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## Distortionary Agricultural Policies: Their Productivity, Location and Climate Variability Implications for South Africa During the 20th Century

by

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# ABSTRACT

During the first half of the 20th century, the policy stance towards South African agriculture swung from suppression to support. More recently, the agricultural support policies were eliminated. Using newly constructed, long-run (1918-2015) data concerning maize production, yield and average price, we show these switching agricultural policy regimes had significant production, productivity, and climate risk implications for the maize sector. At its peak, this policy-induced movement reduced maize productivity by between 7.9 and 15.3 percent. The removal of the distortions coincided with a contraction in the total area planted to maize, but some spatial productivity perturbations still persist.

*Keywords*: South Africa, Maize, Policy, Spatial Economics

*JEL codes*: Q11, Q18, N57, D24

# Distortionary Agricultural Policies: Their Productivity, Location and Climate Variability Implications for South Africa During the 20th Century

## 1 Introduction

For much of the 20th century, South African agriculture took place in the presence of a potent, albeit evolving, package of distortionary and discriminatory farm (and broader economic and social) policies. Following an initial pro-mining stance, policies more favorable to agriculture gained ground during the early 1900s, well before the uptick in Apartheid legislation that occurred with the Malan government beginning in 1948 (Greyling et al. 2018). These favorable-farm policies ushered in a golden age of support that entailed a host of policy and institutional instruments that favored agriculture relative to other sectors of the economy. These sectoral policy distortions occurred in the context of other, blatantly discriminatory policies that either de facto or de jure favored commercial (mostly white) over smallholder (largely black) farmers. Discriminatory policies against black farmers included restrictions on the total amount of accessible land and precisely where in the country they could grow their crops, as well as limits on their access to markets and agricultural support measures (see, for example, Bundy 1988; Van Onselen 1996; Vink 2000). Policies that favored commercial producers included subsidized long-term credit, farmer settlement programs, and controlled marketing and capital tax concessions (see, for example, Brits 1969; De Klerk 1983; Vink 1993; Letsoalo and Thupana 2013).

Although the racially-based (discriminatory) Apartheid policies persisted for decades, they were eventually dismantled. The legislative end of Apartheid came with the De Klerk government in 1991–92, which presaged the Mandela government that took office in the 1994 election.[1] However, changes to the many distortionary policies affecting the country's farm sector predated the broader reforms to the Apartheid policies. They included the gradual withdrawal of direct price supports and other input and output subsidies to the agricultural sector, beginning with the policy reforms launched in the early 1980s and continuing with the subsequent post-apartheid (specifically post-1994) liberalization of international trade and deregulation of domestic agricultural marketing programs. All these policy reform processes were largely complete by the late-1990s (Vink et al., 2017).

In this paper, we show that the changing orientation of these farm policies had a profound effect on the structure of production agriculture in South Africa with both short- and longer-term implications for the productivity performance and climate resilience of the sector. We use the changing fortunes of maize production to illustrate the complex, but clearly evident, interplay between changing farm policy regimes and changing agricultural production realities. Maize has long been, and still is, the dominant crop grown in South Africa, accounting for 82.5 percent of the 3.67 million hectares sown

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[1] This was the first election under universal suffrage in the history of South Africa

to cereal crops in 2015 (and 50.6 of the country's cropped area when averaged over the period 1948–2007) (Liebenberg 2012; DAS 2018; Greyling and Pardey 2019a). It is also an important source of calories, accounting for 27 percent of the country's 3,022 calories consumed per capita per day in 2019 (FAO 2022).[2]

To assess the policy-production-productivity interactions, we compiled a timeline of policy prescriptions and practices that waxed and waned in their agricultural orientation over the course of the 20th century. For extended periods, albeit less so of late, these policies provided substantial targeted support to production agriculture (including maize) and, for much of that time, favored commercial over smallholder farming interests. We juxtaposed this policy timeline against a formal time-series decomposition of a new, historical (1904–2015) compilation of maize production statistics—specifically the planted area, geographical location, and grain yield of maize.

A notable feature of our newly compiled data is the geographical disaggregation of maize production statistics (i.e., yield, planted area, and output) to a spatially standardized set of boundaries. Given the complex interactions between spatially variable environmental factors (including soil, temperature, rainfall, and pests and diseases) and crop genetics, a crop's realized yield and output performance are closely linked to these environmental fundamentals. Thus, cropping agriculture is an intrinsically location-specific production process, but as we show here, these locational choices are also subject to distortionary policy influences.

To presage our main findings, we reveal that the shifting orientation of distortionary farm policies closely accords with changes in maize production patterns. The period during which the South African policy landscape most favored agriculture—beginning in the late 1930s and tailing off by the 1990s—was when the area under maize production and cropped area in total expanded markedly, and yield growth took off. As these farm-favorable policies were gradually abandoned, beginning in 1983, the area under commercial maize production fell, eventually returning in 2015 to the area sown to the crop almost 83 years earlier (in 1932) before many of these supportive farm policies were in place.

Our spatial production data reveal another important, albeit little studied (at least by economists), policy-induced distortion in the location of agricultural production. The favorable production policies induced a substantial expansion of the physical footprint of production into those areas that had hitherto supported little (if any) maize production. We show that the policy-induced expansion of maize area drew in new locations with relatively lower and more variable (rainfed) maize yields than

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[2] Maize is also the most important staple food crop throughout much of sub-Saharan Africa (hereafter Africa), accounting, on average for 40% of the cereal production in Sub-Saharan Africa (SSA), where more than 80% is used as food. The crop provides at least 30% of the total calorie intake of people in Sub-Saharan Africa (Ekpa et al. 2019). A large share (15 percent) of the region's 2015 maize production occurred in South Africa (FAO 2022).

the areas that supported the bulk of the country's maize production before these policy distortions. In other words, the policies sufficiently undermined agroecologically-based spatial comparative advantages to spur production in these less-favorable parts of the country. Notably, once the sectoral support policies were removed, not only did the total area in maize contract markedly, production largely reverted back to the geographical areas with intrinsically higher production (yield) potential and less variable weather. The exceptions to this post-reform area reallocation are the irrigated areas along the Vaal and Orange Rivers, and the Western and Southern Cape regions to a lesser extent. Government support for the installation of irrigation infrastructure—which was at its zenith in the period 1940–1980 (Van Vuuren 2010a,b)—induced a longer-lasting change in the geography of South African maize production, indicating that it is not just the amount, but also the form of the support, that has consequences for economic activity in agriculture.

## 2 Evolving Agricultural Policy and Production Realities

Black and white farmers alike seized the opportunities provided by the mining boom during the second half of the 1800s, although the latter did not take lightly to the competition posed by the former (see Greyling et al. 2018). To stem competition from black farmers, various 'apartheid' policies were enacted by the state in favor of the interests of white farmers. These discriminatory policies led to a dualistic agricultural system; wherein 'white agriculture' enjoyed the benefits of agricultural support programs, subsidized credit, and controlled marketing. Not only were black farmers excluded from accessing these income support and marketing arrangements, but their direct access to land was also restricted to just 13 percent of the available farmland in South Africa by way of the 1913 Land Act (and its successor laws) (Vink et al. 2018).[3] To circumvent these land access restrictions, black farmers opted for various (informal) tenure, sharecropping, 'squatting' and other arrangements, all of which the state endeavored to thwart over the years (see, for example, Trapido 1971; Bundy 1972; Morris 1976; Marcus 1989; Van Onselen 1996; Greyling et al. 2018). Nonetheless, efforts to work around the blatantly discriminatory policies were substantial; at their peak during the 1950s, more than half of smallholder maize was produced outside the former homeland reserves (Greyling and Pardey 2019a).

Ultimately these policy measures succeeded in establishing 'two agricultures;' one characterized by a relatively small (in numbers) group of mostly white 'commercial farmers,' the other characterized by a far larger group of mostly black 'smallholder farmers' (Lipton 1977; Van Zyl et al. 1992). Unfortunately, the agricultural censuses fail to consistently report smallholder production, especially for the sub-national (provincial and municipality) aggregates central to the spatially explicit analyses

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[3] In this instance, farmland excludes government owned land, national parks and cities. Note that the farmed area includes both arable (e.g., seasonal crops) and non-arable (e.g., permanent crops and pasture) land.

conducted for this paper. Nonetheless, Greyling and Pardey (2019a) estimated that while smallholders accounted for approximately 30 percent of total maize output in 1911, that share dropped to about 20 percent by the late 1930s and fell further to around 10 percent by the mid–1960s, where it remained until the end of Apartheid in 1994. Despite the repeal of all racially based land regulations in 1991 and the subsequent post-apartheid policy and land reform initiatives, the output share of smallholder farmers continued to decline to just 2.9 percent by 2007 (Greyling and Pardey 2019a). The inexorable decline in the contribution of smallholder production is partially attributable to the land access restrictions faced by smallholder producers (until 1991) but also reflects a continuing shortfall in the uptake of modern crop varieties and other agricultural technologies required to remain competitive in agriculture. Another manifestation of this agricultural dualism is that the maize yields of smallholders were estimated to be around 41 percent of the yields realized by commercial farmers in 1935, falling to just 18.2 percent of commercial yields by 2003 but then diverging again to 37.3 percent by 2015 (Greyling and Pardey 2019a).

## 2.1 Three Agricultural Policy Regimes

South African maize production during the early 20th century was hampered by a policy regime that favored mining interests over those of the agricultural sector (Greyling et al., 2018). A raft of support policies and government-managed marketing practices introduced during the 1930s and 1940s shifted the policy landscape from one of suppressing agriculture (before 1945) to supporting agriculture (during the period 1945-1988) (Jayne and Jones 1997; Greyling et al. 2018), with the nominal rate of agricultural assistance peaking at 31 percent between 1980 and 1981 (Kirsten et al. 2009). The major policy events during this and subsequent periods are summarized in Appendix A. Market-related policy events of special interest include the promulgation of the Agricultural Marketing Act of 1937, the election of the pro-farmer National Party in 1948, and the partial deregulation of maize marketing in 1988. The 1988 legislation was followed by the implementation of the Marketing of Agricultural Products Act of 1996 that for all intents and purposes constituted a complete deregulation of the agricultural sector by 1998. This evolving policy landscape naturally segments into three quite distinct policy regimes as depicted in Figure 1.

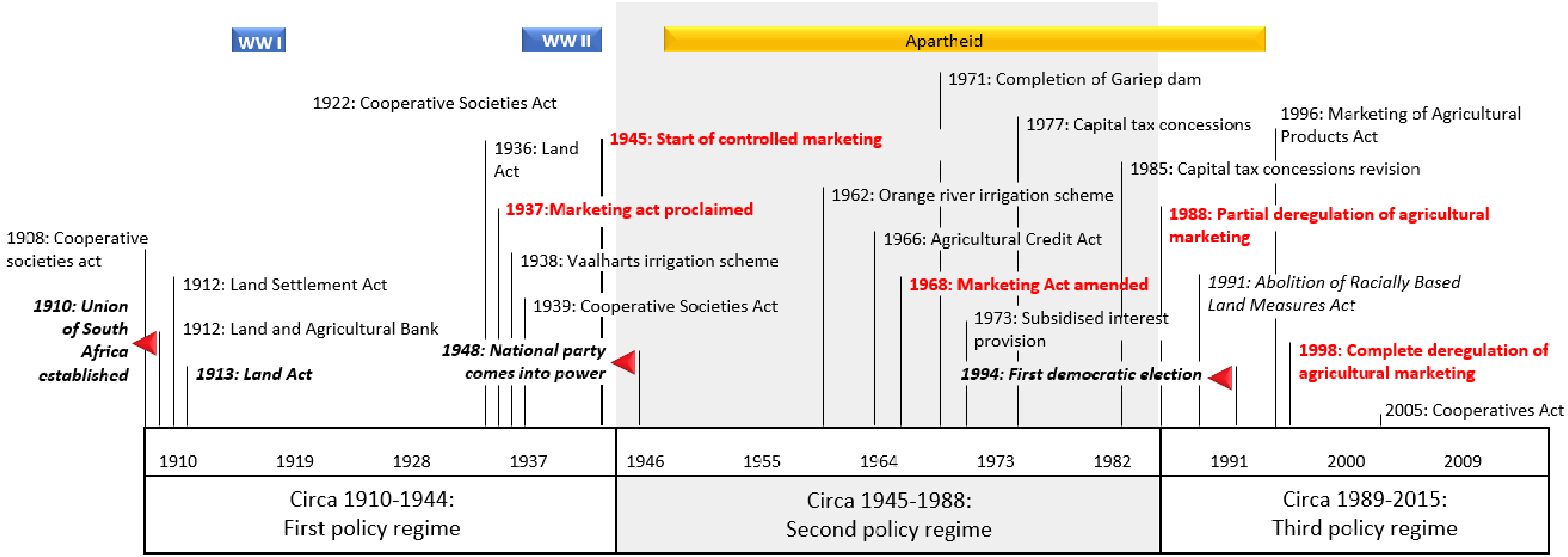

Figure 1: *South African agricultural policy regimes, 1918–2015*

*Source*: See Appendix A.

*Notes:* The policies demarked in red text are the major marketing-oriented policies. Red flags in the figure designate timing of major political events

### *2.1.1 A Pre-regulation Regime: Pre-1948*

The first step toward controlled marketing of maize was taken in 1908 with the passing of the *Cooperative Societies Act* by the then Transvaal Government. It permitted the establishment of cooperative societies to counteract the perceived disproportionate influence of independent marketing middlemen on the price of maize (Brits 1969). In addition, this was also seen as a means to counteract the dominance of the so-called 'alliance of maize and gold', involving cooperation between the mines (as a major maize buyer for their workers) and maize farmers (Trapido 1971; Morrell 1988; Greyling et al. 2018). However, the cooperative farmer movement only began gaining notable traction during the 1930s when the growing discontent between the maize farmers and gold mines drove bigger farmers to cast their lot with their smaller compatriots (see Greyling et al. 2018). The expansion of farmer cooperatives was also aided by the promulgation of the *Cooperative Societies Act of 1922,* which permitted the establishment of limited liability societies. As a result, between 1922 and 1932 the number of farmer cooperatives increased from 54 to 416, with their total membership increasing from 12,800 to 85,600. By 1932 the Central Agency, as the overarching collective marketing body of the farmer cooperatives was called, controlled 60 percent of all maize sold nationally during that year (Brits 1969). Notwithstanding the growth of these cooperatives, Morrell (1988) argued that despite the Central Agency's considerable market share it was still insufficient to exercise any significant market power and realize higher prices for farmers.

### *2.1.2 A Regulated Market Regime: circa 1948-1987*

The objectives of collective marketing were realized with the promulgation of the Marketing Act of 1937, which replaced the Central Agency. Dubbed the "Magna Carta of South African agricultural policy during the 20th century" (Stanwix 2012, p. 8), the Act and its subsequent extensions eventually controlled the marketing of 90 percent of agricultural output for many decades during the 20th century (Brits 1969). In broad terms, the Act aimed to ensure the 'orderly marketing of agricultural produce through establishing various commodity control boards' (Brits 1969). Between 1937 and 1944, the newly established Maize Control Board (hereafter Board) eased the industry toward controlled marketing through a trial and error implementation of the Act. Eventually, the Board settled on a 'single-channel pool' approach; a fixed-price system that established it as the sole maize buyer and wholesale seller of all maize in South Africa under a pan-seasonal and pan-territorial price. In other words, the Board purchased and sold maize at a fixed national price throughout the season, irrespective of when and where it was purchased.[4] The Board also exercised a monopoly on all maize exports and imports (Brits 1969). The Board determined the price of maize before the start of each season through farmer cost-of-production surveys, with the price set at the average surveyed production cost plus an allowance for operator earnings (Brits 1969).[5] To store and handle the grain, the Board appointed local agents to act on its behalf; this was mostly entrusted to farmer cooperatives, thereby establishing them as regional grain-handling monopolies (Kassier Committee 1992; Vink 2012).

An inflated maize price was almost inevitable since the Board was structurally biased toward farmers for two main reasons. First, tasked with setting a 'fair price' for maize, the Board was not necessarily impartial since more than half of the board members were farmers themselves (Brits 1969; Vink 2012).[6] Second, the overrepresentation of both small farmers and those in marginal areas in the price-setting surveys inflated the average production cost and, by implication, the target maize price (Brits 1969; Vink 2012). This system incentivized the expansion of production into marginal regions and resulted in the production of substantial surpluses (see, for example, Brits 1969; Van Zyl et al. 1992; World Bank 1994; Vink 2004, 2012). Throughout this period, the South African farm-gate price was mostly maintained above the U.S. farm-gate price (Greyling et al. 2018); hence these surpluses were exported at a loss, with the taxpayer ultimately footing the bill given that the export stabilization fund was continually in arrears and periodically replenished from national government funds (Vink 2012).

### *2.1.3 A Post-regulation Regime: 1988-present*

The first step towards deregulating the maize industry was taken in 1988 following the change to a single-channel pool scheme, wherein the profits or losses of the stabilization fund could no longer be carried over to the next financial year. This change effectively forced the board to link South African maize prices to the prevailing world price (Vink 1993, 2012). The *de jure* deregulation of agricultural marketing for maize (along with most other crops) commenced after the democratic transition in 1994, with the process completed by the end of 1998 following the implementation of the new Marketing of Agricultural Products Act of 1996. This policy coincided with trade liberalization and increased

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[4] The selling price was set as the producer price plus transport, storage and handling costs. Pan territorial pricing was enabled by the cross subsidization of transport costs. With the Maize Board established as the sole importer and exporter of maize, stabilization was used to capture profits or losses of exports (Vink 2012).

[5] The Maize Board's price recommendation only became official after the approval of the Minister of Agriculture, who also consulted with the National (Agricultural) Marketing Board (Brits 1969).

[6] One could argue that the Maize Board did not have the ultimate say in setting the price since the final decision rested with the Minister of Agriculture, but during the 1948 to 1982 period the Board held significant sway given the pro-farmer political regime at the time (Vink 2012; Greyling et al. 2018).

consumer spending, including increased animal protein consumption (Ronquest-Ross et al. 2015) which increased the demand for maize.

## 3 Dynamics of the Agricultural Policy-Price-Productivity Nexus

It is natural to ask if these notable shifts in policy regimes had measurable economic consequences for the South African agricultural sector. In this section, we first describe and deploy new time-series data to reveal the profound implications of structural shifts in agricultural policies on the trend price of the country's dominant crop, maize. In the following section, we then focus on the spatial implications of policy, a dimension that has significant implications for the productivity performance of the agricultural sector, wherein the geography of production really matters.

### 3.1 Data: Measuring Maize

Quantifying the long-run trends of maize production in South Africa (and the rest of the African continent, for that matter) is tricky. The coverage, completeness, and composition of the reported data vary over the 98 years encompassed by our series spanning 1918–2015, often reflecting shifts in prevailing policy and political norms. The data problems we confronted included changes in the definition of what was being measured, how it was being measured, and in some cases, a lack of measurements altogether. Given these measurement challenges, we endeavored to cross-reference our final estimates wherever possible, using a host of historical articles, book chapters, industry reports, and official documents. All the primary data were digitized, and all the steps in converting these data to the estimates presented in this paper were coded or otherwise documented to ensure data replicability.

To construct the time series, we drew primarily on the *Agricultural Censuses and Surveys* conducted by Statistics South Africa, the *Abstract of Agricultural Statistics* published by the Directorate of Agricultural Statistics of the national Department of Agriculture, Forestry and Fisheries, and data reported annually since 1911 by the South African Grain Information Service (SAGIS) (see Greyling and Pardey 2019b for more specific details). South African maize production comes from both commercial and smallholder producers. Unfortunately, the smallholder production data (specifically planted area and average yields) are less comprehensive (and less reliable) than data on commercially grown maize. So, our formal assessment of the time-series properties of South African maize production relies only on commercially grown maize. Nonetheless, the series closely track each other for the period 1935–2015, where we could compile both commercial and total (inclusive of smallholder) production.[7]

Two types of maize are grown in South Africa. Yellow maize is primarily fed to animals, whereas white maize is predominantly consumed by humans as porridge (called mieliepap in Afrikaans or phutu in Zulu) and represents a major component of the South African maize market. White maize constituted around 56 percent of total commercial maize production during the period 1960–2007 (Greyling and Pardey 2019a).[8] Given the irregular and incomplete reporting of disaggregated data, the remainder of this paper will focus on commercial (white and yellow combined) maize production in South Africa between 1918 and 2007. Commercial maize production was the (increasingly) dominant source of the country's maize output, averaging 96.3 percent of total production in the decade ending in 2007 (and 86 percent of production over the entire 1918–2007 period).

### 3.2 Maize Price Dynamics

Figure 2, Panel a plots the real (2021 U.S. dollars) average farm-gate price of maize in South Africa for 1918-2015.[9] As described above, the chronology of agricultural policies naturally partitions itself into three distinct regimes spanning the pre-1948, 1948-1988, and post-1998 periods. The vertical red bands in Figure 2 represent the confidence intervals of the statistically estimated price breakpoints (see section 3.2.1 below) from one policy regime to another. Notably, these statistical bands span the subjectively derived (albeit evidenced-based, see section 2) regime breaks. They also reflect the reality that the movement from one policy regime to another involves a transition rather than a distinct break in practice, given the time it takes for policy changes to be fully implemented or stickiness in the real economy as large policy changes take time to come into play.

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[7] For example, for a linear regression of the form $y = \alpha + \beta x$, where $y$ is total maize production (in tons) and $x$ is the amount of commercial maize production, the $R^2 = 0.9986$, $\beta = 1.02$ (and is statistically indistinguishable from 1.0), and $\alpha = 343$. Our estimates suggest that the smallholder share of total South African production peaked in 1924 at 28.4 percent, declining to 13.0 percent of total national production by 1960, 4.3 percent in 1974, and recovered a little to 6.3 percent in 2015 (Greyling and Pardey 2019b, Figure 3, Panel a).

[8] Disaggregated data on white versus yellow maize production (and area) was first reported, it seems, in 1961. The production and area (and implicit yield) totals prior to 1961, from sources such as the *Abstract of Agricultural Statistics*, consistently report aggregate white and yellow maize production and, with less consistency and less clarity, separate aggregate smallholder and commercial production (Liebenberg 2013; Greyling and Pardey 2019a).

[9] Our maize price data were primarily taken from the *Abstract of Agricultural Statistics* (1970, 2018) and SAGIS (2018). The nominal series was first deflated to 2021 base-year values using a South African GDP deflator from IMF (2022), then converted to 2009 U.S. dollars using the 2021 market exchange rate published by World Bank (2022)

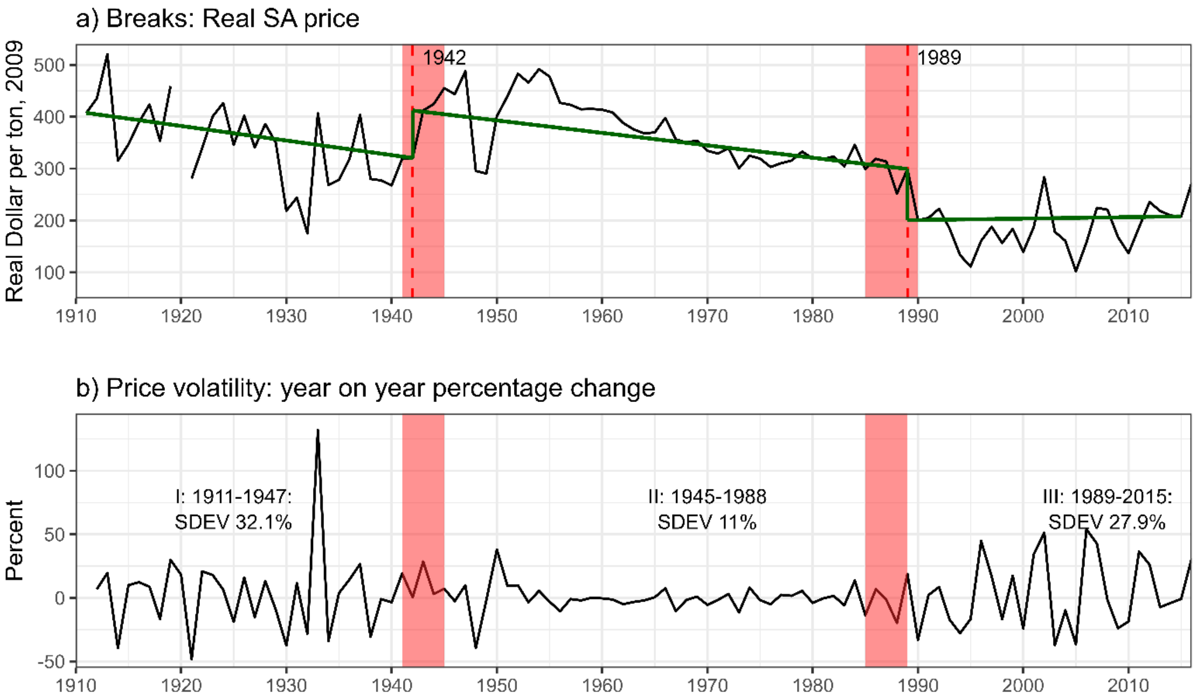

Figure 2: Real maize price level and volatility 1918-2015

*Source*: See Greyling and Pardey (2018b) and text.

*Notes*: Panel a: The fitted trend is colored green with the estimated break dates indicated by the vertical dashed red lines. The red-shaded area shows the 95 percent confidence interval around the break. Panel b: SDEV indicates the standard deviation around the respective period price averages.

Nominal, Rand denominated maize price first deflated to base year 2021 prices using the South African GDP deflator—1911 –1949 from Liebenberg (2012) based on data from South African Reserve Bank; 1950 – present from World Bank (2022) and IMF (2022)—then converted to US dollars using the 2021 average exchange rate of R14.78 per USD sourced from World Bank (2022).

In inflation-adjusted terms, the average maize price paid to South African farmers declined over the long run—from $353 per ton (2021 values) in 1918 to $207 per ton in 2015—albeit unevenly and with some significant discontinuities in the series. The implementation of controlled marketing mechanisms during the 1940s saw prices ratchet up markedly from $267 per ton in 1940 to $487 per ton in 1947, only to gradually decline to $251 per ton by 1988. That year marked the dismantling of the controlled marketing mechanisms and the opening up of South African agricultural markets to more direct international competition. Notably, the implementation of controlled marketing mechanisms also reduced the volatility of the maize price.

### *3.2.1 Structural Price Discontinuities*

Visual inspection of the plotted data in Figure 2, Panel a suggests that the three agricultural policy regimes identified above had measurable market consequences. To formally assess the temporal concordance of agricultural policies and prices, we used the procedure devised by Bai and Perron (1998, 2003a and b) to statistically identify structural breaks in the deflated average maize price received by South African farmers for the period 1911-2015. A feature of the technique is that it allows for the endogenous detection of both the number and location of structural breaks. To this end, the technique uses a dynamic programming approach that computes the confidence intervals around estimated breakpoints using a distribution function.[10]

To examine trend breaks in the price of maize, we regressed the real maize price on time ($tt$), where $\delta_j$ is the break period intercept value, and $\vartheta_j$ is the break period average price growth increase per year. The price function is specified as follows:

$$P_t = \delta_j + \vartheta_j tt + u_t, \qquad t = t_{j-1} + 1, \dots, t_j, j = 1, \dots, m + 1, \tag{1}$$

where $P_t$ is the real (2009) dollar price of maize during period $t$, and $u_t$ is the error term. The objective of the analysis is to determine both the number, $m$, and the timing, $t_j$ ($j = 1, \dots, m$), of the breakpoints.

Implementing the procedure requires that a break parameter (*h*) be set. It defines the minimum break period length in absolute terms as the minimum number of years or the percentage share of all observations per segment in relative terms. The practical implication is that the higher this *h* value, the stricter the break detection and the fewer are identified. We opted to use *h* = 0.2 to strike a balance between the number of breaks identified and controlling for serial autocorrelation.[11]

Table 1 shows the results of the maize price break analysis. Both the coefficients and intercepts of the segmented linear functions fitted to each break period are shown. In addition, the break periods, along with the 95 percent confidence interval around each break period, are also shown. Two breaks were identified for the price series, one in 1942 and one in 1988. They are plotted in Figure 3, Panel a as vertical dashed lines with their respective standard errors. They delineate three distinct price regimes spanning the periods 1911 to 1942, 1943 to 1988, and 1989 to 2015, whose timing closely concords with the three policy regimes discussed above.

Historical shifts in South African agricultural policy (Figure 1) not only align closely with structural changes in the real price received by South African farmers, they also concord closely with changes in the volatility of farm prices (Figure 2, Panel b). The controlled marketing regime centered in the third quarter of the 20th century (1945-1988) was characterized by markedly less volatile prices than either the preceding or following policy periods. During the second policy era, the standard deviation of year-

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[10] We conducted the analysis in R using the "*strucchange*" package developed by Zeileis et al. (2002). It implements the Bai and Perron (2003a and b) procedure but does not allow partial break models. For more information see Zeileis and Kleiber (2005). The authors thank Achim Zeileis for his help with the implementation.

[11] A value between *h* = 0.1 and *h* = 0.2 is typical in the prior literature (Zeileis et al. 2002), although a higher value is recommended if serial autocorrelation is present (Bai and Perron 2003a, p. 15).

on-year absolute price changes was just 11.0 percent, compared with 32.1 percent in the first policy period (1910-1945) and 27.9 percent during the third, post-1988 period[12].

Table 1: Maize price breaks (1911–2015) (2021 dollars)

| | Coefficient and intercept estimates ($h = 0.2$) | | |
|---|---|---|---|
| *Break period* | 1911–42 | 1943–89 | 1990–2015 |
| *Coefficients* | $\hat{\boldsymbol{\vartheta}}_{\mathbf{1}}$ | $\hat{\boldsymbol{\vartheta}}_{\mathbf{2}}$ | $\hat{\boldsymbol{\vartheta}}_{\mathbf{3}}$ |
| | -4.874*** | -3.491*** | 0.791 |
| | (12.54) | (4.12) | (13.83) |
| *Intercepts* | $\delta_1$ | $\delta_2$ | $\delta_3$ |
| | 431.738** | 564.173** | 89.197 |
| | (20.56) | (53.749) | (97.024) |
| | Corresponding breakpoint estimates | | |
| | $\hat{t}_{\mathbf{1}}$ | $t_{\mathbf{2}}$ | |
| *Break date* | 1942 | 1989 | |
| *95% confidence interval* | (1941–1945) | (1985–1990) | |
| *SupF stat* | | | |
| 85.81** | | | |

*Notes:* Bracketed data represents the standard errors for $\hat{\vartheta}_i = (\boldsymbol{i} = \mathbf{1}, \dots, \mathbf{5})$ and the 95 percent confidence intervals for $\hat{T}_i (i = 1, \dots, 4)$.
Breaks were endogenously chosen based on the Bayesian Information Criterion (BIC).
**Denotes statistical significance at the 5 percent level
***Denotes statistical significance at the 1 percent level

### 3.3 Maize Production, Area Planted, and Yield Dynamics

While the real farm-gate price of maize trended down during the 20th century (Figure 2, Panel a), commercial maize output increased dramatically, albeit erratically, from just 0.9 million tons in 1918 to a historical peak in production of 14.4 million tons in 1981 (Figure 3, Panel a). In 2015, 12.1 million tons was produced, and although less than the 1981 peak, it nonetheless represents a 7.5-fold increase over 1918 production levels. This large increase in maize output from 1918 to 2015 went hand in hand with a 9.4-fold increase in average maize yields (Figure 3, Panel b). The blue dotted lines represent the Loess fitted trend in maize production and yield.

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[12]. The large 1933 spike in maize prices in Fig. 2 coincides with South Africa's abandonment of the gold standard (Minnaar 1990).

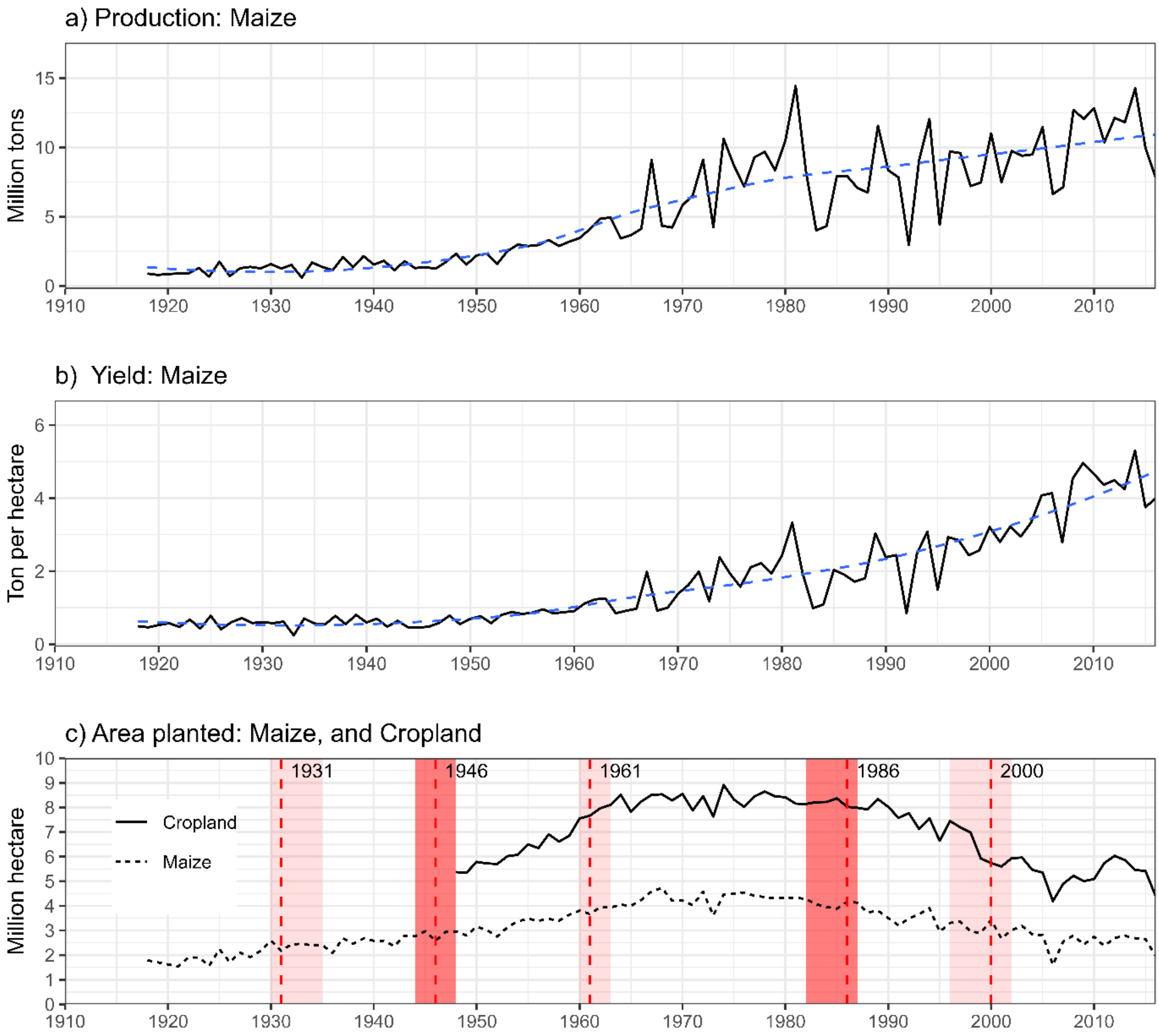

Figure 3: Maize production, yield, and planted area and total cropland area planted, 1918-2015

*Source*: See Greyling and Pardey, 2018b and text.

*Notes*: The dotted blue lines in Panels a & b denote the fitted Loess trends. In Panel c, the red-shaded area shows the 95 percent confidence interval around the estimated break points, denoted by the vertical red dashed lines. The dark red confidence intervals align with shifts in policy regimes and the price breaks we identified. The light red bars represent confidence intervals around area trend breaks within each of the policy regimes.

Maize yields grew by 1.3 percent per year during the first policy period (1920 to 1947) (Figure 3, Panel b). Yield growth picked up markedly during the 1948-1988 policy period (averaging 3.1 percent per year), in parallel with a substantial expansion in the use of hybrid maize varieties. The first thirteen bags of hybrid maize were sold to South African farmers in 1949. From a slow beginning, the pace of adoption picked up markedly around 1965 so that by 1979 hybrids had effectively replaced open-pollinated varieties on all the country's commercial acreage (Greyling and Pardey 2022). The increased use of hybrid maize varieties occurred along with increased fertilizer use and chemical weed and pest control measures (De Klerk 1983; Liebenberg 2012; Liebenberg and Pardey 2012), plus improved farming practices such as deep tillage (to optimize soil moisture use) and controlled traffic for field cultivation (to minimize soil compaction). During the third policy period (1988–2015), maize yields continued growing at a rapid, albeit slightly reduced rate, averaging 2.1 percent per year.

While maize production and yields grew throughout the 20th century, the same was not true for the area planted with maize. The crop occupied 1.8 million hectares in 1918, reaching a peak of 4.7 million hectares in 1968 (Figure 3, Panel c). This 2.6-fold expansion in the harvested area was associated with a rapid increase in tractor use. South African farmers had access to just 6,000 tractors in 1937, increasing to 20,000 immediately after WWII and peaking at 174,000 units in 1976 (Liebenberg 2012). This replacement of animal draught with tractor power enabled individual farmers to cost-effectively increase the cropped area per farm–and so the overall area in crops expanded—while also opening up land for crop production that had hitherto been used for the production of animal feed (Brand 1969; Van Zyl, Vink and Fényes 1987).

The favorable farm policies that prevailed for many decades following the shift to a regulated marketing regime in the 1940s saw a continued expansion in the overall cropped area through to the 1960s and 70s (Figure 3, Panel c) to peak at 9.1 million hectares in 1974. Thereafter, the total cropped area declined markedly (by 40 percent to 5 million hectares in 2010) as the bundle of farm-friendly policies began to unwind.

We also conducted a formal assessment of breaks in harvested maize area to assess their temporal alignment with the changes in policy regimes discussed above and summarized in Figure 1. To do so, we ran the following regression

$$a_t = \alpha_j + \varepsilon_t,\ t = t_{j-1} + 1, \dots , t_j , j = 1 , \dots , m + 1 \tag{2}$$

where $a_t$ is the log of the area planted, $t$ is time, and $\alpha_j$ is the break period intercept value. In this instance, the error is represented by $\varepsilon_t$, and by convention $t_0 = 0$ and $t_{(m+1)} = T$, the timing of the breakpoints. The regression results are reported in Table 2. The fit is good (F value significant at one percent level), and the coefficients are highly significant.

Six area-in-maize segments were identified using the break-model above. The breaks shown in Table 2 are plotted in Figure 3, Panel c, with the vertical red-dotted line showing the respective breaks and the red bands showing the confidence interval around them. Two area breaks (1946 and 1986), with 95% confidence intervals around these break indicated by the darker red bands, align closely with the significant transition points between the three agricultural policy regimes (Figure 1) and the estimated price-breaks identified in Section 3.2.1.

The three lighter bands indicate confidence intervals around several sub-periods within each of the respective policy regimes. The period before 1948 (the transition date between the first and second policy regimes) saw a steady expansion in the area planted to maize, albeit with two sub-periods (before and after 1931) that had different trend rates of growth (2.5 versus 1.1% per year on average). The area sown to maize continued to expand after 1948 as the controlled marketing policies kicked in. However, during the sub-period 1961-1986, the growth in maize area slowed and stalled, peaking in 1974. While maize production and yields continued increasing thereafter (Figure 3, Panels a and b, respectively), the decline in maize area accelerated during the fourth sub-period (1986-2000) as the deregulation of agricultural marketing continued to roll out during the post-1988 policy regime.

Table 2: Maize area breaks (1911–2015)

| Coefficient and intercept estimates ($h = 0.15$) | | | | | | |
|---|---|---|---|---|---|---|
| *Break period* | 1918-1931 | 1932-1946 | 1947-1961 | 1962-1986 | 1987-2000 | 2001-2015 |
| | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | $\alpha_4$ | $\alpha_5$ | $\alpha_6$ |
| *Intercepts* | 14.459*** | 14.748*** | 14.994*** | 15.255*** | 15.049*** | 14.782*** |
| | (0.05) | (0.025) | (0.072) | (0.015) | (0.034) | (0.041) |
| Corresponding breakpoint estimates | | | | | | |
| | $\hat{t}_{\mathbf{1}}$ | $\hat{t}_2$ | $\hat{t}_3$ | $\hat{t}_4$ | $\hat{t}_5$ | |
| *Break date* | 1931 | 1946 | 1961 | 1986 | 2000 | |
| *95% confidence interval* | 1930-1935 | 1944-1948 | 1960-1963 | 1982-1987 | 1996-2002 | |
| *SupF stat* | 102.29 *** | | | | | |

*Notes:* Bracketed data represents the standard errors for $\hat{\boldsymbol{\alpha}}_{\boldsymbol{i}} = (\boldsymbol{i} = \mathbf{1}, \dots, \mathbf{5})$ and the 95 percent confidence intervals for $\hat{T}_i(i = 1, \dots, 4)$.
Breaks were endogenously chosen based on the Bayesian Information Criterion (BIC).
**Denotes statistical significance at the 5 percent level
***Denotes statistical significance at the 1 percent level

The reduced area planted to maize was offset by a substantial surge in the area under planted pastures. Between 1976 and 2005, the area under planted pastures increased from 0.93 to 3 million hectares (Appendix B Panel a). Notably, the area planted to wheat peaked shortly after maize at 2 million hectares in 1972, a level at which it stabilized until its decline after 1988 (Appendix B Panel b). In addition to introducing planted pastures into areas previously planted to maize (and wheat), cropped area was also reallocated to sunflowers and soybeans; between 1980 and 2015, the area planted to these crops increased from 0.29 to 0.57 and 0.025 to 0.79 million hectares, respectively. We detecte a fifth maize area break in 2000 after which the area in maize somewhat stabilized after the post-1988 dergulation processes had fully run their course.

## 4 Spatial Cropping Consequences of Changing Policy Regimes

Several prior commentators (e.g., Breitenbach and Fényes 2000; Vink 2000 and 2004) suggested that shifts in agricultural policy regimes also had consequences for where crops (including maize) were grown in South Africa, not just how much total area was planted to maize or how much total maize was grown. However, none of these prior studies were informed by spatially explicit data on South

African crop production, nor did they attempt to draw out the empirical links between policy and locational changes, especially spanning the sweep of history pertaining to South African agriculture over the 20th century.

Location really matters for the productive performance of agriculture (Beddow et al. 2010; Beddow and Pardey 2015), and a host of location-centric questions stand unanswered regarding South African agriculture. For instance, as farmer-friendly policies were undone during recent decades, did the geographical pattern of maize production in South Africa retreat to its early 20th-century footprint just as the total area under maize shrunk to its early 20th-century totals? Do changes in the geographical patterns of relative yields support the notion that the significant structural changes in the country's agricultural policies distorted the production implications of more fundamental determinants of (spatial) comparative advantage? In particular, was it the areas with less favorable climate (and other agroecological) attributes that disproportionately benefited from the supportive policy environment of the first half of the 20th-century, as Brand et al. (1992) claimed?

In this section, we present evidence that directly addresses these questions and empirically identify a strong concordance between changes in agricultural policy regimes and the spatial realities of South African maize production. In so doing, tracking the geographical movement of maize, in addition to changing area totals, reveals additional and hitherto undocumented insights regarding the long-run persistence of policy choices, and, critically, for a mostly rainfed production system like South Africa, their climate resilience implications over the longer term.

## 4.1 Data: Spatializing Maize Production

To assess the concordance between changes in agricultural policy and changes in the location of maize production, we conduct both a centroid and a spatial index analysis. This process required compiling and standardizing a spatial representation of sub-national production, area planted, and yield data. From the *Agricultural Censuses,* we extracted tabulated subnational (specifically magisterial district) data for 17 census years beginning in 1918.[13] Given the number of magisterial districts grew over time—from 207 in 1918 to 321 in 2007—and the boundaries of some districts changed as well, a major effort was invested in matching district-level tabular to geo-coded boundary data, and then standardizing the areal representation of these data in a spatially explicit format.

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[13] Specifically, the agricultural censuses report data for the agricultural years ending in 1918, 1922, 1930, 1937, 1946, 1950, 1956, 1960, 1965, 1971, 1976,1981, 1983, 1988, 1993, 2002 and 2007. In these data, for example, 1918 refers to the agricultural year 1917/1918, which spans the months September to August. Notably, the Union Census of 1911 reports some agricultural data, and there has been no agricultural census taken in South Africa after 2007. All agricultural statistics are reported according to the magisterial districts used in the South African legal system. These spatial aggregates are smaller than district municipalities (or ADM2, administrative district 2 boundaries) but larger than local municipalities (ADM3), thus they represent a set of "ADM2.5" boundaries.

Using a modified version of the procedure developed by Beddow and Pardey (2014), the first step in developing a standardized areal representation of the data was to digitize and then geo-code the boundaries of all the magisterial districts using printed map sources spanning the years 1918 to 2007, as described in detail by Senay et al. (2022). Then all the district data were mapped to the district boundaries for the closest available year. Each of the districts was subsequently divided into arrays of five arc-minute pixels.[14] By this means, the data for each year were converted from areal (district polygon) to raster (pixelated) data, allocating the district's production and area to each pixel in proportion to the pixel's share of the district area or production obtained from the year 2005 spatial representation of production and area obtained from the 2005 SPAM dataset (You et al. 2017).

Reaggregating the time series of raster data into 2007 ADM3 municipal district boundaries represents one option for developing an invariant spatial standard. However, the 234 districts delineated by these 2007 boundaries vary in size between 0.027 to 3.63 million hectares, with a median size of 0.37 million hectares. The variation in district size is even more pronounced over time. The 17 censuses included in our analysis spanned 4,956 magisterial districts in total, where the minimum area was 0.00062 million hectares and the maximum 8.48 million hectares (with a mean of 0.43 and a median of 0.24 million hectares). Since the spatial indexes are not weighted with respect to district size, this size variation can distort our indexing results. To avoid this possibility, we used the same procedure described above to create a raster of "standardized districts," each with a fixed area of 0.25 million hectares, approximating the median area size across all of the districts across all the censuses included in this study.

Given the varying spatial coverage of the underlying maize production data over time, not every (standardized) district includes an observation of area planted and production in every census year. Neither maize area planted nor production data were reported in 8.6 percent of the 3,978 district-years in our panel, so we took that to indicate maize production was absent from those district-years.[15] However, suppose some of these missing or null districts report a yield for the base year (in this instance, 1918) of the Laspeyres area index discussed in the section to follow. In that case, there is a potential bias introduced into the index since the district in question will then be excluded, by

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[14] A five-arc minute cell or pixel represents an area that is 10km$^2$ at the equator. For more information see http://harvestchoice.org/labs/how-big-one-5-arc-minute-grid-cell.

[15] It is possible that maize was being produced in a particular district in a particular year but data were withheld for privacy reasons. We think that unlikely in most cases as only 2 percent of the district years for which no data were reported also failed to report data in either of the adjacent years. In addition, when they did report production in an adjacent year it was often trivial. From these two observations we determined they are likely to be marginal production district-years such that the absence of reported data indicates little to no actual production.

construction, from the index values in all subsequent years.[16] To avoid this potential problem, we estimated a counterfactual yield in those district-years lacking yield observations, representing the yield that would have occurred had maize been grown in that district during that year. To do so, we used an inverse-distance weighted mean function to impute the missing yield in a given district-year combination based on the district's three nearest maize-producing neighbors for the year in question.

## 4.2 Mean-centers and Spatial Indexes

The centroid, or more precisely for our analysis, mean-center, of a spatial variable represents the point that minimizes the sum of squared distances to all other points of that spatial variable.[17] For example, the geographic center of a symmetrical triangle formed by three points would be equidistant from all three points. In this instance, we calculate the geographic center of each district and assume when calculating crop movement, that all the production and area planted in each district takes place at this point.[18] In our case, the national geographic center point has both a location and a weight. Thus, the national *mean-center of production* for a specific year represents the point on the map that minimizes the sum of squared distances between the production-weighted geographic centers of all the maize producing districts.

To quantify the production consequences of the changing location of production, in conjunction with changes in average yields and the total harvested area, we deployed the spatial indexing procedure developed by Beddow and Pardey (2015). Using their nomenclature, a Laspeyres ($I_Y^L$) yield index (equation 3) uses base period maize areas to weigh both current and base period yields. It thus shows the change in maize output attributable to yield changes if the spatially-explicit area planted were held constant at *base period* quantities. Similarly, the Laspeyres ($I_A^L$) area index (equation 4) shows the change in maize production attributable to changes in area if spatially-explicit yields were held constant.

$$I_Y^L = \frac{y_t{}' a_b}{y_b{}' a_b} \tag{3}$$

$$I_A^L = \frac{a_t{}' y_b}{a_b{}' y_b} \tag{4}$$

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[16] As Beddow and Pardey (2015) explain, the technical reason for this estimation problem is that the numerator in the Laspeyres area index involves an inner product of the base-year (1918) area and the yield in any given census year thereafter.

[17] When a weighting is used, the centroid is sometimes referred to as the "mean center," while "centroid" is reserved for unweighted spatial calculations (Arcgis 2022).

[18] These were calculated according to the Albers Equal Area Conic projection as proposed by Snyder (1987). See Beddow and Pardey (2013) for additional information.

A Paasche specification of the yield ($I_Y^P$)and area ($I_A^P$) indexes have a similar interpretation, but in this instance, they are weighted by *current* period yields and areas, respectively.

However, taking the area indexes at face value confounds the effect of changes in the *total* national area planted to maize and changes in the *relative spatial allocation* of maize production. Beddow and Pardey (2015) overcome this through an alternative specification that separates the scaling effect of changes in the total area planted from the spatial reallocation effect, the focus of our interest. This objective can be achieved by scaling the Laspeyres ($I_A^L$) and Paasche ($I_A^P$) area indexes by the ratio of the total maize area planted nationally during the base year, $A_b$, and the national area planted in year $t$, $A_t$, as shown in the respective reallocation indexes below:

$$I_R^L = I_A^L \frac{A_t}{A_b} \tag{5}$$

$$I_R^P = I_A^P \frac{A_t}{A_b} \tag{6}$$

These relative spatial reallocation indexes answer slightly different questions from the area indexes. The Laspeyres index ($I_R^L$) (equation 5) reflects the change in maize output associated with changes in the relative spatial allocation of area, weighted by base-year yields. The Paasche index ($I_R^P$) (equation 6) reflects the change in maize output attributable to changes in the relative spatial allocation of area, weighted by current period ($t$) yields.

Below we draw on these mean-center and spatial indexing concepts to statistically track the geographical movement of South African maize over the past century. In conjunction with the changing spatial attributes of maize yields, we then use that information to dig deeper into the changing trajectories of the national area, and output aggregates witnessed over the historical past.

### *Spatial Changes in Maize Production and Productivity*

To quantify the extent and timing of the shifting location of maize production in South Africa, we tracked changes in the production-weighted geographic centers of all the maize-producing districts for each agricultural census year from 1918 to 2007. Table 3 shows the area and production mean centers calculated for each census year included in this study (see Appendix C for a mapped summary). The centroid movement of maize area and output is expressed in kilometers to the west (westing) and north (northing), relative to the production location in the base year 1918, with negative values indicating movements in the opposite direction, either east or south. Two types of indicators are shown concerning each census and the output and area variables: the year-on-year movement of the respective centroids and their cumulative movement relative to 1918. The three policy periods discussed above are indicated in the first column, with the transition between each regime period highlighted in grey.

Table 3: Maize mean center movement, 1918–2007

| Policy phase | | Area movement in kilometers | | | | Output movement in kilometers | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Easting (+) | | Northing (+) | | Easting (-) | | Northing (-) | |
| | Year | Change | Cumulative | Change | Cumulative | Change | Cumulative | Change | Cumulative |
| *Column* | | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* |
| Phase I | 1918 | - | - | - | - | - | - | - | - |
| Phase I | 1922 | -16 | -16 | 5 | 5 | 35 | 35 | 15 | 15 |
| Phase I | 1930 | 5 | -10 | 12 | 18 | -15 | 20 | 19 | 35 |
| Phase I | 1937 | -20 | -31 | -10 | 8 | -21 | -1 | -15 | 20 |
| Transition | 1946 | -11 | -41 | 2 | 10 | -7 | -8 | 24 | 43 |
| Transition | 1950 | -10 | -52 | 1 | 11 | -19 | -27 | -11 | 32 |
| Phase II | 1956 | -20 | -72 | 16 | 26 | -37 | -64 | 28 | 61 |
| Phase II | 1960 | -20 | -92 | 7 | 34 | -9 | -73 | -4 | 57 |
| Phase II | 1965 | -9 | -101 | 0 | 34 | 25 | -49 | -6 | 50 |
| Phase II | 1971 | 21 | -80 | 12 | 46 | 14 | -35 | 10 | 60 |
| Phase II | 1976 | -11 | -91 | -6 | 39 | -17 | -52 | -1 | 59 |
| Phase II | 1981 | 18 | -72 | 11 | 50 | 12 | -40 | 15 | 75 |
| Phase II | 1983 | 0 | -73 | 4 | 54 | 5 | -35 | -6 | 68 |
| Phase II | 1988 | -8 | -81 | 6 | 60 | 17 | -18 | 2 | 70 |
| Transition | 1993 | 1 | -79 | -9 | 50 | 9 | -9 | -16 | 54 |
| Phase III | 2002 | -15 | -94 | -18 | 33 | -56 | -65 | -10 | 44 |
| Phase III | 2007 | -2 | -96 | -12 | 20 | -5 | -70 | -15 | 29 |

*Source*: Authors' calculations, see text for sources.

*Notes*: The change value represents the movement of the maize area and production mean centre to the east (easting) or north (northing), relative to the previous centroid. The cumulative value represents the movement of the area and production mean centre relative to 1918.

The onset (beginning in 1867) and then rapid expansion of diamond mining, followed by gold mining in 1886, along with the associated expansion of the rail network, acted as a catalyst for commercial maize to feed the rapidly growing mining workforce (Burtt-Davy 1914, pp. 58-60; Morrell 1988; Trapido 1971). Proximity to the goldfields in Witwatersrand spurred a concentration of production within the South African equivalent of the U.S. Corn Belt known locally as the "Maize Triangle," whereby the towns of Carolina, Mafeking, and Ladybrand, located in the central north-eastern part of the country, form the corners of this triangle (Saunders 1930 and Appendix A Figure 2). In 1918, around 65% of South African maize production (and 72% of maize area) occurred within the maize triangle, with the mean center of production located close to Bothaville.

By the middle of the 20th century, not only had the total area in maize increased substantially (by 94% from 1918 to 1956), but the location of maize production had also shifted, with the area mean-center of production moving 72 kilometers west of its 1918 position by 1956, and 26 kilometers north (Table 3, Columns 2, and 4). As the total area in maize continued to increase through to the mid-1970s, the location of production continued to shift westward, but with little to no latitudinal movement. After the mid-1970s, the total area in maize production shrank markedly so that by 2015 it had returned to the totals that prevailed around 1944. As the area under maize reverted to its early 20th century total, the geography of maize production also tended to revert to its original maize triangle roots. Moreover, the timing of the shifts in the geographical trajectory of maize production suggests these spatial shifts were heavily influenced by changes in the policy environment facing agriculture.

The second half of the pro-farm policy regime (1945-1988) saw substantial investments in rural electrification (Marwah 2017) that enabled the development of irrigation (mostly pivot) infrastructure along the Orange River and its feeder rivers from the late 1970s onward (Conley and Van Niekerk 2000). During this policy period, maize production also continued shifting westward, and by 1988 the area centroid of production lay 81 kilometers to the west of its 1918 value (Table 4, Column 2). The pro-farm policies also coincide with a continuing northward shift in production that by 1988 was centered 60 kilometers north of its 1918 position(Table 4, Column 4). Thereafter, as government support to agriculture was withdrawn, the crop rapidly reversed its northerly movement and, by 2017, was almost centered back to the latitudinal locations it occupied almost a century earlier. The westerly movement was also effectively stalled but did not reverse course, likely due to the nature of the prior policy actions that promoted its westerly movement. The irrigation investments in the Orange River area constituted a long-term capital and infrastructure investment that continued to operate once the general policy environment pivoted away from agriculture, thus resulting in a geographical stickiness in this westward movement that was not evident in the northerly shifts in production.

The national average trend in maize yields discussed earlier masks consequential changes in the spatial dimensions of maize yields, some of which are revealed in Figure 4, where we summarize the spatial distribution of average yield per district for selected census years from 1918 to 2007 using smoothed density plots. The vertical line represents the national average yield for each census year. The largely static and peaked spatial yield distribution plots from 1918 to 1956 indicate that maize yields on average and spatially among districts varied little during the period spanning the first half of the 20th century. During this period, average yields increased by just 1.0 percent per year. As the adoption of hybrid maize varieties took off around the middle of the 20th century and new pro-farm policies kicked in—notably various measures that gave farmers access to subsidized credit, which helped spur farm mechanization, irrigation, and other farm improvements (e.g., Vink et al. 2010)—the rate of yield growth accelerated, averaging 3.1 percent per year during the second policy phase (1945 to 1988). Thus, maize yields that averaged 0.6 tons/hectare during 1918-1944, grew markedly to a national average of 2.2 tons per hectare in 1988 and 4.3 tons per hectare in 2015.

Climate (along with other natural factors like soil type and quality, terrain, and so forth) are important determinants of crop yield performance (Odgaard et al. 2011). To the extent these natural factors vary over the landscape, crop yields will also vary as the location of maize production shifts over time. The spatial distribution of yields during the first half of the 20th century looks distinctly different than the pattern that prevailed during the second half of the century (Figure 4). Only 25 percent of maize growing districts reported yields averaging more than 0.84 tons/hectare in 1956, with 25 percent still averaging less than 0.43 tons per hectare. Almost 60 years later, in 2007, while a few districts were still reporting average yields of less than 1.0 ton per hectare (1.6 percent of all districts), the 25 percent of top-ranked districts now reported yields averaging more than 5.3 tons per hectare. After normalizing for differences in average yields over time, the coefficient of variation of the spatial distribution of South African maize yields increased from 46.4 percent in 1950 (and 46.5 percent in 1918) to 52.7 percent in 2007; indicative of a substantial increase in the spatial spread of maize yields.

The change in maize output associated with the spatial movement of the crop can be discerned from the Laspeyres and Paasche area reallocation indexes (Table 4 and Figure 5). Both the Laspeyres ($I_Y^L$) and Paasche ($I_Y^P$) yield indexes (Table 4) showed a marked increase during the analysis period, especially after the introduction of hybrid maize during the 1950s and 60s (Greyling and Pardey 2018). The Laspeyres ($I_A^L$) and Paasche ($I_A^P$) area indexes mirror the trend in the area planted, with both peaking during the early 1980s and declining to 27 and 20 percent above the base period for the respective specifications by 2007.

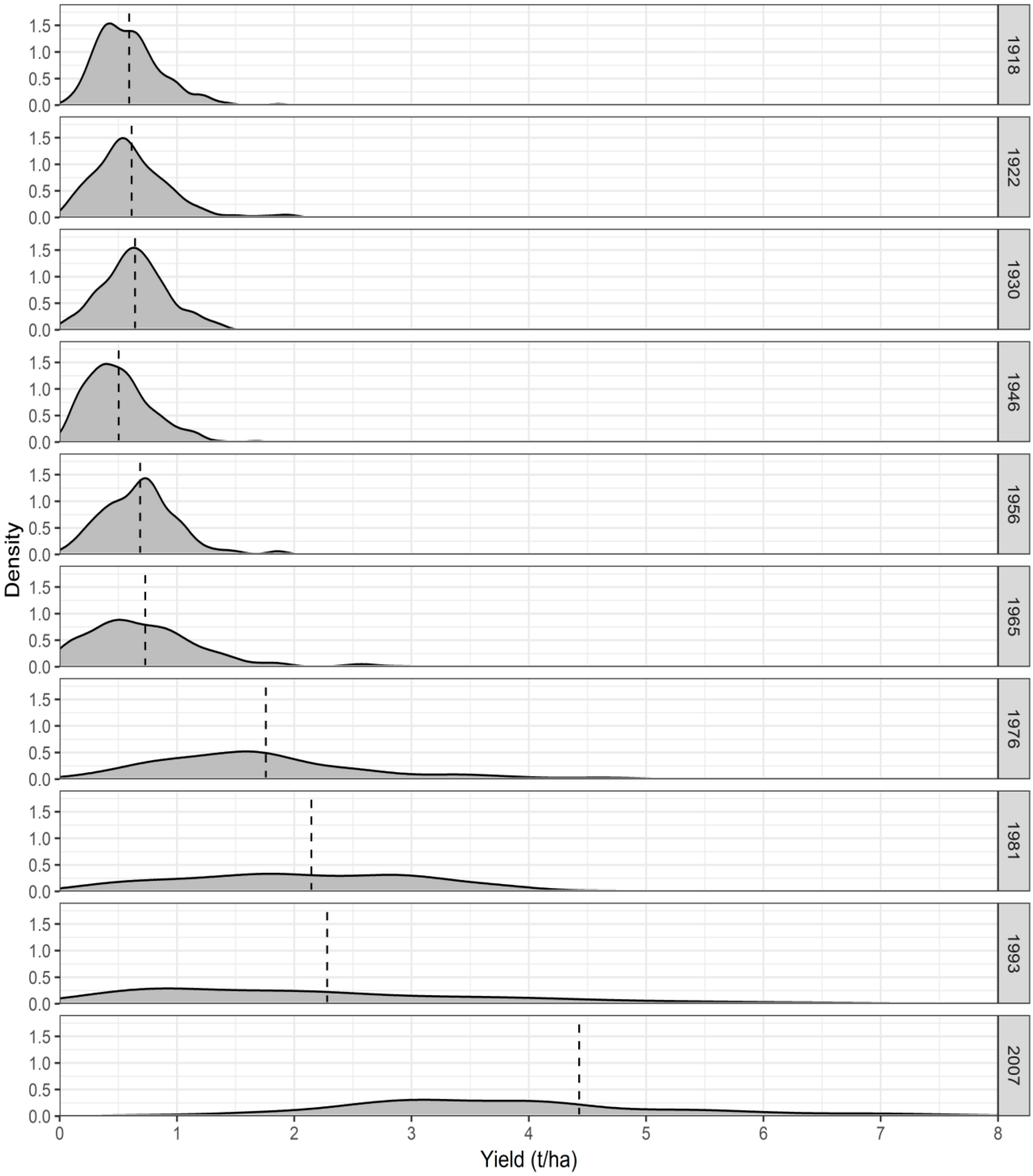

Figure 4: Spatial distribution of maize yields, 1918–2007

*Source:* Compiled from Union Statistics and Abstracts of Agricultural Statistics, 1960–2009.
*Notes:* The data represents dustributions of district averages in the respective census years based on the standarised district data, see text. Vertical dotted lines represents the distributional mean yield.

The Laspeyres ($I_R^L$) reallocation index indicates the output impact of the spatial reallocation of production in each year, assuming relative yields were held at their base year (1918) values, while the Paasche ($I_R^P$) reallocation index tracks the output consequences of crop movement assuming relative yields are held at their terminal year (2017) values.[19] The indexes indicate that over the long run (from 1918 to 2017), a relatively small share (0.2 to 6 percent) of the considerable growth in national maize production was attributable to shifting the location of the crop (Table 4, Figure 5). This change is of little surprise, given the locational consequences of the switching policy regimes discussed above. Specifically, the farm-favorable regime during the 1948-87 period shifted the location of production considerably, increasing its transitory northward area movement. By 1988, movement in the mean center of production area peaked, laying 60 kilometers to the north of its base period position. However, the withdrawal of these policy distortions thereafter saw the mean center of the planted maize area retreat much closer to its initial 1918 geography (Table 4).

Table 4: Yield, area, and reallocation indexes, 1918–2007

| | Yield | | Area | | Reallocation | |
|---|---|---|---|---|---|---|
| Year | Laspeyres | Paasche | Laspeyres | Paasche | Laspeyres | Paasche |
| | $\mathrm{I}_{\mathrm{Y}}^{\mathrm{L}}$ | $I_Y^P$ | $I_A^L$ | $I_A^P$ | $I_R^L$ | $I_R^P$ |
| | | | *(index value, 1918 = 100)* | | | |
| 1918 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1922 | 99.76 | 96.11 | 105.6 | 101.73 | 101.5 | 97.78 |
| 1930 | 124.45 | 121.98 | 145.72 | 142.82 | 100.73 | 98.73 |
| 1937 | 157.99 | 154.65 | 152.47 | 149.25 | 101.68 | 99.53 |
| 1946 | 97.44 | 95.46 | 146.69 | 143.71 | 102 | 99.92 |
| 1950 | 147.01 | 138.77 | 179.63 | 169.56 | 101.98 | 96.27 |
| 1956 | 163.52 | 171.13 | 195.25 | 204.33 | 102.86 | 107.64 |
| 1960 | 182.37 | 177.3 | 220.94 | 214.8 | 103.88 | 100.99 |
| 1965 | 201.99 | 178.49 | 232.78 | 205.7 | 104.08 | 91.97 |
| 1971 | 351.84 | 320.7 | 231.22 | 210.75 | 102.76 | 93.66 |
| 1976 | 365.12 | 338.74 | 239.73 | 222.41 | 102.83 | 95.4 |
| 1981 | 513.61 | 508.43 | 246.58 | 244.09 | 103.24 | 102.2 |
| 1983 | 241.92 | 225.91 | 240.04 | 224.15 | 103.47 | 96.62 |
| 1988 | 438.61 | 373.57 | 221.57 | 188.71 | 102.61 | 87.4 |
| 1993 | 283.83 | 232.25 | 209.87 | 171.73 | 102.89 | 84.19 |
| 2002 | 652.29 | 600.21 | 104.28 | 95.96 | 105.65 | 97.21 |
| 2007 | 692.72 | 654.65 | 127.37 | 120.37 | 106.03 | 100.2 |

*Source*: Authors' calculations, see text for sources.

Because the geography of maize production ended up reasonably close to where it started (Table 3), changes in the location of production were not a significant factor in accounting for the *overall*

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[19] As Beddow and Pardey (2015) observed, "…the change in corn output attributable to the spatial relocation of production is a *mutatis mutandis* attribution with respect to the spatial pattern of technology adoption, with a multitude of factors both enabling and being affected by these spatial shifts. That is, technological change over time for the national aggregate is controlled for by anchoring the assessment of the relocation effect by the use of base year (Laspeyres) or current year (Paasche) yields so that only the spatially variable aspects of changes in technology are embedded within the reallocation index."

growth in maize output when comparing the 1918 and 2007 period endpoints. However, the Laspeyres and Paasche reallocation indexes in Table 4 and Figure 5 track quite distinctive paths over time and, when taken together, provide insights into the output growth consequences of crop movement during certain policy sub-periods of the 20th Century. Spanning all three policy regimes during the 20th Century, the Laspeyres reallocation index indicates a small but reasonably steady increase in the share of national maize output attributable to moving the crop. This reallocation index uses base period yield weights, which, as Figure 4 reveals, are relatively low on average with relatively limited spatial variation (ranging from a low of 0.07 to a high of 1.7 ton per hectare). This modest spatial variation in historical (1918) yields means there is relatively little output to be gained (or lost) from changing the physical footprint of production if yields were stalled at their historical levels.

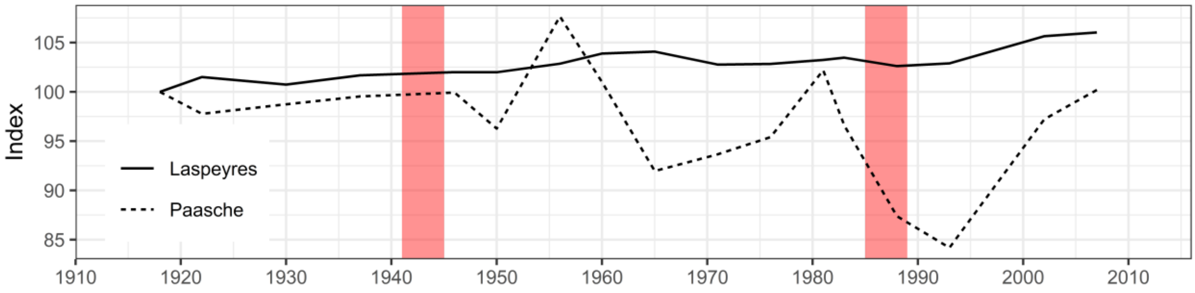


Figure 5: Calculated reallocation indexes, 1918–2007

*Source:* See text.

In stark contrast, the trajectory of the Paasche reallocation index varies by policy regime. This form of the index uses more contemporary (2007) yield weights that differ markedly by location, from a low of 0.56 to a high of 13.5 ton per hectare (Figure 4). Thus, the index is much more sensitive to the location of production. During the pre-regulatory regime (before 1948), when there was comparatively little spatial movement in the location of production, the Laspeyres and Paasche indexes tracked each other reasonably closely, and thus attribute little of the change in output to changes in location (Figure 2). However, during the regulated market regime (1948-1987) the two indexes substantially diverge. The Paasche reallocation index declined markedly, such that by 1988, we estimate that output had been reduced by almost 15.3% as a consequence of the (policy-induced) movement of maize over this period. Thereafter, as the policy distortions were undone—and in tandem with a reduction in maize area and a reallocation back to pre-distortionary locations—the Paasche reallocation index recovered, such that by 2007 there was no longer an output penalty associated with the movement of the crop.

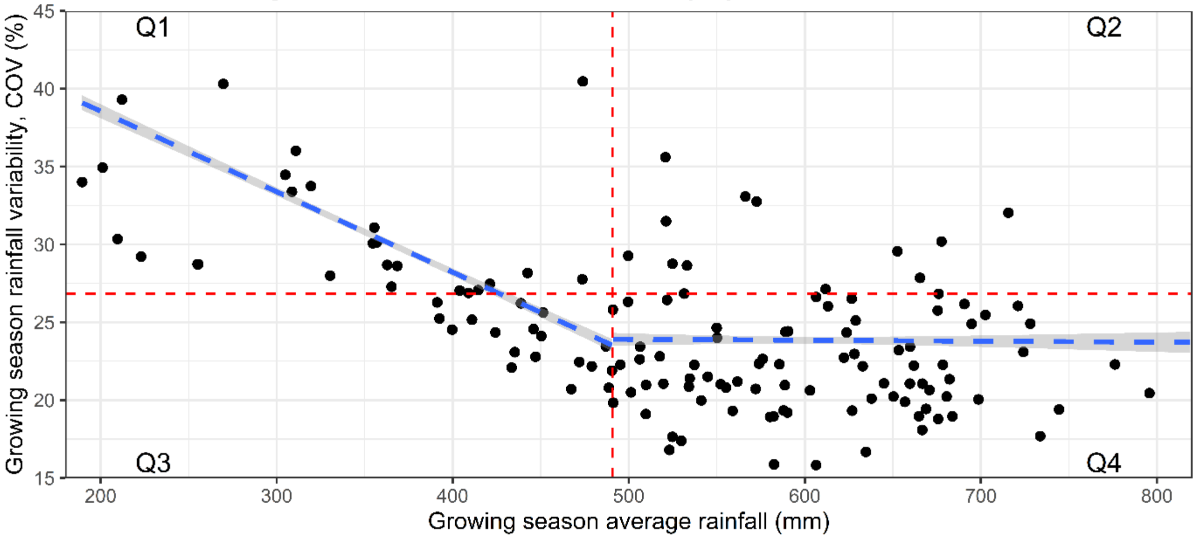
### *4.3* Cropping Area Changes and Spatial Climate Risk

To evaluate the implications of changing the location of maize production on the climate affecting the country's maize crop, we turned to geo-coded daily rainfall data spanning the period 1911-2000 compiled by Lynch (2004) from 12,153 rainfall stations located throughout South Africa. Figure 6, Panel a is a scatter plot of all the non-irrigated (2007) maize growing districts, stratified by the variability (coefficient of variation) of rainfall during the (November-April) growing season for maize (Y axis) against the seasonal average rainfall (X-axis). It shows that from a spatial perspective, average rainfall and rainfall variability are inversely related, especially for locations with lower rainfall averages. Pooling the weather data during the 20th century (specifically 1911-2000) and using magisterial districts as the spatial unit of analysis, a simple linear regression applied to the data in Panel a reveals a relatively strong ($R^2$ = 0.71), negative relationship between rainfall averages and variability below the median rainfall (Q1 and Q3). Based on this relationship, moving maize production into areas where the growing season average rainfall is less than the median (490 mm) results in a 7 percent increase in rainfall variability for every 100 mm decrease in rainfall.

To illustrate the climate risk implications of the three policy regimes we identified, Figure 5, Panel b shows the changes in rainfall averages and variability associated with the regime-specific pattern of crop movement, where the change is calculated from the first to the last census within each regime period. Each dot represents a non-irrigated maize-growing magisterial district. The size of the dot indicates the extent of the area change within each of the maize-growing districts, while the color signals the direction of change (ranging from red, decreasing, to green, increasing). The horizontal and vertical dashed lines represent the period median for both rainfall variables.

The most dramatic developments took place during the second and third policy regimes. The preponderance of large green dots during the farm-friendly regime of the 1945-1988 period indicates a substantial (56%) increase (from 2.5 to 3.9 million ha) in the total area planted to maize. But notably, most of this additional area was added in regions with lower than national mean rainfall and relatively higher rainfall variability (Panel b, quadrant 1). As these policies were withdrawn after 1988, these same locations (Panel b, quadrant 1)—with lower and more variable than mean rainfall—were the principal areas where maize production declined (see large red and yellow dots) as the overall area in maize declined from 4.5 million ha in 1976 to 2.8 million ha in 2007 A mapped version of these same trends is illustrated spatially in Appendix D. This shows that the area added during the second policy regime and removed during the third regime lie mainly in the northwestern corner of the South African 'Maize triangle.'

Panel a: Growing season rainfall, rainfall variability by district



Panel b: Panel a plus change in district area planted by regime

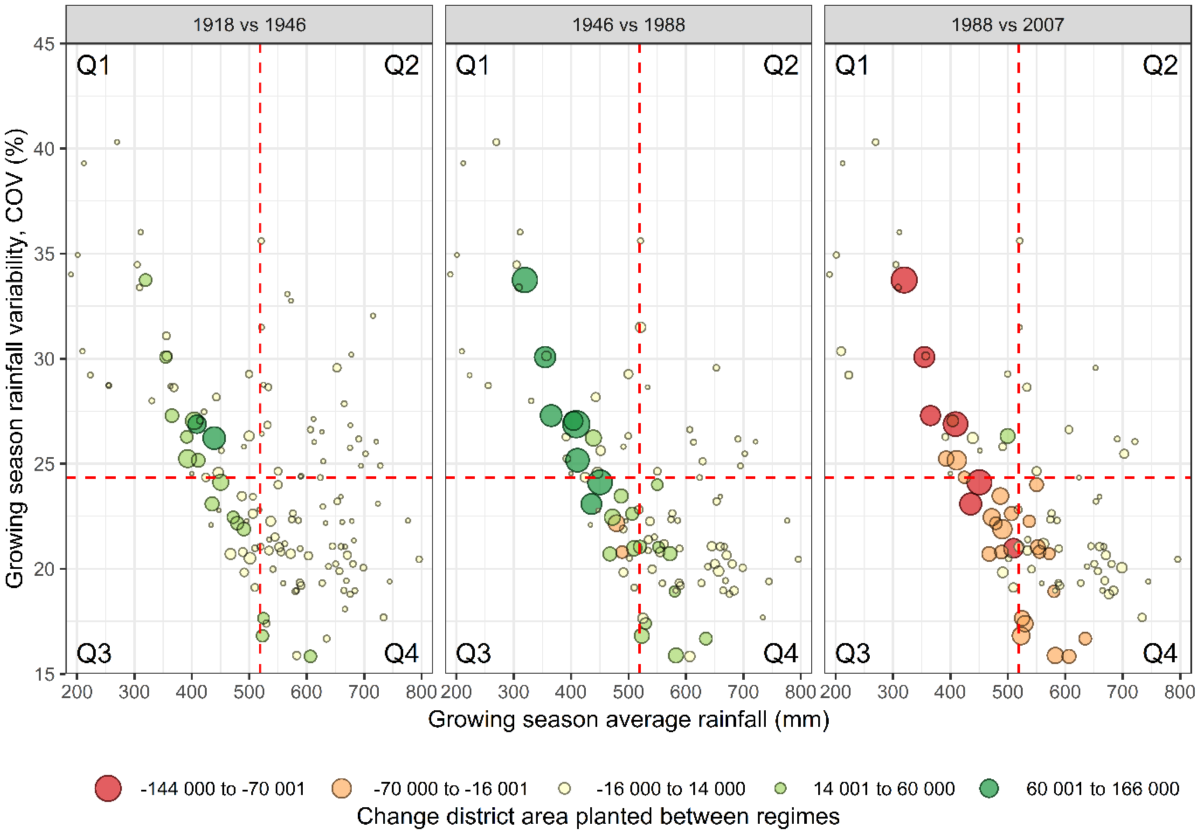


Figure 6: Growing season rainfall, rainfall variability, and change in area planted

*Source:* Rainfall data: Lynch (2004), own calculations. Growing season November to April, averages 1910 to 2000. Maize data: See text.

*Note:* Districts where more than 50% of the maize area in 2007 is irrigated, are excluded. The dotted blue line in Panel a represents the segmented fitted linear regression. The dotted red lines in all panels represent the medians of the respective variables.

The results summarized in Table 5 reveal the empirical backstory to the output implications of crop movement by segmenting area, production, and yield by the climatic quadrants, as discussed above and shown in Figure 6. Panels A, B, and C reflect changes between quadrants, while Panels D, E, and F show changes within quadrants over time. At the end of the first policy regime, as represented by the 1946 census, 84 percent of national production was concentrated in quadrants 3 and 4 (Table 5, Panel A). Most of the remaining maize area (15 percent) was located in quadrant 1, with almost no area in quadrant 2. Relative to the area allocations of 1946, by the end of the second (farm-friendly) policy regime, 10 percent of the total non-irrigated maize area had shifted to quadrant 1 at the expense of areas in quadrants 3 and 4 (Panel A). This allocation among quadrants persisted even though Panel D reveals that the national decline in maize area involved an area decline in all quadrants.[20]

Expressing average quadrant yields for each census year relative to those in quadrant 4 (Table 5, Panel F), the differences among districts were comparatively small at the end of the first policy regime (+/- 11 percent). Yield differences widened considerably thereafter: by the end of the second policy regime, the average yield in quadrant 1 had fallen 42 percent below those in quadrant 4, while the quadrant 3 average was 28 percent below. By the end of the third regime, yields regained some (but notably not all) relative ground, with the average yield in the low rainfall quadrants 1 and 3 lagging the quadrant 4 average by only 18 percent. The observation that quadrant 1 (low average, high variability rainfall) average yields were on par with quadrant 3 (low average rainfall, low variability rainfall) yields in 2007 suggests that improvements in crop genetics and crop management techniques were effective in mitigating the effects of rainfall variability but not lower rainfall as revealed by the still lower average yields in quadrants 1 and 3 relative to quadrant 4.

Switching focus to within-quadrant trends, Table 5, Panels D, E, and F express area, production, and average yield by quadrant relative to the first policy regime. As expected, the area planted in quadrant 1, a sub-optimal maize growing location with relatively low and highly variable rainfall, increased by 159% during the second policy regime, only to decline to 38% above the 1946 (end of regime 1) area total by the end of the third policy regime. The area planted in quadrant 3, shows a similar trend, with the area planted increasing to 40% above 1946 levels during the second regime, then contracting to 24% below it by the end of the third regime. Yields expressed relative to the first policy regime increased across the board, although the gains were more pronounced in quadrant 4 (after setting aside quadrant 2, which has a small total area in maize). Looking at production trends, the magnitude of the yield gains was sufficiently large in quadrants 1 and 2 to offset the declines in

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[20] A complicating factor is the changing spatial comparative advantage of maize relative to other crops. For example, between 1974 and 2007 the area planted to soybeans and sunflower increased by 1,477 and 31 percent, respectively (see Appendix B). Among the large area quadrants (1,3,4), quadrant 4 has comparative advantage in maize production (see relative yields Panel B). It is also a produce area for soybean production such that maize and soybeans, which limits the maize acreage in a given year. This is distinct from the maize areas in quadrant 1 where they grow little soybeans and have a high share of continuous maize cropping.

maize area, but not so for quadrants 3 and 4. Nonetheless, quadrants 3 and 4 still accounted for 76 percent of national maize output in 2007 (82 percent in 1946).

Table 5: Change in area, production and yield by policy regime

| **Panel A** | **Area share (%)** | | | |
|---|---|---|---|---|
| | *Quadrant 1* | *Quadrant 2* | *Quadrant 3* | *Quadrant 4* |
| **Rainfall** | *low average, high variability* | *high average, high variability* | *low average, low variability* | *high average, low variability* |
| 1946 | 15 | 2 | 44 | 40 |
| 1988 | 25 | 0.3 | 40 | 34 |
| 2007 | 25 | 0.5 | 40 | 34 |
| **Panel B** | **Production share (%)** | | | |
| | *Quadrant 1* | *Quadrant 2* | *Quadrant 3* | *Quadrant 4* |
| 1946 | 17 | 1.9 | 41 | 41 |
| 1988 | 19 | 0.5 | 37 | 44 |
| 2007 | 23 | 0.7 | 37 | 39 |
| **Panel C** | **Yield (%), relative to quadrant 4** | | | |
| | *Quadrant 1* | *Quadrant 2* | *Quadrant 3* | *Quadrant 4* |
| 1946 | 107 | 111 | 90 | 100 |
| 1988 | 58 | 150 | 72 | 100 |
| 2007 | 82 | 131 | 82 | 100 |
| **Panel D** | **Relative Area (%)** | | | |
| | *Quadrant 1* | *Quadrant 2* | *Quadrant 3* | *Quadrant 4* |
| 1946 | 100 | 100 | 100 | 100 |
| 1988 | 259 | 26 | 140 | 134 |
| 2007 | 138 | 24 | 76 | 71 |
| **Panel E** | **Relative Production (%)** | | | |
| | *Quadrant 1* | *Quadrant 2* | *Quadrant 3* | *Quadrant 4* |
| 1946 | 100 | 100 | 100 | 100 |
| 1988 | 655 | 162 | 526 | 629 |
| 2007 | 766 | 205 | 503 | 517 |
| **Panel F** | **Relative Yield (%)** | | | |
| | *Quadrant 1* | *Quadrant 2* | *Quadrant 3* | *Quadrant 4* |
| 1946 | 100 | 100 | 100 | 100 |
| 1988 | 252 | 632 | 375 | 469 |
| 2007 | 555 | 860 | 663 | 729 |

*Source:* Rainfall data: Lynch (2004), own calculations. Growing season November to April, averages 1910 to 2000.
Maize data: See text.

*Note:* Districts where more than 50% of the maize area in 2007 is irrigated, are excluded.

This body of empirical evidence shows that these switching policy regimes coincide with a) a major increase followed by a decrease in the total area planted to maize as the farm-friendly policies of the 1945-1988 period came to an end, and b) more subtly, but perhaps more profoundly, these pro-farm policies concentrated the expanded maize producing areas in locations that experienced below-average amounts and above-average variability in rainfall thus increasing the climate risk exposure of the South African maize sector..

The persistent aspects of the mid-century, pro-farm policy regime stem from the (knowledge capital) investments in and uptake of improved maize varieties and the substantial crop storage, logistic, and irrigation infrastructure (physical capital) investments. These investments had both crop productivity and climate resilience implications. They helped drive the persistent (albeit slowing of late) gains in crop yields throughout the past century, along with the geographical expansion of production into the irrigated areas of the Vaal and Orange rivers. In addition, investments in hybrid maize varieties and improved cultivation practices enabled farmers to increase yields on average while at the same time increasing the spatial differences in yield (Figure 5 Panel C and Figure 4).

In an era where climate change is increasingly affecting agricultural production, deepening our understanding of the relationship between agricultural policy and the location of agriculture can have profoundly important implications for the productivity performance and resilience of the sector.

## 5 Conclusion

During most of the 20th century, South African agriculture was subject to changing regimes of distortionary farm policies that were eventually dismantled after the mid-1980s. We show that the changing orientation of these farm policies had a profound effect on the structure and performance of production agriculture in South Africa and the sector's exposure to climate risk.

We show that during the past century, South African maize production was subject to three distinct policy regimes and that maize production patterns exhibit a close concordance with the respective regimes. Starting in the 1940s and tapering by the 1980s, the maize industry enjoyed a golden age of support. This farm-favorable regime induced a substantial expansion in the physical footprint of production in those areas that had previously supported little (if any) maize production, given their relatively lower rainfall amounts and higher rainfall variability. These distortionary policies thus undermined the environmentally-based spatial comparative advantages of production.

Using spatial reallocation indexes, we estimated that at its peak in 1993, the spatial reallocation of production reduced output by 15.3 percent. Once the sectoral support policies were removed, not only did the total area planted to maize contract markedly, but production also largely reverted back to the geographical areas with intrinsically higher production (yield) potential and lower rainfall variability. As a result, by 2007, the spatial reallocation index recovered to 0.2 percent above the base year (1918) reference. But we also find a degree of persistence given that some production remained in relatively lower-yielding areas given that the current period weighted (Paasche) reallocation index still lagged the base period (Laspeyers) index by 5.8 percent. This situation can be explained by the cumulative movement in the area mean centers, which shows that by the end of the period, the area planted almost returned to the 1918 reference on the north-south axis but remained close to the westernmost extreme on the east-west axis.

One of the principal factors that enabled the persistence of production in relatively lower-yielding areas is the state-sponsored hybrid maize breeding program, increasingly private after 1965, that prioritized the breeding of drought-tolerant hybrid varieties. This development resulted in a 4.2-fold increase in the yield per unit of rainfall between 1950 and 1993 (Greyling and Pardey 2018). In addition, the persistence was also enabled by research on maximizing rainfall utilization in dryland agriculture; this included the development of deep tillage (400 to 1,200 mm) practices and the implementation of controlled traffic maize production systems with wide maize row widths (1,500 to 2,100 mm) during the late 1980s and early 1990s (Bennie, Hoffman, and Coetzee 1995; Bennie and Botha 1986). Another contributing factor is the development of infrastructures such as grain storage and handling systems, expanded road and rail networks, or irrigation systems such as those along the Vaal and Orange Rivers, and the Western and Southern Cape to a lesser extent. Government support to the installation of irrigation infrastructure (which was at its zenith in the period 1940–1980, (Van Vuuren 2010b; 2010a) induced a longer-lasting change in the geography of South African maize production, indicating that it is not just the amount, but also the form of the support, that has consequences for economic activity.

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# Supplementary material

## Appendix A: Summary of 20th century South African agricultural policy and other events

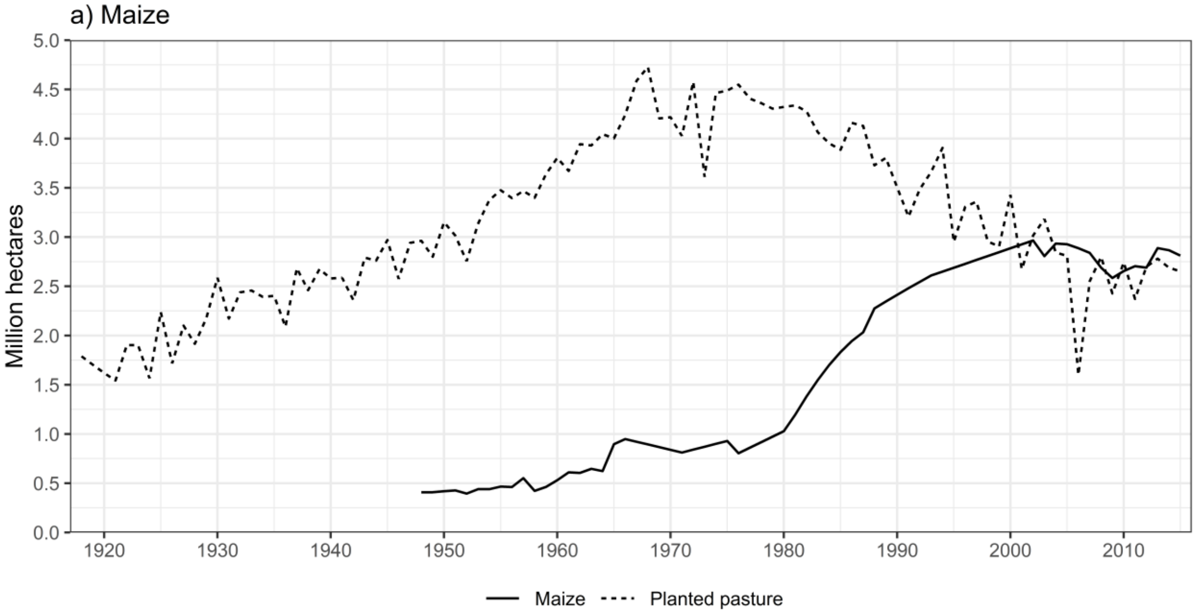
| Year | Name | Distor-tionary | Discri-minatory | | Description | Source | | |
|---|---|---|---|---|---|---|---|---|
| | | | De jure | De facto | | Author | Year | Page |
| 1912 | Land and Agricultural Bank | X | | X | Provide subsidized loans to commercial farmers<br>Long term loans to farmers who could not access credit from commercial banks | Vink<br>Ortmann & King | 1993<br>2007 | 153 |
| 1912 | Land Settlement Act | X | | X | 1) Provided for the acquisition of state and privately-owned land to settle white farmers; the use of public funds to buy the land with the state subsidy of up to 80 percent of the sale price; and the provision of advances for production costs.<br>2) Standardized the acquisition, exchange, and disposal of state lands for white settlement | Letsoalo & Thupana<br>The World Bank | 2013<br>1994 | 299<br>52 |
| 1913 | Land Act | X | X | | Restricted black farmers to 7.3 percent of available land and attempted to stem alternative land access strategies such as land tenure and sharecropping arrangements. | Vink et al. | 2018 | 347 |
| 1922 | Cooperative Societies Act | | | X | It permitted the establishment of limited liability cooperative societies | Brits | 1969 | 202 |
| 1936 | Land Act | | X | | Released a further 5.7 percent of available farmland for black farmers after being procured by the state | Letsoalo & Thupana | 2013 | 299 |
| 1937 | Marketing Act of 1937 | X | | X | Controlled marketing - Establishes the state as the sole buyer and seller of most agricultural products. Pan-seasonal and territorial prices. Implemented on a trial and error basis prior to 1944. | Brits<br>Vink | 1969<br>2004 | 204 |
| 1938 | Vaalharts irrigation scheme | | | X | First farmers settled on what is to become the biggest irrigation scheme in South Africa consisting of 29 100 hectares | Van Vuuren | 2010 | 24 |
| 1939 | Cooperatives Societies Acts | | | X | Secure input supply and output marketing services | Ortmann & King | 2007 | 46 |

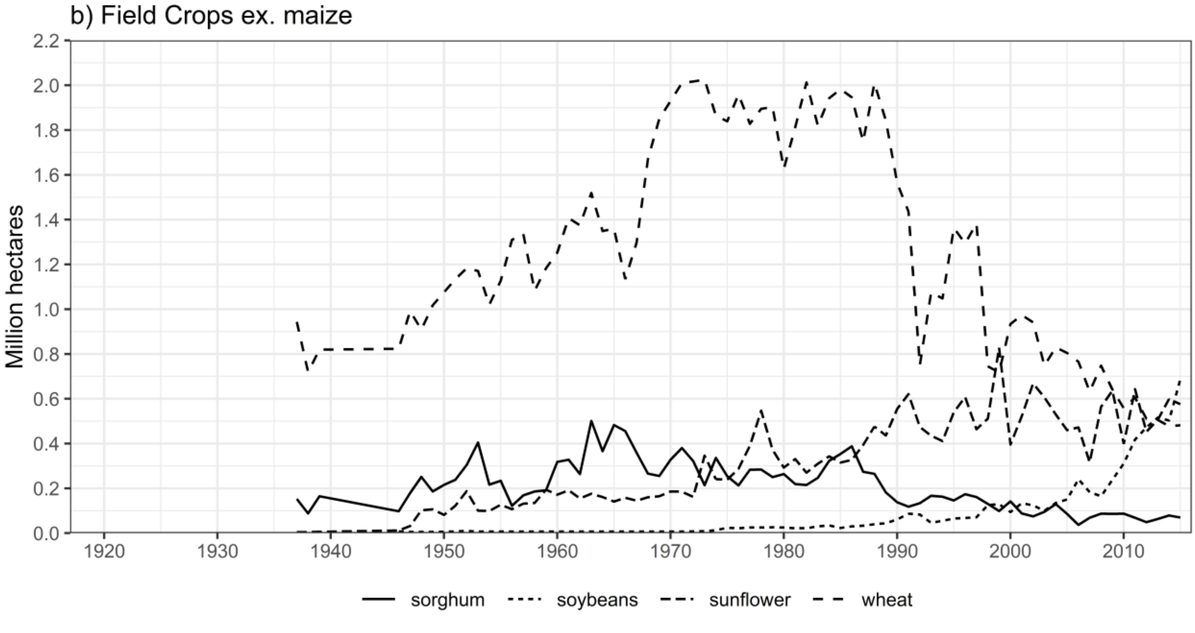
| Year | Name | Distortionary | Discriminatory | | Description | Source | | |
|---|---|---|---|---|---|---|---|---|
| | | | De jure | De facto | | Author | Year | Page |
| 1948 | National Party comes into power | | | | Generally regarded as the start of grand apartheid. Pro-farmer, applies the policy foundation laid during the first part of the 20th century for broad-scale (white) farmer support | Greyling et al. | 2018 | |
| 1962 | Orange river scheme | | | | Initiation of the Orange River scheme that would eventually expand the irrigated area in South Africa by 40 percent | Water Wheel | 2010 | 21 |
| 1966 | Agricultural Credit Act | X | | | To provide for assistance to persons carrying on or undertaking to carry on farming operations, for the exercise of control in respect of assistance rendered, and for other incidental matters | Republic of South Africa | 1966 | |
| 1968 | Marketing Act of 1968 | | | X | Revised the 1937 marketing act | Vink | 2004 | |
| 1971 | Completion of Gariep dam | | | | Biggest dam in South Africa and cornerstone of the Orange River Scheme | Water Wheel | 2010 | 25 |
| 1973 | Subsidised interest | X | | X | Subsidised credit was provided to farmers through the Land Bank. Real interest rates were negative between 1970 and 1984 | The World Bank | 1994 | 145 |
| 1977 | Capital tax concessions | X | | | Tax concession that enabled farmers to write down the entire cost of new machinery in the year of purchase, thereby reducing both their tax liability and the cost of new machinery | De Klerk | 1984 | 20 |
| 1985 | Capital tax concessions revision | | | | Reduced the machinery write down from 1 to 3 years, thereby reducing immediate tax benefit of capital expenditure. | Kirsten et al. | 1994 | 36 |
| 1988 | Partial deregulation of maize marketing | | | | The profits or losses of the stabilization fund could not be carried over, effectively forcing the board to link the South African price to the world price | Vink | 1993 | 5 |
| 1991 | Abolition of Racially Based Land Measures Act in 1991 | | | | Revokes all racially based land measures | Vink et al. | 2018 | 351 |
| 1994 | First democratic election | | | | End of apartheid | | | |
| 1996 | Marketing of Agricultural | | | | Deregulation of agricultural marketing, started in 1996 and completed in 1998 | Vink et al. | 2018 | 338 |

| Year | Name | Distor-tionary | Discri-minatory | | Description | Source | | |
|---|---|---|---|---|---|---|---|---|
| | | | De jure | De facto | | Author | Year | Page |
| | Products Act, No. 47 | | | | | | | |
| 2005 | Cooperatives Act | | | | Modernises existing cooperatives act | Ortmann & King | 2007 | 47 |

*Source:* Compiled by authors.

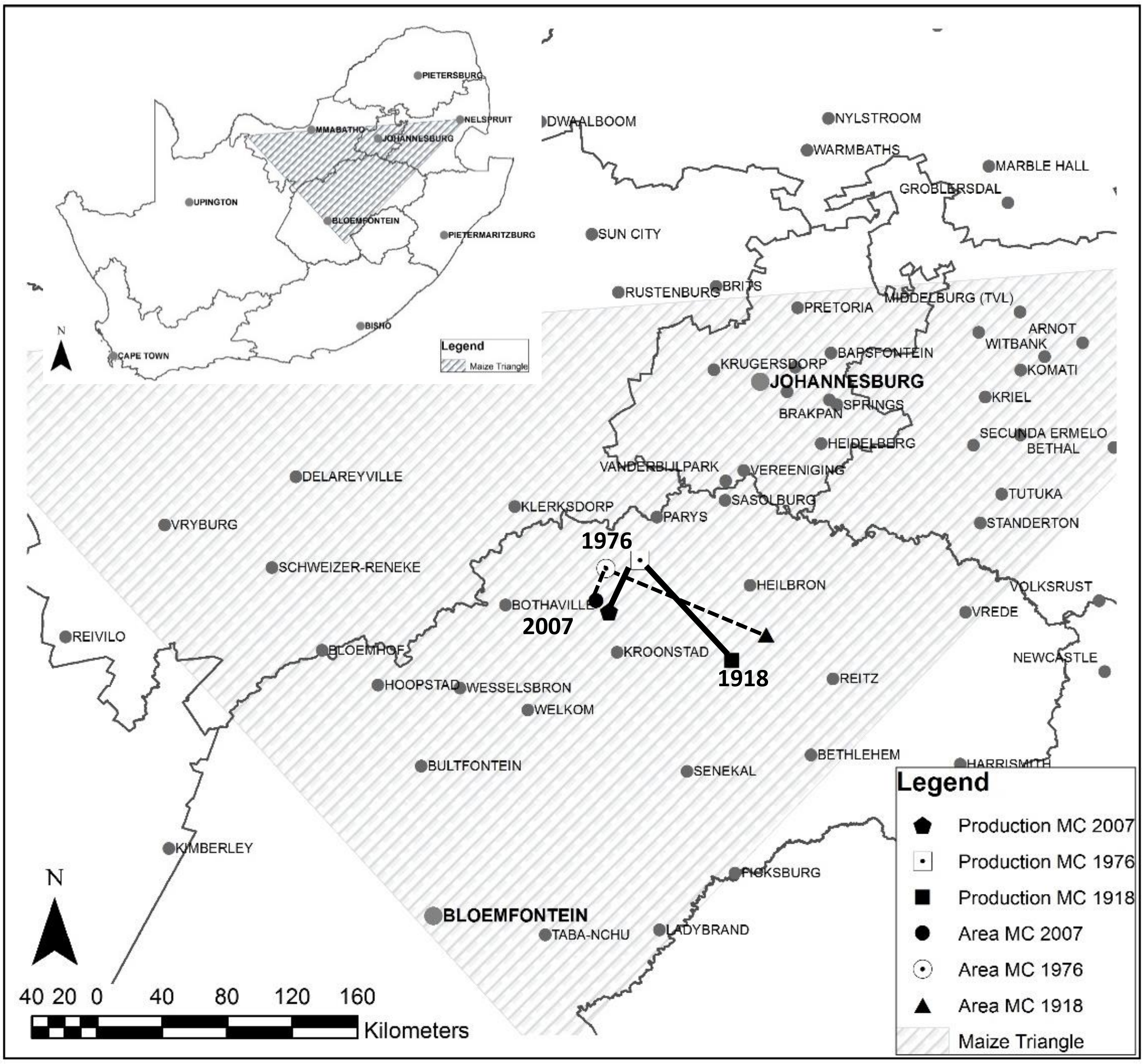
## Appendix B: Maize and field crop area


a) Maize


b) Field Crops ex. maize

*Source:* Agricultural Censuses and Abstracts of Agricultural Statistics various years.

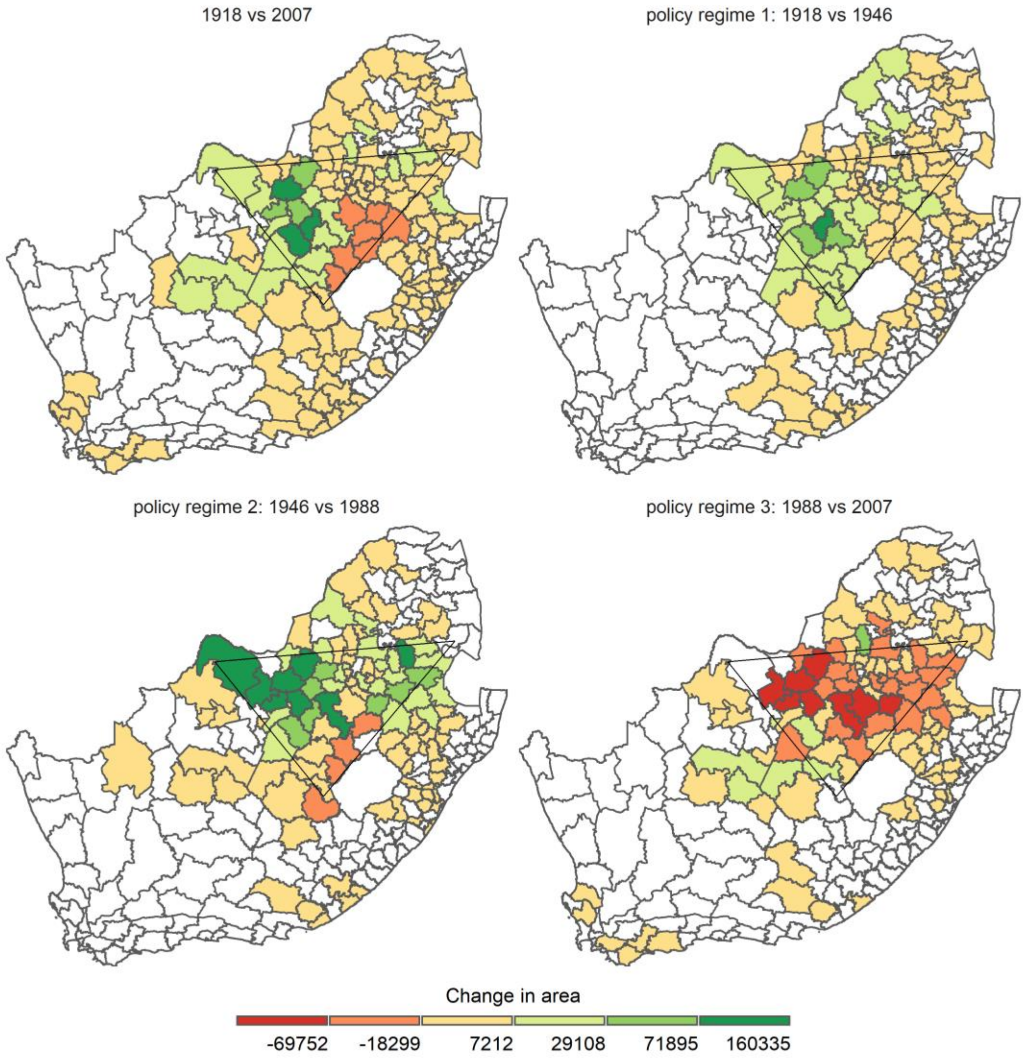
# 6 Appendix C: Area and production mean centre (MC) movement, 1918, 1976 and 2007



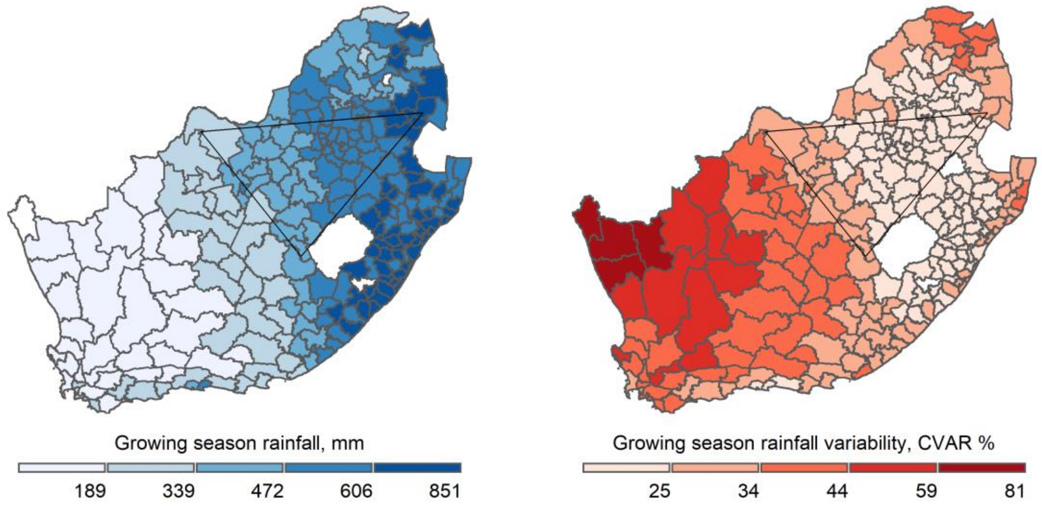
*Source:* Own calculations see text.

# 7 Appendix D: Changes in maize area planted by policy remigme

Panel a: Area movement



Panel b: Growing season rainfall, meand and variability



*Source:* Rainfall data: Lynch (2004), own calculations. Growing season November to April, averages 1910 to 2000. Maize data: See text.