observation at a time. The set of estimated factor elasticities is then available from

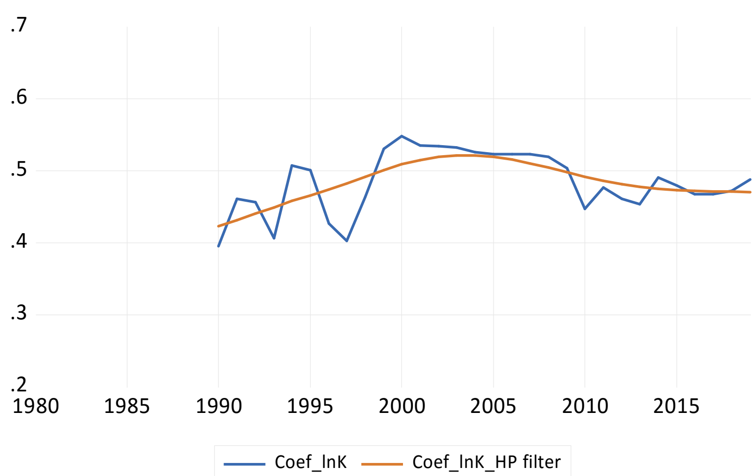
1990 onwards. The time-varying elasticities obtained in this way provide an indication of the relative changes in capital, labour and land intensities in the agricultural production process.[8] The average factor elasticities for the three 10-year periods from 1990 onwards are summarised in Table 6 and depicted graphically in Figures 1a – 1c, showing the time-varying changes over the sample period.

**Table 6: Input factor elasticities**

| Period | *Capital* | *Human capital* | *Land* |
|---|---|---|---|
| 1990 - 1999 | 0.455 | 0.503 | 0.042 |
| 2000 - 2009 | 0.526 | 0.350 | 0.123 |
| 2010 - 2019 | 0.470 | 0.436 | 0.094 |
| Average 1990 – 2019 | 0.483 | 0.436 | 0.086 |

The production process appears to have been more labour-intensive during the 1990s, whereas from the beginning of the 2000s, the process changed to more capital-intensive practices. However, given the consistent decline in physical capital in real terms over the sample period, from the decade starting in 2010, a shift back to an increased labour share in output has appeared. The share of land (interacted with rainfall) is the lowest of the three factor inputs, with an increase in the 2000s but followed by a decline after 2010, coinciding with agricultural land re-appropriation and years of lower-than-average rainfall between 2014 and 2017.

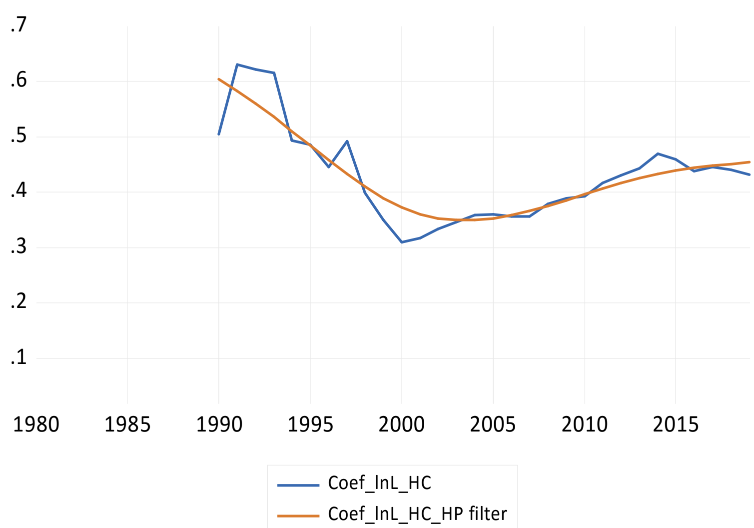
**Figure 1a: Recursive coefficient for capital**




[8] An alternative method to obtain time-varying factor elasticities is through state-space modelling (Kalman et al., 1969).

The share of fixed annual capital in production fluctuated between 0.39 in 1990 and 0.55 in 2000, attributed to the reintegration of South Africa's economy into the global economy. This process came with major changes to political and social structures. There were lucrative opportunities after the sanctions were lifted, leading to more international companies investing in South Africa (Mboweni, 2000). Access to international markets and positive real interest rates played a role during this decade (Van Zyl et al., 2000). A decline in the share of gross fixed capital was recorded from 0.55 in 2000 to 0.45 in 2010 as a result of the global financial crisis and decreasing rates of real fixed capital formation; however, this was followed by a marginal increase to 0.49 in 2019 representing the positive reaction of farmers to political changes and adoption of new farming technologies.

**Figure 1b: Recursive coefficient for labour (human capital)**




Labour's share in output decreased from 0.63 in 1991 to 0.32 in 2000, then increased and reached 0.43 in 2019. Van Zyl et al.'s (2000) research indicates that the downward trend in agricultural employment can be partly attributed to the decline in the agricultural sector's contribution to the economy, declining from 10.7% in 1960 to 1.9% in 2019 (World bank, 2020). Using mechanisation and new technologies also impacts employment in the sector as farmers strive to minimise costs and increase profit.

**Figure 1c: Recursive coefficient for land**

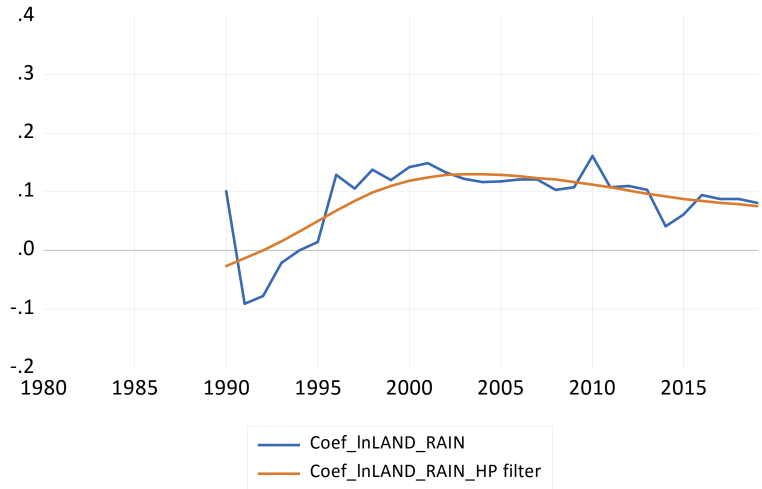



Figure 1c shows increases in the share of agricultural land in the production process from no real contribution to 0.15 in 2009 before stabilising around 0.10 during the late 2000s. A further decline was recorded from 0.16 in 2010 to 0.04 in 2014. The decline is attributed to the shift in agricultural land use for other purposes, such as residential or mining. A study by Lidzhegu and Palamuleni (2021) shows that the decline in agricultural activity results from a change in ownership and management skills as land is transferred from commercial to smallholder farmers or communities and land claimants. In a case study, De La Hey and Beinart (2017) suggest that the decline in the productive use of arable land results from a shortage of labour for agricultural purposes, despite high unemployment in the former homelands under consideration.

### 4.5 Determination of total factor productivity

An index of TFP in agriculture guides the overall efficiency of agricultural production. The production process utilises capital, land and labour as inputs, while the outputs entail gross agricultural value added accumulated from crops, horticulture and livestock industries. Figure 2 contains the calculated TFP growth rate based on 10-year averages of input factor elasticities (as reported in Table 6), the actual annual growth rates in output (gross value added) and inputs capital, labour and land.[9] In addition, the computed TFP growth based on the analysis carried out in the preceding sections is compared to the

[9] The TFP growth rate is calculated using the ten-year averages of input factor elasticities and the actual annual growth rates in gross value added, capital, labour and land, as follows (the factor contributions estimated for the period 1990 to 1999 is applied for the full period from 1980 to 1999):

$$tfp\_gr_t = gva\_gr_t - (0.455 * k\_gr_t) - (0.503 * l\_hc\_gr_t) - (0.042 * land\_rain\_gr_t),\ \ t = 1980, \dots, 1999.$$

$$tfp\_gr_t = gva\_gr_t - (0.526 * k\_gr_t) - (0.350 * l\_hc\_gr_t) - (0.123 * land\_rain\_gr_t),\ \ t = 2000, \dots, 2009.$$

$$tfp\_gr_t = gva\_gr_t - (0.470 * k\_gr_t) - (0.436 * l\_hc\_gr_t) - (0.094 * land\_rain\_gr_t),\ \ t = 2010, \dots, 2019.$$

TFP for the South African agricultural sector, obtained from the Economic Research Services, United States Department of Agriculture (USDA), using the Food and Agricultural Organisation (FAO) and International Labour Organisation (ILO) data (USDA, 2019). It is evident from Figure 2 that the TFP computed in this study the TFP from the USDA (2019) displays a similar growth trend over the period 1980 to 2019. The USDA TFP measure is estimated using employment in agriculture, agricultural land and fixed capital stock.[10]

**Figure 2: Total factor productivity growth**

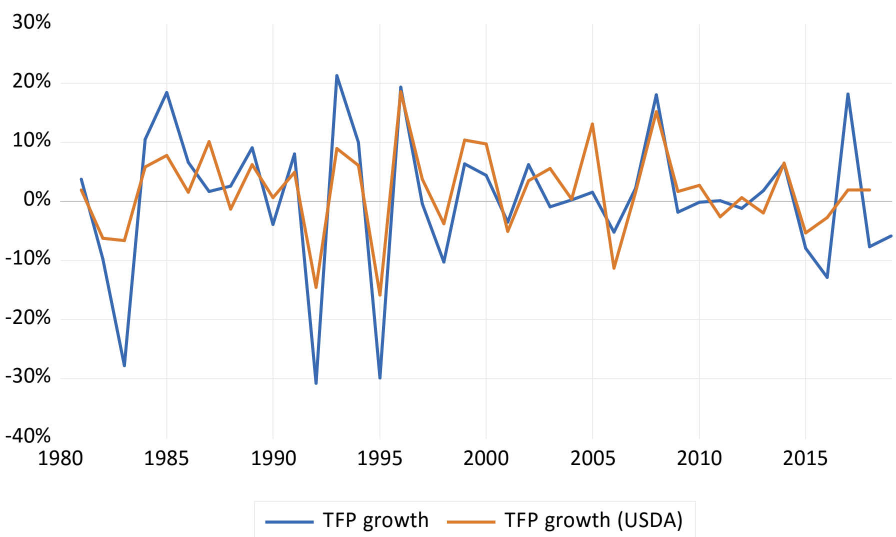



Table 7 contains 10-year averages for the annual growth rates in agricultural output (gross value added), factor inputs and the resulting TFP growth in column 4. Figure 2 and Table 7 show that TFP realised a 2.23% average growth rate between 1980 and 1989. During 1982, the country experienced severe drought conditions, which affected agricultural output resulting in a 24% decline in TFP growth before it improved and reached a 20% growth rate in 1985. The decreasing trend in TFP growth during the period 1990 and 1999, during which period an average growth rate of 0.41% was registered) may be attributed to policy changes that emanated from the end of the apartheid era and, consequently, the opening up of the economy, mainly through trade liberalisation. This was further supported by the introduction of the Marketing of Agricultural Produce Act number 47 of 1996.

[10] https://www.ers.usda.gov/data-products/international-agricultural-productivity/.

**Table 7: Aggregate output, inputs and TFP growth rates for the agricultural sector in South Africa over the four periods**

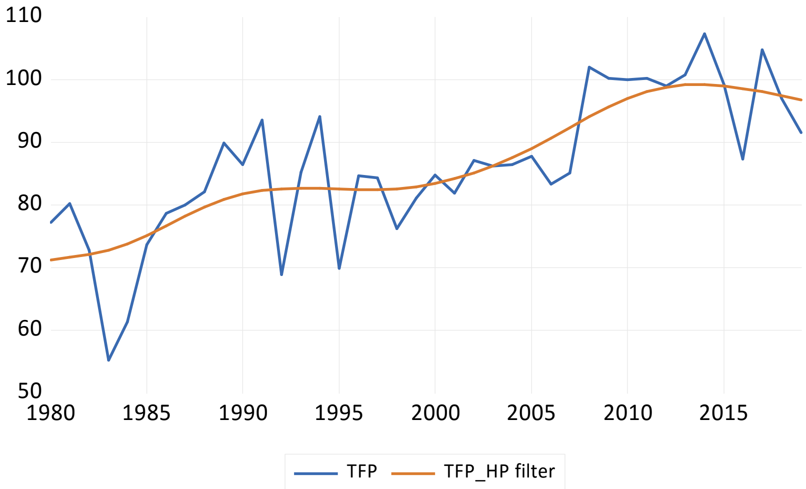
| *Period* | *Output growth* | *k* | *Input growth land_rain* | *l_hc* | *TFP growth – estimated* | *TFP growth - USDA* |
|---|---|---|---|---|---|---|
| 1980 - 1989 | 3.30 | -0.27 | 0.03 | 1.31 | 2.23 | 2.10 |
| 1990 - 1999 | 0.77 | -0.19 | 0.11 | 0.45 | 0.41 | 2.47 |
| 2000 - 2009 | 2.74 | -0.01 | -0.06 | 0.47 | 2.34 | 3.77 |
| 2010 - 2019 | 0.82 | -0.03 | 0.08 | 1.33 | -0.55 | -0.24 |
| Avg. 1980 - 2019 | 1.91 | -0.13 | 0.04 | 0.89 | 1.11 | 2.02 |

*Source: Authors' estimation and USDA (2019).*

The period between 2000 and 2009 saw increased growth rates again, reaching a 2.34% average growth in TFP but was later affected by the global financial crisis of 2008/9 with a significant impact on the real sector of the economy in early 2009. The TFP growth was relatively slow from 2010 to 2019 compared to the previous period, partly attributed to the drought that affected the agricultural sector. This result is supported by Arndt and Pratt (2020), who also report a decline in productivity growth, although their study finds the decline to start even earlier than 2008, notably from 2005 onwards. The final column contains the 10-year averages for the TFP growth rate reported by USDA (2019). Overall, the computed TFP growth in this study is 1.11% on average, compared to an average of 2.02% in the TFP growth rate reported by the USDA. An earlier study by Liebenberg and Pardey (2012) recorded a total factor productivity growth rate over the extended sample period of 1945 to 2010 of 1.5%. The marginally lower growth rate found in the current analysis may partly be due to the sustained decline in real agricultural capital stock from 1983 onwards (average annual growth rate of -0.4% over the period 1983 to 2019), after a relatively substantial increase between 1946 and 1982 (average annual growth rate of 2.84% over the period 1946 to 1982). Refer to Figure A.2 in Appendix A for a graphical depiction of real capital stock, *k*.

Figure 3 presents the total factor productivity index generated from the TFP growth series derived from the growth accounting exercise, using 2010 as the base year.

**Figure 3: Agricultural sector total factor productivity (2010 = 100)**




## 5 CONCLUSION AND POLICY IMPLICATIONS

This study aimed to determine the production structure of the agricultural sector in South Africa using a growth accounting exercise based on a Cobb-Douglass production function specification. It also examined the contributions of the production factors inputs in the production process and the time-varying trend thereof and measured the total factor productivity using time series data from 1980 to 2019.

The results show the impact and the share of the three production factor inputs (i.e., capital, labour and land) in output and yield the derivation of TFP. The share of land augmented with rainfall is shown to be a positive impacting factor in agricultural production. However, the change in agricultural land ownership and management skills influenced by land transfer from commercial to emerging farmers negatively impacts the productive share of land in the agricultural production process. This can be attributed to reduced land productivity when it is transferred to small-scale farmers without the necessary farm support, such as training to acquire skills and limited access to water rights and markets.

Mechanisation and technology adoption also contributes to changes in labour in the sector. The labour contribution decreased sharply up to 2000, then increased to a share of 0.43 in 2019. This labour factor share fluctuation is consistent with economic and policy changes in the sector during the period under consideration. During the 1980s, agricultural employment was mainly affected by political instabilities in the country coupled with occurrences of droughts and other environmental shocks. Furthermore, the introduction of new land regulations, such as the Extension of Security of Tenure (ESTA) Act of 1997, resulted in increased farm worker evictions, consequently impacting labour as farmers changed the conditions of farm workers from permanent to casual workers to avoid violating the ESTA Act. However, the substantial investments in labour-intensive industries such as fruits and nuts in the last decade have somewhat improved the employment opportunities in the sector despite others sub-sectors, such as livestock and field crops losing workers and shifting to mechanisation. The shift towards high-value and export-oriented crops is evident in the results that illustrate a good correlation between the increase of labour and capital formation, implying that as the sector experienced growth, the share of labour and capital formation also increased.

Empirical results show that the agricultural TFP measured is comparable to the results obtained from the USDA. However, TFP growth rates are suggested to be marginally lower, attributable to a decline in real fixed capital stock not anticipated in the USDA analysis. The average growth for the TFP constructed in the current analysis is 1.1%, compared to the USDA TFP, which is reported as 2.0% over the 1980 to 2019 period. The TFP growth trend analysis depicts a fluctuating pattern recording negative values during 1983, 1992 and 1995, whilst the highest positive values of TFP growth were recorded during 1985, 1993, 1996, 2008 and 2017. These fluctuations in TFP growth are consistent with political and economic changes that the South African agricultural sector underwent over the past four decades. In particular, the deregulation of agricultural marketing coupled with farmer support, agricultural finance and trade reforms in the mid-1990s, as well as the adoption of more advanced technology and investment in R&D, stimulated the TFP between 2008 and 2019.

The analysis highlights the importance of the government and its role in ensuring that investment-friendly and sound policies are developed to support the South African agricultural sector. It is crucial that government design and implement policies that support and improve TFP in the agricultural sector. Land reform is one of the policies that require the urgency of government intervention in order to accelerate the process. This policy needs to be accompanied by a comprehensive farmer support programme to upscale access to land, water rights and skills development. Accelerating land redistribution without complementary farmer support will likely impact TFP in the near future and erode the country's ability to produce and export food.

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## APPENDIX A

### A.1 Testing for the presence of unit roots

The first step in time series data analysis is to test for the presence of a unit root. This study applies the Augmented Dickey-Fuller (ADF) unit root test (Dickey & Fuller, 1979 and 1981) and the Elliot-Rotenberg-Stock (ERS) point optimal test (Elliot et al., 1996), respectively, both with and without a deterministic trend. The ADF equation is estimated by OLS as follows:

$$\triangle Y_t = \alpha + \gamma t + (\phi - 1)Y_{t-1} + \sum_{i=1}^{k} \theta_i \, \Delta Y_{t-i} + \mu_t \qquad \text{(A.1.1)}$$

where is $Y_t$ is the series under investigation, t is a time trend and $\mu_t$ are white noise residuals. The number of lagged dependent values to include is based on model selection criteria such as Schwarz Bayesian Criterion (SBC), Akaike Information Criterion (AIC) and Hannan-Quinn Criterion (HQC).

To improve the power of the unit root test, Elliot, Rothenberg and Stock proposed a local to unity detrending of the time series. ERS developed a feasible point optimal test, which accounts for serial correlation in the error term. According to Evans and Kelikume (2018), the ERS point optimal test is computationally more robust than the popular ADF and PP unit root tests.

### A.2 Testing for cointegration amongst selected variables

This study applies a multivariate cointegration procedure where the cointegrated Vector Autoregression (VAR) model (Johansen, 1988, 1991) is used to test for cointegration among the variables in the theoretical production function specification.

A VAR model of order $k$ is given by:

$$X_t = A_1 X_{t-1} + \cdots + A_k X_{t-k} + \mu + \varepsilon_t \qquad \varepsilon_t \sim IN\ (0, \Sigma) \qquad \text{(A.2.1)}$$

where $X_t$ is (n x 1) and each $A_i$ is an (n x n) matrix of parameters. According to Johansen (1988), subtracting $X_{t-1}$ on both sides, and re-arranging yield the following equation:

$$\Delta x_t = \Gamma_1 \Delta x_{t-1} + \cdots + \Gamma_{k-1} \Delta x_{t-k+1} + \Pi x_{t-k} + \mu + \varepsilon_t \qquad \text{(A.2.3)}$$

This can be simplified as follows:

$$\Delta x_t = \sum_{i=1}^{k-1} \Gamma_i \, \Delta x_{t-i} + \Pi x_{t-k} + \mu + \varepsilon_t \qquad \text{(A.2.4)}$$

where $\Gamma_i = -(I - A_1 - \cdots - A_i)$ , $(i = 1, \dots , k-1)$, $\Pi = -(I - A_1 - \cdots - A_k)$, $x_{t-k+1}$ , … , $x_0$ are fixed, and the parameters $\Gamma_1, \dots , \Gamma_{k-1}$ and $\mu$ are allowed to vary without restrictions.

Any of this linear combination of the rows would lead to stationarity, meaning that $X_{t-k}$ has stationary components if the rank of Π is $\Pi < n$ . Since Π of rank is $r < n$, the row of rank may be written as:

$\Pi = \alpha\beta'$ for suitable $n \times r$ matrices $\alpha$ and $\beta$. (A.2.5)

The approach of Johansen proposes two likelihood ratio tests, namely the trace test and the maximum eigenvalue test. These tests can be conducted to examine the actual number of cointegration vectors in the system. If these tests demonstrate the presence of cointegration amongst the variables, VECM is selected as an estimation model. Equation (A.2.5) can be interpreted as an error correction model. The matrix $\beta$ contains the $r$ cointegrating vectors (long-run coefficients) and $\alpha$ is the loading matrix containing the speed of adjustment to long-run equilibria (the error-correcting terms).

## A.3 Graphical depiction of data used in the analysis

**Figure A.1: Data series in natural log transformation**

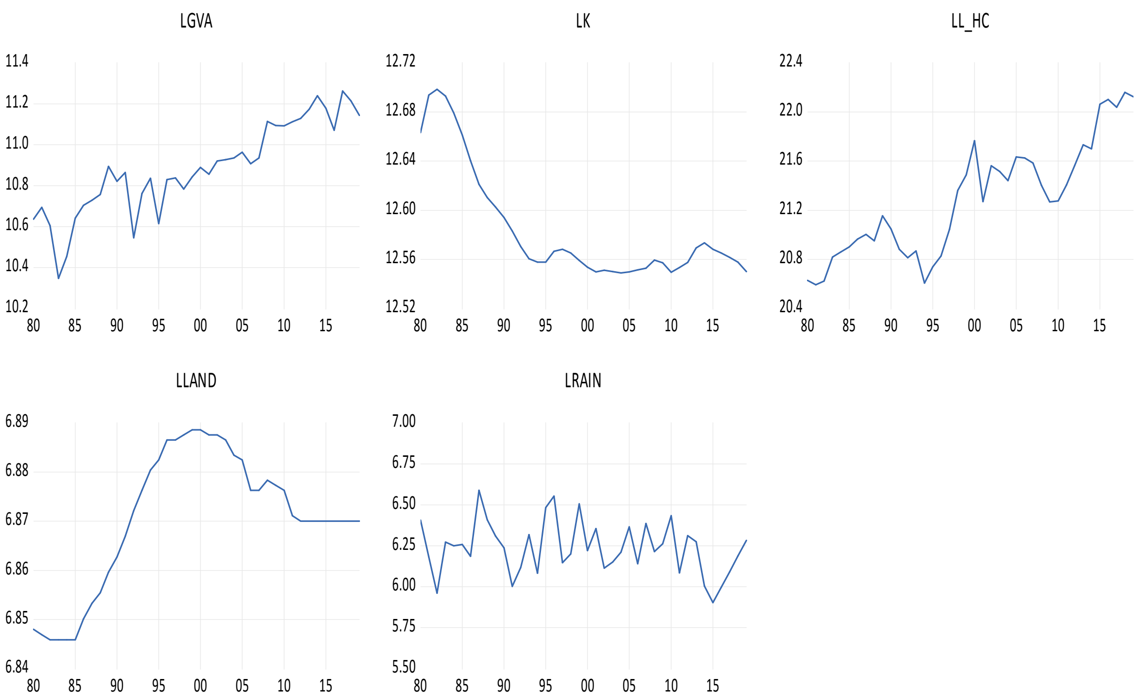
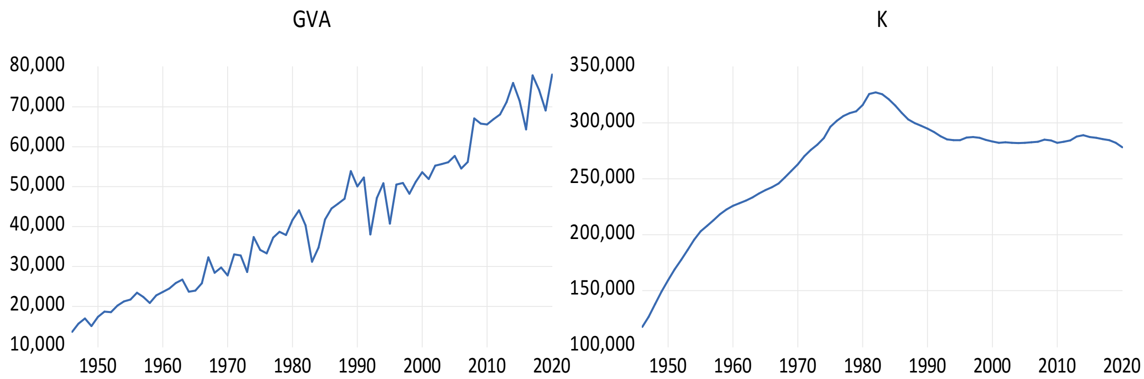


**Figure A.2: Real agricultural gross value added and real capital stock, 1946 - 2020**




## A.4 VAR lag order selection for multivariate cointegration test

**Table A.1: VAR lag order selection for Model (1) in Table 3**

Endogenous variables: *lngva, lnk, lnl_hc lnland_rain*
Exogenous variable: *constant*

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | 101.7028 | NA | 5.16e-08 | -5.427932 | -5.251986 | -5.366522 |
| 1 | 217.6602 | 199.7044* | 2.01e-10* | -10.98112* | -10.10139* | -10.67407* |
| 2 | 233.2751 | 23.42242 | 2.13e-10 | -10.95973 | -9.376211 | -10.40704 |
| 3 | 244.6507 | 14.53550 | 3.03e-10 | -10.70282 | -8.415514 | -9.904488 |
| 4 | 254.1898 | 10.06902 | 5.24e-10 | -10.34388 | -7.352787 | -9.299907 |

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion