Policy, production, and productivity: Spatial dynamics in the South African maize industry during the 20th century

by

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Declaration

By submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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Summary

This dissertation investigates the way distortionary agricultural policies, responding to political tensions during South Africa's structural transformation, also distorted the location of production. Taking the example of maize, it explores the interplay between changes in policy, production and productivity, and changes in the spatial footprint of production. The study covers more than a century (1904–2015), so as to include all the agricultural policy phases typical of an economy undergoing structural transformation. It finds that changes in agricultural policy after the mid-1930s, enacted in response to the political tensions that emanated from the converging and diverging interests of groups within the mining and agricultural sectors, are reflected in changes in maize production and prices. With the implementation of supportive policies, production expanded into areas previously supporting little maize, thereby undermining environment-based comparative advantages of production. Using spatial indexes, the study estimates that at its peak this policy-induced shift in the location of production reduced productivity by between 7.9 and 15.3 per cent. The dismantling of supportive policy during the 1980s and 90s coincided with the removal of land from maize production by farmers. By 2015 the area planted to maize had reverted back to the level it had reached almost 80 years earlier in 1935, before supportive measures were implemented. But spatial inefficiency partly persisted because some production continued in drier, lower-yielding regions.

After the distortionary policies were removed, some of the spatial distortion remained, despite the lower productivity, because of region-specific investments in improving plant material, farming practices and infrastructure. So, while some of South Africa's maize production ended up in the wrong places, technological improvements eventually made the wrong places more right. Despite the misguided policies, drought-focused research-and-development investment in technologies such as hybrid maize generated a sequence of innovations which more than quadrupled the maize yield per unit of rainfall between 1950 and 1993. The South African case serves to show that distortionary policies carry both short- and long-term costs. This is particularly relevant to sub-Saharan Africa, several of whose countries have pursued or are still pursuing various forms of maize and other agricultural intervention. The case also offers an example of successful adaptation to adverse weather conditions and suggests that a change in the location of production can serve as a proxy for climate change.

Three new historical datasets for the period were created specifically for this study: maize price, trade and production data; hybrid adoption, replacement and yield trial data; and district-level maize output and area planted data compiled from 17 digitised agricultural censuses, standardised to current spatial boundaries. Although the datasets are limited to maize, the procedures devised to construct them can be used by future researchers to extend the analysis to other crops and regions.

Opsomming

Hierdie proefskrif ondersoek die manier waarop verwronge landboubeleid, in reaksie op politieke spanning gedurende Suid Afrika se strukturele transformasie, ook die ligging van produksie verwring het. Vanuit die perspektief van mielies, verken dit die wisselwerking tussen beleidsverandering, produksie en produktiwiteit, en veranderinge in die ruimtelike voetspoor van produksie. Die studie strek oor meer as 'n eeu (1904–2015), sodat dit al die onderskeie landboubeleidsfases insluit wat tipies is aan 'n ekonomie wat 'n strukturele transformasie ondergaan. Dit vind dat veranderinge in landboubeleid na die middel-1930s, in reaksie op die politieke spanning wat voortgespruit het uit die gedeelde- and botsende belange van groepe in die myn- en landbou sektore, gereflekteer word in veranderinge in mielie-produksie en pryse. Met die implementering van ondersteunende beleid, het produksie uitgebrei tot gebiede wat voorheen min mielies verbou het, sodoende is die omgewingsgebaseerde vergelykbare voordeel van produksie ondermyn. Ruimtelike indekse word gebruik om te beraam dat hierdie beleidsgeïnduseerde verskuiwing, produktiwiteit met tussen 7.9 en 15.3 persent verlaag het. Die aftakeling van die ondersteunende beleid gedurende die 1980s en 90s strook met die onttrekking van grond van mielieproduksie. Teen 2015 het die aangeplante area teruggekrimp tot 'n vlak wat dit byna 80 jaar vantevore in 1935 gehandhaaf het, voor die ondersteunende maatreëls. Maar die ruimtelike ondoeltreffendheid het gedeeltelik voortgeduur omdat produksie steeds plaasgevind het in sommige droër gebiede met 'n laer opbrengspotensiaal.

Nadat hierdie beleide verwyder is, het die ruimtelike verwringing gedeeltelik voortbestaan, ten spyte van die laer produktiwiteit, as gevolg van streekspesifieke beleggings in die verbetering van plantmateriaal, verbouingspraktykte en infrastruktuur. So, alhoewel van Suid Afrika se mielieproduksie in die verkeerde plekke beland het, het tegnologiese vooruitgang hierdie verkeerde plekke uiteindelik meer reg gemaak. Ten spyte van onbedagte beleid, het droogte gefokusde navorsing-en-ontwikkeling beleggings in tegnologieë soos batermielies, opeenvolgende innovasies tot gevolg gehad wat mielie opbrengs per eenheid reënval meer as viervoudig verhoog het tussen 1950 en 1993. Die Suid Afrikaanse geval wys dat verwronge beleid beide kort- en langtermyn kostes dra. Dit is besonder relevant tot sub-Sahara Afrika waar verskeie lande histories of tans verskillende vorme van mielie en ander bemarkingsintervensies voortsit. Die Suid Afrikaanse geval bied ook 'n voorbeeld van 'n suksesvolle aanpassing tot ongunstige klimaatsomstandighede and stel voor dat 'n verskuiwing in die ligging van produksie kan dien 'n proksie vir klimaatsverandering.

Drie historiese datastelle vir die periode is spesifiek vir hierdie studie ontwikkel: mielieprys, handel en produksie-data, bastermielie aanneming-, vervanging- en proef opbrengs-data, and distriksvlak mielieproduksie en geplante area data saamgestel uit 17 gedigitaliseerde landbousensusse, gestandaardiseer tot huidige distriksgrense. Alhoewel die datastelle beperk is tot mielies, sal die prosedures wat ontwikkel is om hulle daar te stel ook deur ander navorsers toegepas kan word om die analise uit te brei na ander gewasse en streke.

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Opgedra aan my aan my Ma,

Dalené Greyling

(20 Mei 1963 – 15 Maart 2019)

Preface

This dissertation is presented as a compilation of 6 chapters. Each chapter is introduced separately and is written according to the style of the journal to which it was submitted for publication:

Chapter 1

Introduction

Chapter 2

Greyling, J.C. & Pardey, P.G. 2018. Measuring Maize in South Africa: The Shifting Structure of Production During the Twentieth Century, 1904–2015. *Agrekon*. https://doi.org/10.1080/03031853.2018.1523017

The chapter presents and discusses an entirely new historical compilation of South African maize production data for the period 1904–2015. The candidate was responsible for collecting, digitising and cleaning the data used to construct the respective datasets and for analysing it.

Chapter 3

Greyling, J.C., Vink, N. & Van der Merwe, E. 2018. Maize and Gold: South African agriculture's transition from suppression to support (1886–1948). In H. Willebald & V. Pinilla (eds.). Basingstoke: Palgrave MacMillan *Agricultural Development in the World Periphery: A Global Economic History Approach*.

This chapter illustrates the complexity of the political tensions which gave rise to the policy transition from implicitly suppressing South African commercial agriculture prior to the 1940s to supporting it thereafter. The candidate was responsible for the conceptualisation and execution of the analysis. Vink and Van der Merwe assisted with background research.

Chapter 4

Greyling, J.C. & Pardey, P.G. 2018. *Hybrid Maize Adoption in South Africa During the 20th Century: Policy Failures and Climate Adaptation Successes*. InSTePP Working paper. St Paul: International Science and Technology Practice and Policy (InSTePP) center, University of Minnesota, forthcoming.

This chapter reports the results of my study on the initial adoption of hybrid maize by commercial farmers in South Africa during the 1950s to late 1970s. The candidate was responsible for collecting, digitising and cleaning the data used to construct the respective datasets and for analysing it.

Chapter 5	Greyling, J.C., Senay, S. & Pardey, P.G. 2018. *Politics, Production and Productivity: 20th Century Farm Policies and the Consequences for Maize Production in South Africa*. InSTePP Working paper. St Paul: International Science and Technology Practice and Policy (InSTePP) center, University of Minnesota, forthcoming. This chapter integrates the results of the preceding chapters and supplement them with spatial indicators to illustrate the complex interplay between changing farm policy regimes, agricultural production and productivity. The candidate was responsible for collecting, digitising and cleaning the data used to construct the respective datasets and for analysing it. Senait was responsible for the digitisation of the district boundaries and the spatial disaggregation and reaggregation of the output and area indicators according to contemporary boundaries.
Chapter 6	Summary and conclusion

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Chapter 1:
Introduction

1.1 The structural transformation

Long-term change in the sectoral composition of economies is both the cause and effect of economic growth. This structural transformation is characterised by four interrelated forces: a decline in the relative share of the agricultural sector, an acceleration in rural to urban migration, an increase in the importance of the manufacturing and service sectors, and a decline in birth and mortality rates. The eventual result for the agricultural sector is that agricultural capital and labour productivity becomes indistinguishable from the productivity of the non-farm economy.

This productivity convergence is not always a smooth process and typically goes through several stages (Timmer, 2009). Before the transformation, subsistence farming constitutes the lion's share of economic output and employs most of the labour force. During the initial stages of development, most workers are engaged in subsistence production and the objective is simply to 'get agriculture moving' by increasing the output per worker sufficiently for the workforce to generate transferable surpluses (Mosher, 1965). Thereafter, an agricultural sector on the move assumes a central role in contributing to economic growth: meeting the domestic demand for food, supplying inputs for processing, earning foreign exchange through exported surpluses, releasing labour for the non-farm economy where it can be used more productively, generating capital for investment, and providing a market for manufactured inputs and consumables (Johnston & Mellor, 1961). Eventually these contributions also get the non-farm sector moving, typically at a faster rate than the farm sector (McMillan & Rodrik, 2011). At this stage agricultural labour productivity start to trail that of the broader economy, primarily because of the decline in the real value of agricultural produce over time due to 'the farm problem' and the labour rigidities.

The former is the outcome of the inelastic demand for food, known as 'Engels' law', the continued increase in agricultural productivity (Gardner, 1992). While is the result of friction in the agricultural labour market that slow the transfer of labour out of the sector because of the fixity of human and physical capital within the sector (Johnson & Quance, 1972). As a result, farm incomes begin to fall behind those earned in the rest of the economy, thereby contributing to the political tensions typically experienced during structural transformation (Timmer, 2009).

When we analyse the historical patterns of agricultural policy, we find that policymakers have shown an almost uniform response to these political tensions: supplementing farm incomes by protecting them from international competition or providing direct and indirect support through subsidies and other initiatives (Lindert, 1991). While such initiatives relieve the tension over the short term, they eventually become politically unsustainable given the budgetary and distortionary costs, and the declining political importance of farmers because of the continued rural-urban demographic transition (Timmer, 1988). In the absence of such support measures and the movement of labour out of agriculture, to remain competitive output per worker in agriculture must increase, with the result that agricultural productivity and incomes tend to converge with those of the non-farm economy. From a sector-level perspective we see agricultural value added and labour share converging with that of the non-agricultural sector, with the completion of a successful transformation signalled when they reach parity (Timmer, 2009).

1.2 The South African transformation

The South African structural transformation has featured in various cross-country comparative studies of specific aspects of this persistent process (see for example Timmer, 2007; Losch, Fréguin-Gresh & White, 2012; Vries, Timmer & Vries, 2013; De Brauw, Mueller & Lee, 2014). In a recent study, Binswanger-Mkhize (2014) regarded South Africa's structural transformation as an example of a failed transformation, since farm and non-farm incomes, together with the farm sector's value added and labour shares, failed to converge after the removal of public support to the agricultural sector during the late 1980s and 1990s. He attributed this failure to the persistent disparity between small- and large-scale farmers and the inability of the mining and manufacturing sectors to absorb sufficient labour. Various authors have deliberated on specific components of South Africa's economic transformation, particularly highlighting the agricultural sector's role in the boarder process of the country's economic development. This has been studied both at both a sector-level (e.g., Du Plessis & Swanepoel, 1963; Brand, 1969; Vink, 2004; Greyling, 2012) and a sub-sector level (Van Zyl & Nel, 1988). However, more work can yet to be done on the structural transformation of the South African economy in general and the agricultural sector in particular, most notably highlighting the technological and spatially sensitive aspects of this process as is done in this thesis.

Subsistence farming dominated agricultural production in the interior of South Africa before the discoveries of diamonds in 1866 and gold in 1886. The greatly expanded market for agricultural goods that resulted from these mineral discoveries, in conjunction with the limited transport infrastructure which provided a level of protection against import competition, gave the impetus to get farming in the interior of the country moving. However, there soon arose a conflict of economic interest between the farmers and the mining companies. The companies were eager to depress the price of agricultural products, especially maize, since they had to bear the cost of feeding their migrant workers (Trapido, 1971). Initially the farmers sought to counteract this through collective action with the establishment of farmer cooperatives, but only managed to do so after gaining enough political influence to secure various forms of direct and indirect support. Chief among these was the Marketing Act of 1937, which established the state as the sole buyer and seller of most agricultural products, at a price determined with the input of farmers and other stakeholders. This and other policy measures, notably the concerted efforts to eliminate competition from black farmers, heralded a golden age of agricultural support to commercial, aka white, farmers that started after the Second World War and continued until the early 1980s. When the farmers' political influence dwindled after they isolated themselves from the ruling National Party by siding with the Conservative Party in 1983 (Bernstein, 2004), and the state became unable to afford the various forms of direct and indirect farmer support measures (Kassier Committee, 1992), agricultural policy did an about-face. Beginning with the partial deregulation of maize marketing in 1988, the gradual removal the removal of virtually all direct and indirect support was completed ten years later (Vink, Kirsten & Van Zyl, 2000).

Many aspects of this still unfolding process have been well documented by numerous studies. These studies can be categorized according to their broad themes: those that examined macro policy trends and stages (see for example Vink & Kassier, 1991; World Bank, 1994; Vink, 2012; Vink et al., 2018), *ex ante* and *ex post* studies of the deregulation of agricultural marketing (Brits, 1969; Van Zyl & Groenewald, 1988; Kassier Committee, 1992; Vink, 1993; Kirsten, Van Zyl & Van Rooyen, 1994; Groeneweld, 2000; Vink, Kirsten & Van Zyl, 2000; Vink, 2004; Vink & Van Rooyen, 2009; Greyling, Vink & Mabaya, 2015), studies that measure the extent of government interventions as subsidy equivalents or rates of assistance (OECD, 2006; Kirsten, Edwards & Vink, 2007, 2009), and an extensive historiographical literature on the political economy of the sector in general (Morris, 1976; Morrell, 1986; Bernstein, 2004, 2013) and the dispossession and suppression of black farmers specifically (De Kiewiet, 1942; Bundy, 1972; Wolpe, 1972; Onselen, 1988; Marcus, 1989; Hendricks, 1990; Feinberg, 1993; Van Onselen, 1996). Hence South Africa provides a well-documented example of how agricultural policy evolves in response to the shifting political tensions created by the transformation process.

1.3 Towards an integrated spatial approach

Surprisingly, since agricultural production is a location-specific endeavour, agricultural and development economists have hitherto paid little attention to the long-term changes in the location of agricultural production during the structural transformation. The typical unit of spatial analysis in the structural transformation literature is simply the country itself. The structural change literature acknowledges the importance of location for farm structure and production methods, but it pays no specific attention to spatial factors (see for example Johnson & Quance, 1972; Chavas, 2001). The agricultural productivity literature that quantifies the effects of machinery, fertiliser, improved crop genetics and other factors on crop yields also fails to take location into account, hence ignoring the important productivity and output implications of crop movement as addressed. Even much of the recent climate change literature assumes the footprint of crop production is invariant (see for example Mendelsohn, Nordhaus & Shaw, 1994; Ashenfelter & Storchmann, 2010; Deschênes & Greenstone, 2012). The recent study by Beddow and Pardey (2015) is a notable exception, which extends the work of Parker and Klein (1966) and Olmstead and Rhode (1994) to estimate the production and productivity implications of the spatial reallocation of U.S. maize production during the twentieth century.

If the analysis is restricted further to explore the link between policy and the location of production, the U.S. literature is limited to those who assess the impact of the Conservation Reserve Programme (CRP). Through this programme the U.S. government pays farmers to remove cropland from production as a way to reduce land erosion, improve water quality and effect wildlife benefits. Studies on this topic focus on measuring either the overall economic impact of the program (Sullivan et al., 2004) or the unintended consequences thereof, and aspects that are implicitly spatial in nature such as the 'slippage effect,' whereby less productive land is removed from production while more productive land is retained or brought in to agriculture (Wu, 2005).

Long-term changes in the location of South African agricultural production have not received specific attention in the literature, although some studies have linked spatial changes in production to the distortionary agricultural policies in effect during the late-1930s to 1990s. For example, Brits (1969), Kassier CommIttee (1992), and Van Zyl, Fényes & Vink (1992) argued that supportive agricultural policies incentivised the expansion of maize, and other crops, into marginal areas that would not have been cultivated otherwise (Brits, 1969; Kassier Committee, 1992; Van Zyl, Fényes & Vink, 1992). Some also argued that these spatial production distortions were reversed after the removal of the distortionary policies, bringing substantial productivity gains as a result (Groenewald, 2000; Vink, 2012). However, none of these studies has sought to quantify the precise nature, timing and extent of these spatial changes, the technological aspects associated with the changes, or their crop production and productivity implications, gaps this study attempts to fill.

1.4 Main objective and contribution

This dissertation reports the results of an investigation into the policy-induced distortions in the location of agricultural production in South Africa. It explores the complex interplay between changing agricultural policy regimes, agricultural production and productivity, and changes in the spatial footprint of production, taking the perspective of maize, the principal South African field crop. The study covers a period of more than a century (1904–2015), a period that encompasses many of the agricultural policy phases that characterise the structural transformation of an economy. Through the application of recent advances in spatial analytical methods, this study measures the physical movement of maize production and quantifies the productivity impact thereof. This makes it possible to estimate the spatial impact of the shifting orientation of agricultural policies experienced by the sector during this time. To this end, the late 1930s, as the period prior to the implementation of the various supportive policies, serves as a reference point to which the subsequent spatial changes in response to the implementation and removal of the various distortionary policies can be compared.

In showing how the location of production is linked to changes in policy regimes, the study contributes to the structural transformation literature by demonstrating that political tensions also carry a spatial impact, the extent of which can be measured and the productivity impact quantified. The study also illustrates the complexity of the stakeholder interactions that give rise to the political tensions and eventual supportive agricultural policy measures that result. In addition the study shows how region-specific investments in improvements in plant material, farming practices and infrastructure enabled the changes in the location of production.

The study was made possible by the use of a newly constructed database of South African maize statistics spanning the period 1904–2018 that I compiled for this study. Not only does this new historical compilation encompass an extensive time period in a consistent manner, but in its construction I fully documented the sources of all data entries, and coded the data cleaning and spatialization of the series whenever possible. This makes it possible to replicate the results and apply the processes and procedures developed for this study to other commodities and census indicators.

The database consists of three components. The first spans more than a century (1904–2015) and distinguishes between the maize output and area planted by commercial (large-scale, historically white) and smallholder (small-scale, historically black) farmers, and also between white and yellow maize. The second component involved the digitisation, cleaning and spatialising of agricultural census reports spanning the period 1918 to 2007, the year of latest such report. This in itself was a large undertaking, given that the database includes 17 agricultural censuses that span nine decades and were unusable in their raw form because of various reporting and boundary inconsistencies. However, new analytical and mapping techniques enabled me to standardise the data spatially in accordance with a current set of spatial boundaries. The third component is a newly constructed spatially disaggregated dataset on the adoption of hybrid maize. It includes both the initial adoption of the state-developed hybrid varieties and their replacement by so-called 'elite' private-sector hybrids. This new data compilation also includes the results of early period yield trials.

1.5 Chapter overview and objectives

This dissertation consists of six chapters, of which Chapters 2 to 5 have been developed as standalone publishable pieces. While the structural transformation of the South African agricultural economy serves as a foundational and unifying theme of this study, the transformation process per se does not feature with equal prominence in each of chapters.

Chapter 2 deals with the first objective of this study, which was to measure South African maize production and area planted during the twentieth century. The South African maize sector has for many years accounted for a significant share of the country's overall agricultural economy, accounting for 82.5 per cent of the 3.67 million hectares sown to cereal crops in 2015 and an average of 50.6 per cent of the country's cropped area over the period 1948–2007 (Liebenberg, 2012; DAS, 2017). However, in seeking to provide a broad contextual overview of the industry, I found that there was little consensus in the literature on the true extent of South African output and area planted, especially if viewed over the longer term. The disagreement stems from the dualistic (arguably pluralistic) structure of South African agriculture, which is made up large commercial farmers and various groups of smallholders. During the past century, the output and area planted by the two types of farmers have been reported in varying degrees of detail, frequency and accuracy. In addition, historical datasets often do not differentiate between white and yellow maize production and area planted, the relative shares of which show significant temporal and spatial differences.

The chapter presents and discusses an entirely new historical compilation of South African maize production data for the period 1904–2015. The dataset includes commercial and smallholder production indicators, with the latter disaggregated into homeland and non-homeland smallholders wherever possible. Production is disaggregated into their respective output, area planted and yield components. The data sources are carefully described, and the apparent limitations and other issues with the data are discussed. In addition to the national aggregates, the data are also disaggregated into their white and yellow maize components in accordance with the current nine provinces for the period 1960–2015.

Chapter 3 illustrates the complexity of the political tensions which gave rise to the policy transition from implicitly suppressing South African commercial agriculture prior to the 1940s to supporting it thereafter. This is analysed from the perspective of the maize industry during the period after the discovery of gold in 1886 up to the start of apartheid in 1948. To date numerous scholars have studied aspects of the political tensions that emerged during the transformation of the economy, but from the perspective of specific stakeholder interactions or specific agricultural policies (Trapido, 1971, 1978; Morrell, 1986, 1988; Bundy, 1988). However, stakeholder interactions are yet to be analysed from the perspective of the overall structural transformation of the country's agricultural economy. To this end I integrate the existing literature and supplement it with new data, compiled by way of this study, such as the aggregate maize production and trade indicators, and also by other authors, notably the data on government research and support spending compiled by Liebenberg (2012). Collectively, the existing literature and the new data sources enable an analysis of the complex interactions between the three main stakeholder groups–white farmers, black farmers and the mining interests–to show how their shared or conflicting interests shaped agricultural policy during the first half of the twentieth century, thereby determining the agricultural policy agenda for the next half century.

Recent work on structural transformation processes has shown that while the process itself can be described according to several stylised facts, the same cannot be said for the policies that support or inhibit it, since these policies tend to be shaped by underlying, often country-specific, fundamentals (Losch, Fréguin-Gresh & White, 2011, 2012). The South African case illustrates both the complexity of the country-specific fundamentals that drove the policy formation process and their long-term effects on subsequent policy and economic outcomes.

Chapter 4 reports the results of my study on the initial adoption of hybrid maize by commercial farmers in South Africa during the 1950s to late 1970s. Technological change is an intrinsic, and important, feature of any agricultural transformation process (Schultz, 1964; Alston & Pardey, 2018). Unlike the case of the U.S., where the topic has received substantial scholarly attention (Griliches, 1957a, 1960, 1980; Dixon, 1980; Sutch, 2011), the South African case is yet to be studied from an economic perspective. To this end I used my new historical compilation of national and subnational hybrid adoption rates, relative hybrid and non-hybrid yields and the relative share of private and publicly developed hybrid maize varieties in an effort to answer some important questions.

The first question was why South African hybrid maize adoption lagged behind the US by almost two decades despite the early efforts to import US breeding material and an active hybrid breeding programme. To this end I compare the institutional structures and adoption rates of the two countries. The second question was whether South African hybrid adoption varied among regions in both the rate and timing of adoption, as Griliches (1957) found to be the case in the United States. I also applied and extended my dataset to test and refine Sutch's (2011) hypothesis that the revealed drought advantage of hybrid maize acted as a major driver of the initial adoption of the technology. Building on this, I also explored the effectiveness of the South African breeding programme in improving the drought tolerance of hybrid maize. I quantified this using a simple yet informative rainfall productivity index, which is commonly used by soil scientists (see for example Bennie, Hoffman & Coetzee, 1995). And lastly, I studied the replacement of so-called public hybrids with elite private hybrids, to provide more detail on the institutional failures in the South African hybrid seed industry.

In Chapter 5 I realise the fourth and final objective of this study, which was to integrate the results of the preceding chapters and supplement them with spatial indicators to illustrate the complex interplay between changing farm policy regimes, agricultural production and productivity. I analysed the policy-production-productivity interactions in three steps. The first step was to test the temporal concordance between changes in policy and production, to establish whether policy had an impact on overall maize area planted and average prices. To do this I extended the policy context provided in Chapter 3 to the entire period (1910-2015) and summarised it as a timeline of the ever-changing policy prescriptions and practices affecting the South African economy. I then econometrically juxtaposed this with my 1904–2015 time series decomposition of the maize area planted (compiled in Chapter 2) and a newly compiled dataset of domestic and international farm gate prices, and net exports.

The second step was to estimate the shift in the location of South African maize production, and to quantify its productivity impact during the twentieth century. I achieved this by applying the techniques developed by Beddow and Pardey (2015) to a new database, which I compiled from 17 agricultural censuses conducted between 1918 and 2007. This database reports maize output, area planted, and yields according to a spatially standardised set of municipal boundaries.

The third step was to integrate the preceding results to determine whether there is evidence of policy-induced distortions in the location of agricultural production. Did the favourable production policies result in a substantial expansion of the physical footprint of production into areas that had previously supported little (if any) maize production? And if this was the case, did the total area revert to the geographical areas that were used before the implementation of the distortionary policies?

The results of Chapters 2 to 5 are then summarised and synthesised in Chapter 6, leading into recommendations for policy and for further research.

1.6 Delineations and terminology

This is a study of the impact of agricultural policy on the location of South African maize production between 1904 and 2015. In this study the term ‘maize production’ refers to the combined production of commercial and smallholder farmers. Throughout this dissertation I distinguish between these two types of farmers, with the latter sub-divided into homeland and non-homeland smallholders whenever possible. These demarcations are consequential, and I highlight them to the extent that the data allow. I am aware of the value of doing more along these lines than is presently possible, especially when assessing the developments affecting the maize sector over the historical long-run.

Before the democratic transition in 1994, race played a central role in the collection and reporting of agricultural statistics. Historically, the *Agricultural Censuses* primarily reported the production of white farmers, but at times also reported the production of black ('native') farmers in 'reserves' and less frequently the production of black farmers on 'white farms'. In this dissertation I have opted to distinguish between farmers on the basis of their location and to a lesser extent the scale of their operations, to accommodate the pre-transition categorisation of farmers while also making it possible to quantify longer-run trends, first in the structural changes after the 1950s, and then in the political and market changes that came with the democratic transition. Before the 1960s, for example, the statistical distinction between commercial and non-homeland smallholder farmers is not entirely clear, given their mutual dependence due to various sharecropping and tenant arrangements. At the same time, white farmers who lacked the necessary resources (most notably draft animals) to cultivate the land themselves often entered into sharecropping arrangements with smallholder producers (see for example Onselen, 1988). Smallholders operating in the homelands also consisted of a diverse group of farmers–distinguished, for example, by differences in the area size of their farming operations–who collectively increased their total production during the 1940s (see for example Simkins, 1981)

In addition, the category designated 'non-homeland smallholders' becomes empirically irrelevant by the 1970s following the apartheid government's efforts to stem tenant production and the forced removal of black farmers from so-called 'black spots,' as discussed in Chapter 2. After the transition to democracy, 'commercial farm production' refers to all production outside the former homeland areas, irrespective of the scale of the farm or the race of the farmer, and 'smallholder production' refers exclusively to production in the former homeland areas.

The production of both farmer groups was included in the analysis wherever possible, since reporting smallholder maize production is one of the main objectives of Chapter 2 and the interaction between commercial and smallholder farmers is analysed as one of the key stakeholder relationships in Chapter 3. However, smallholder farmers are excluded in the analysis of Chapters 4 and 5 because of a lack of available data or reporting inconsistencies.

Chapter 2:
Measuring maize: The shifting structure of production during the twentieth century (1904–2015)

2.1 Introduction

Maize has dominated the South African countryside for decades. Between 1970 and 2015 an average of 57 per cent of the commercial area in field crops was dedicated to the production of maize. In addition to being a major South African feed and food staple, over this same period an average of 25 per cent of the country's maize crop was exported, mostly to Southern African neighbours (DAS, 2017). Maize rose to prominence as a South African crop during the latter part of the ninetieth century. Given the dominance of pastoral livestock production during these early years, plus a lack of suitable export markets, the crop was mainly cultivated for local subsistence needs (Vorster, 1952). The market realities for maize began to change with the discovery of diamonds (1866) and gold (1886) at Kimberly and the Witwatersrand respectively. Largely protected from international competition due to unnavigable rivers and lack of rail infrastructure, black and white farmers alike seized the opportunity to supply maize to meet the rapidly expanding demand from the booming mining population located in the interior of the country (Greyling, Vink & Van der Merwe, 2018).

In subsequent decades, the maize industry had a pivotal place in shaping the South African political, policy and economic landscapes. The relationship between maize and mines during the first half of the 20th Century is extensively documented (see, for example, Trapido, 1971; Morrell, 1988; Greyling, Vink & Van der Merwe, 2018). This involved the emergence of 'two agricultures;' one that suppressed the production potential of 'smallholder' black farmers (thus undermining self-subsistence and ensuring a supply of cheap labour for white farmers and the mines); the other that enhanced the production possibilities for 'commercial' (essentially white) farmers via substantial public investment, institutional and policy support (Lipton, 1977; Bundy, 1988; Marcus, 1989; Hendricks, 1990; Van Onselen, 1996).[1] Beginning around 1983, in a process that

[1] This black-white or commercial-smallholder dualism, which is often used to describe the great divide in South African agriculture, is, of course, an over simplification. The dual processes of legislative suppression and support affected both black and …

lasted until the late 1990s, the government gradually reduced public support to white farmers, most notably the dismantling of controlled commodity marketing schemes, once again reshaping the maize landscape (see, for example, Brits, 1969; Van Zyl, Fényes & Vink, 1992; Vink, Kirsten & Van Zyl, 2000; Bernstein, 2013) as part of the changing political economy for maize farmers (Bernstein, 2004).

Notwithstanding this extensive literature, there are comparatively few studies that assess in any comprehensive detail the shifting historical structure of South African maize production. Moreover, almost all such studies focus exclusively on the changing production realities faced by commercial farming, to the exclusion of smallholder producers. Burtt-Davy (1913) and Saunders (1930) provide some initial insights into the early phases of commercial maize production in South Africa during the first half of the 20th century, which was revisited some years later by Vorster (1952). De Klerk (1983) examined the mechanisation of commercial maize harvesting in six districts of the Western Transvaal between 1968 and 1981, while Van Zyl, Vink & Fényes (1987) studied employment trends for three major maize producing districts between 1950 and 1980. Using the conceptual framework laid out by Johnston & Mellor (1961), Van Zyl & Nel (1988) evaluated the macro-economic role that the maize industry played in the South African economy during the 1970s and 1980s, but did not delve into any details of the structural trends within the industry. Breitenbach & Fényes (2000) quantified production trends within the commercial maize and wheat industries during the 1985 to 1999 period, including a decomposition of maize production into its output and planted area components for nine provinces. Most recently, Greyling, Senait & Pardey (2018) evaluated the output consequences of the shifting location of commercial maize production in South Africa throughout the entire twentieth century.

The literature on the extent of smallholder maize production is especially limited. Wilson (1971) and Wolpe (1972), commented on the decline of smallholder production in the former homeland areas after the 1930s, but gave limited empirical support for these claims. Simkins (1981) quantified the value of smallholder agricultural output in the former homeland areas between 1918 and 1969, but gave no maize-specific details.

Here I address the omissions of prior studies, most notably taking a data-centric approach. I present and discuss an entirely new, historical compilation of South African maize production spanning the period 1904–2015 (see Appendices A to D). My compilation includes both

white farmers, but not all farmers and not all to the same extent. Nonetheless, the parallel land markets created by the 1913 Natives Land Act made the distinction between black and white farmers considerably more stark than would otherwise been the case.

commercial and smallholder production, decomposed into their respective output, planted area and yield components. In presenting these estimates I carefully describe my data sources and the evident limitations and issues with the underlying data. In addition to the national aggregate evidence, for the period 1960–2015 I also decompose commercial maize production by type, into its white and yellow maize components, and by location, standardising the location in terms of the geographical boundaries delineated by the country's current nine provinces.

2.2 Data definitions, sources and estimation issues

The data series I developed and summarize in this paper draws from various sources (Appendices C and D). Given the 112 years encompassed by my series, there were inevitably a host of data problems to address, including changes in the definition of what was being measured, how it was being measured, and in some cases a lack of measures altogether. Given these inconsistencies, I endeavoured to cross-reference my 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 the data to the estimates presented in this paper were coded or otherwise documented to ensure data replicability. While most of my aggregate maize production estimates could be cross-referenced by at least two sources, the same cannot be said for many of the planted area estimates, especially those relating to areas under smallholder production. Thus these smallholder estimates are on less firm footing, but I deemed them of sufficient reliability and interest to include in my compilation, not least given the substantial policy and livelihood implications of this disaggregated production evidence.

While I drew on a number of different data sources, the preponderance of my estimates were derived from three primary sources, namely:

- The ***Agricultural Censuses and Surveys*** conducted by Statistics South Africa and its predecessor agencies between 1918 and 2007. This constitutes the main data source for most variables prior to 1972, especially those relating to smallholder farmers. The digitisation of these Census documents was primarily done by the late Frikkie Liebenberg, and used in forming the various versions of the output, partial- and multi-factor productivity estimates reported in Liebenberg & Pardey (2012) and Liebenberg et al. (2015).[2] The enumeration areas for each of the censuses were magisterial districts

[2] Substantial further cleaning, (re-)processing and spatial disaggregation of these national aggregate data was conducted by Jan Greyling for the spatial maize dynamics analysis reported in Greyling, Senait & Pardey (2018) and the various series reported in this paper.

(whose numbers and boundaries change over time). Earlier censuses were carried out by the South African police (Union of South Africa, 1949), while more recent censuses were conducted via mailed or emailed surveys.

- The ***Abstract of Agricultural Statistics*** published by the Directorate of Agricultural Statistics of the National Department of Agriculture, Forestry and Fisheries serves as the main source for aggregate (commercial and smallholder) output and area indicators after 1972. As pointed out by Liebenberg (2012), the *Abstract* has always reported the (pre-aggregated) area and production of both farmer groupings. I cross-referenced the *Abstract* data against SAGIS and FAO datasets, and discuss the discrepancies in subsequent sections.
- The ***South African Grain Information Service*** (SAGIS)[3] serves as the main source for disaggregated output and area data after 1986, both for smallholder and commercial farmers as well as for white and yellow maize.

Appendices A and B summarize the compilation of maize production estimates I developed for this study. With respect to the production and area planted by all farmers (i.e., commercial and smallholder), my tabulations distinguish between the reported evidence and an aggregated version that I developed. Vorster (1952), for example, differentiates between total (commercial and smallholder) production and that of commercial farmers, while the respective *Abstracts of Agricultural Statistics* report only total production and planted area estimates (Liebenberg, 2012). The largest production discrepancies between the reported and aggregated quantity totals were in the 1920s, with the maximum discrepancy being 8.8 per cent in 1924 (1,020,000 tons reported versus 930,000 tons in the aggregated total) (see Appendices A and B). For planted area, the largest discrepancies were in 1978 (12.4 per cent, 4,412,000 hectares reported versus 4,960,000 hectares from the aggregated total) and 1988 (10.5 per cent, 4,736,000 hectares reported versus 4,241,000 hectares aggregated). However, I deemed the use of the aggregated totals to have a negligible influence on the overall trends and production relativities reported in this paper, and so opted to use these aggregated totals in all the figures and discussion in the subsequent sections.[4] For example, averaging over the entire 1904–2015 period, aggregated

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[3] SAGIS is a section 21 company that was established in November 1997, after the marketing deregulation of the South African maize sector. Its objective is the gathering, processing and timely distribution of reliable grain data. The organisation is funded by legacy contributions made to the now defunct Maize, Oil Seed, Sorghum and Winter Cereal Trusts.

[4] Not only were the discrepancies between the two totals generally negligible, use of the aggregated totals also meant that the national estimates were directly comparable with the sub-national decompositions presented in this paper.

national maize production was just 0.2 per cent smaller than the reported aggregate while the aggregated area planted was just 0.1 per cent greater than the reported total.

2.3 Aggregate, smallholder and commercial production

Figure 2.1 shows annual production (panel a), planted area (panel b) and national average yield (panel c) estimates for all South African maize producers during the period 1904 to 2015. The national aggregate estimate is indicated by the continuous solid black line shown in the production and area panels, while the stacked bar charts represent the respective production and area totals for commercial and smallholder producers. South African maize production totalled 328,000 tons[5] in 1904 (Saunders, 1930) and grew to 1.68 million tons by 1935. It continued its upward trend at an average rate of 2.0 per cent per year thereafter to reach 2.9 million tons in 1948. The area planted expanded at an average annual rate of 1.9 per cent per year from 1935 to 1948, meaning yields were effectively stagnant during this period (and averaged 0.6 tons per hectare for commercial farmers for whom I have area and production estimates back to 1918).

Planted area continued to increase after 1948, peaking at 5.59 million hectares in 1964. With production expanding at a far brisker rate (3.9 per cent per year) than planted area (0.6 per cent per year), annual yield growth averaged 3.1 per cent for the period 1949–1964. The continued increase in planted area, particularly after the mid–1930s was enabled by the rapid adoption of tractors (and other agricultural machinery). In 1937, South African farmers were using just 6,019 tractors, which increased to 20,292 by 1945, and continued growing to a peak of 173,570 units by 1976 (Liebenberg, 2012). The replacement of draught oxen by tractors enabled farmers to expand their area under crop production since it freed up land for marketable cropping purposes previously used to feed traction animals, while also increasing the amount of land an individual farm family could practically manage within a cropping season (Brand, 1969; Van Zyl, Vink & Fényes, 1987).

Average yield growth accelerated to 3.8 per year between 1965 and 1981, which enabled production to reach its second highest historical total of 14.87 million tons in 1981. This was despite an average rate of decline in planted area of 0.6 per cent per year, which saw planted area falling from 5.59 million hectares in 1964 to 4.93 million hectares in 1981. The adoption of

[5] Bosman and Osborne (1924) and the Union Statistics (1960) report a total of 361,169 tons. We chose to use the Saunders estimate given that Vorster (1952) and the subsequent *Agricultural Censuses* are in agreement with Saunders.

hybrid maize (in conjunction with other modern inputs such as fertilizer and irrigation) played a significant role in maize yield growth in U.S. agriculture during the 20th century (Beddow & Pardey, 2015). The uptake of hybrid maize also contributed to the increase in South African maize yields beginning in the late 1940s.

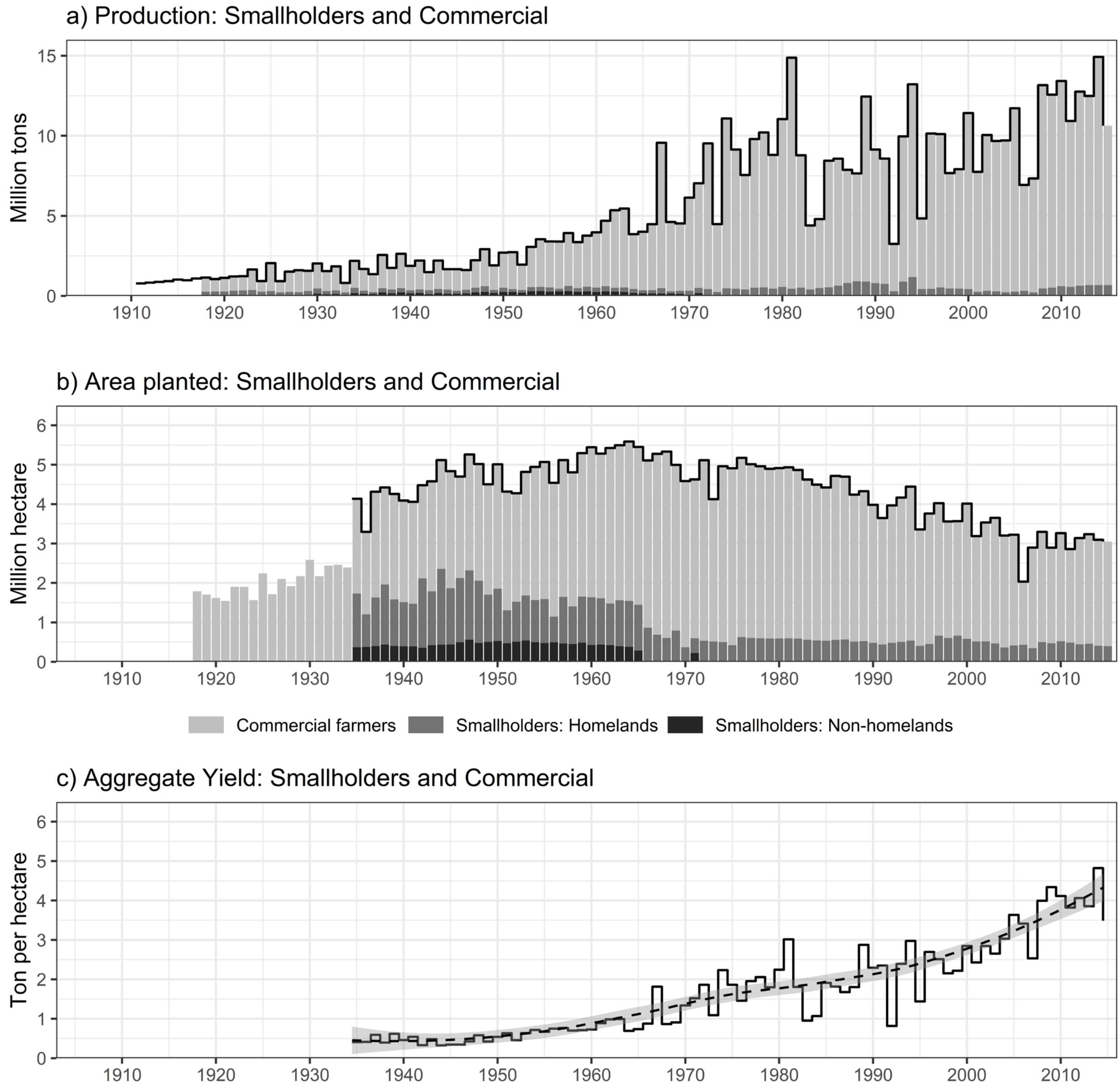

Figure 2.1: Production, area planted and yield by farmer type

Source: *Authors estimates based on data from sources in Appendices C and D.*

Notes: *No data on smallholder area planted were reported before 1935. The dotted line in Panel c shows a fitted loess regression, with the grey area around the fitted function delineating the 95 per cent confidence interval.*

Although the first hybrids were distributed to commercial farmers in 1949, hybrids constituted only 6 per cent of commercial maize seed sales in 1954. However, their share increased rapidly thereafter, rising to 29 per cent of maize seed sales by 1960, 64 per cent by 1965, and around 98 per cent by 1979 (Greyling & Pardey, 2018a). Yield growth continued after 1982 albeit at a slower rate (of 2.0 per cent per year through to 2015), noting the near complete adoption of hybrid maize by the beginning of this period. This continued growth in yields saw production reach an all-time high of 14.92 million tons in 2014, notwithstanding the continued contraction in planted area (by 1.4 per cent per year on average) to just 3.0 million hectares by 2015.

2.4 Delving into the maize details

2.4.1 Smallholder output and area

For much of the 20th century, black farmers were excluded from agricultural support measures, and there were additional, deliberate steps taken to limit their ability to compete with commercial farmers for the lucrative consumer market (Lipton, 1977; Bundy, 1988). As Lipton (1977) observed, this effectively created 'two agricultures'; one characterised by a large group (by number) of mostly black 'smallholder farmers' primarily located in homeland areas; the other by a relatively small group (by number) of 'commercial farmers.' The reality was often subtler and more complex than this. For example, I was able to quantify production for three groups of farmers, wherein the smallholder group was split into two sub-groupings; one group operating within the homeland areas and the other who farmed on land outside the homeland areas, with the former restricted to just 14 per cent of the available farmland by the 1913 and the 1936 Land Acts. These Acts also included provisions to restrict labour and rent tenancy, but these restrictions were never strongly enforced.

Smallholder farmers skirted these legislative restrictions in numerous ways. 'Labour Tenants' for example, gained access to land owned by white farmers and the mines, in exchange for providing a negotiated amount of contract farm labour per household per year to the white land owners (see, for example, Marcus, 1989). Another strategy for land access off the homeland areas involved a 'sharecropping' arrangement, whereby black farmers opted to share the proceeds of their efforts (typically 50 per cent of production) as payment for access to white-owned land (see, for example, Van Onselen, 1996).

Another strategy involved 'squatting', whereby black farmers accessed land from speculative landholding companies, absentee landholders, and commercial farmers, by paying cash rents for the use rights to agricultural land (see, for example, Bundy, 1972; Morris, 1976;

Trapido, 1978). Numerous speculative landholding companies were established after the mineral discoveries in 1866, and it is reported that they preferred to lease their land to smallholder 'squatters' since they were deemed more dependable rent payers than white farmers (probably due to the lack of alternative opportunities afforded black farmers at that time). The amount of land accessed in this way was substantial. For example, at the turn of the 20th century, a single landholding company owned more than 1,300 farms in the Transvaal, of which a single 'tribe' rented more than 22 farms, while a Natal farmer is said to have housed more than 800 squatters on his 50,000 morgen (42,827 hectare) farm (Bundy, 1972).

In addition, black farmers accessed land by purchasing it through a missionary who acted as an intermediary, given that they were legally prohibited from purchasing land directly (Trapido, 1978). This created the so-called 'black spots' or 'Mission reserves' since they were regarded as 'practically' homelands outside of the legally demarcated homelands. These areas were extensive; in 1916 they encompassed more than 58,000 hectares, with the average mission farm ranging from 2 to 5 000 hectares (Beaumont Commission, 1916). The Tomlinson Commission (1955) estimated that a total of just under 161,000 hectares was held in this way in 1955. Ultimately the clearing of these 'black spots' by the apartheid government between 1960 and 1983 resulted in the forced relocation of an estimated 3.5 million people (Platzky & Walker, 1985). This is also reflected in the smallholder data. Figure 2.2 distinguishes between the amount of production (Panel a) and planted area (Panel b) accounted for by smallholders operating on homeland and non-homeland areas respectively. Figure 2.2 Panel c reports average yields for smallholders operating in homeland areas (1918–2015) and those operating in non-homeland areas (1935–1971). Smallholder production showed a steady increase from 265,600 tons in 1918 to 600,000 tons in 1961. The area planted by smallholder producers peaked at 2.36 million hectares in 1944. This increase was partly enabled by provisions in the 1936 Land Act that laid down the legal framework for increasing the size of the former homeland areas by 6 per cent. Consequently, the state added an additional 3.9 million hectares to these homeland areas between 1936 and 1952 (Tomlinson Commission, 1955: 85). Thereafter, the total (homeland and non-homeland) area devoted to smallholder farming began to decline, falling to 1.45 million hectares by 1965 and down to 366,000 hectares in 1970.

During the first half of the 20th century, the share of total smallholder production coming from smallholders operating in non-homeland areas was substantial; increasing from 38.6 per cent in 1935 to a peak of 53.1 per cent in 1956 (while at the same time increasing their share of total smallholder maize area from 25.5 to 32.4 per cent). During this period, smallholders operating in non-homeland areas doubled their maize yields from 0.3 tons per hectare in 1935 to 0.6 tons per hectare in 1956. By comparison, maize yields for commercial farmers averaged 0.6 in 1935, increasing to 0.9 tons per hectare in 1956. Both commercial and non-homeland smallholder yields substantially exceeded the yields reported for smallholders operating in homeland areas, even though the latter group of producers also managed to double their yields in this period from an estimated 0.1 tons per hectare in 1935 to 0.2 tons per hectare in 1956.

The post–1950s decline in non-homeland smallholder production and the complete disappearance of production from these farmers after 1971 (see Figure 2.2, Panels a and b) appears not to be a data anomaly. During the 1960s the state endeavoured to reduce the number of 'surplus people' within rural areas by restricting the operations of non-homeland smallholders. As a consequence, these former farmers were left with few options but to become hired labourers on commercial farms or work in the mines, thus reducing the competition they posed to commercial farmers for land and markets (Marcus, 1989). To this end, the 1964 revision of the 1936 Native Trust and Land Act included a provision through which magisterial districts could declare labour tenancy and squatting to be illegal within their district. For some years this provision had been taken up by only a handful of Transvaal districts, but by 1967 labour tenancy and squatting practices were banned in 36 districts nationally, including 17 in Transvaal and 19 in Natal. The number of districts enforcing such a ban continued to grow, such that by 1973 labour tenancy had been completely outlawed within all provinces except Natal, where limited duration contracts were still issued, the last of which was deemed to have expired by 1980 (Marcus, 1989: 81).

Maize production sourced from smallholders operating in homeland areas also declined during the 1960s to a low of 138,500 tons in 1968, but grew steadily thereafter with a spike of production of 1.19 million tons in 1994 given exceptionally favourable weather that year for maize production throughout the country. As noted above, during the 1960s the area planted by smallholders sharply declined from the 1.16 million hectares in 1965 to a mere 365,700 hectares in 1970, whereafter the smallholder maize area more-or-less settled, fluctuating around an average of 508,100 hectares from 1971 to 2015 (the last year of available data). Taken at face value, the yield data plotted in Figure 2, Panel c indicate that smallholder maize yields for farmers operating in homeland areas underwent a structural shift in the late 1960s/early 1970s, growing markedly (albeit erratically) from 0.2 tons per hectare in 1965 to a peak of 2.2 tons per hectare in 1994 after a long period of low and only gradually increasing yields during the preceding three decades.[6]

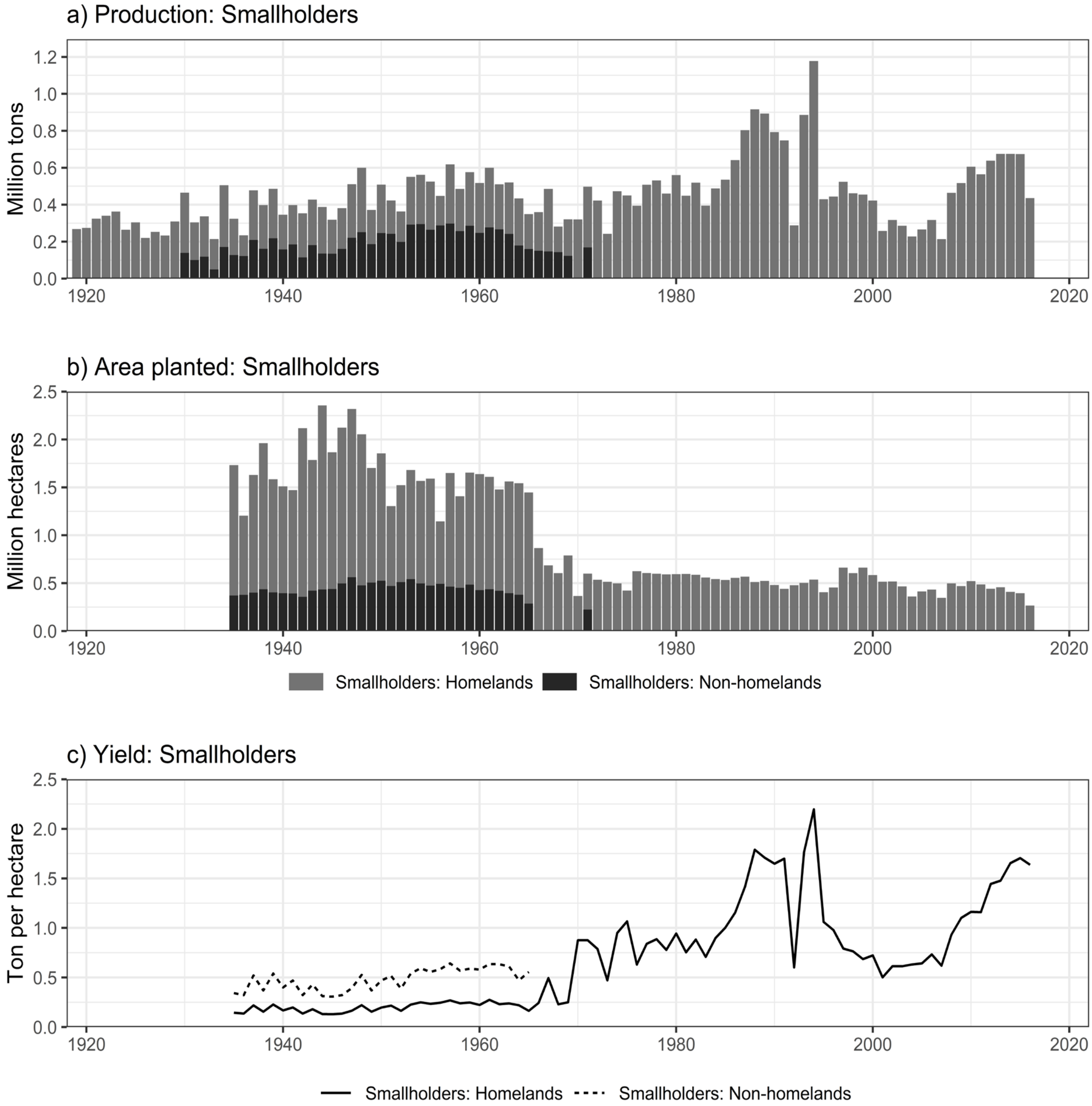

Figure 2.2: Smallholder production, area planted and yield

Source: Authors estimates based on data summarized in Appendices A and B.
Notes: No data on smallholder area planted were reported before 1935.

[6] The exceptionally low yield of just 0.8 tons per hectare in 1992 was due to one of the most devastating droughts in recent history. For example, Bothaville, one of the country's main maize producing districts, received only 65 per cent of its long-term (1879-2000) growing season (Oct-Apr) average rainfall during that year (Authors calculations drawing on data obtained from Lynch, 2004).

2.4.2 Smallholder versus commercial maize production relativities

Figure 2.3 provides details of total smallholder maize production (from both homeland and non-homeland areas) relative to production by commercial farm operators. Panels a and b express smallholder production and planted area, respectively, as a percentage share of total (i.e., smallholder plus commercial) maize activity. Panel c plots smallholder yields relative to commercial yields, differentiating between smallholder yields averaged across farms operating in homeland areas versus those operating outside the homelands. All the data reported in Figure 2.3, Panels a and b are taken directly from primary sources (see Appendices C and D). These sources report production and planted area data from which I imputed the yield data plotted in Figure 2.3, Panel c. The plots in Panels b and c reveal some segments with thicker lines, which indicate persistent (and, to me at least, questionably invariant) planted area and yield relativities. Even though the data sources report smallholder planted area and yield estimates for all the years for which I plot data, it seems that for some years the *smallholder* area estimates are imputed relative to observed commercial production and assumed yield relativities. Bearing these aspects in mind, I proceed with an assessment of this new compilation of smallholder maize data, being careful not to over-interpret the evidence.

My estimates suggest that smallholder producers accounted for a substantial share (roughly one-fifth) of total South African maize production in the early 1920s (Figure 2.3, Panel a). Smallholder production shares declined steadily thereafter, from an estimated high of 23.4 per cent in 1924 to just 4.8 per cent in 1974, with the lion's share of the decline taking place after 1945. The data suggest there was a small, albeit transitory, resurgence in smallholder production shares during the 1980s and early 1990s. Panels b and c suggest this resurgence was a *relative* yield not a *relative* area effect, such that the yields of smallholders grew faster than the corresponding yields of commercial operators, while the smallholder share of planted area stayed proximally constant relative to the commercial (and overall) area under maize. However, the apparently interpolated nature of some of the area data during these decades means this measured resurgence should be taken with a pinch of salt. Nonetheless, the overarching trend revealed by these data may be indicative of the real trend, and indicate that the share of smallholder production in recent decades has plateaued at a relatively low level by historical standards, averaging just 4.0 per cent of total production since 2000 (through to 2015).

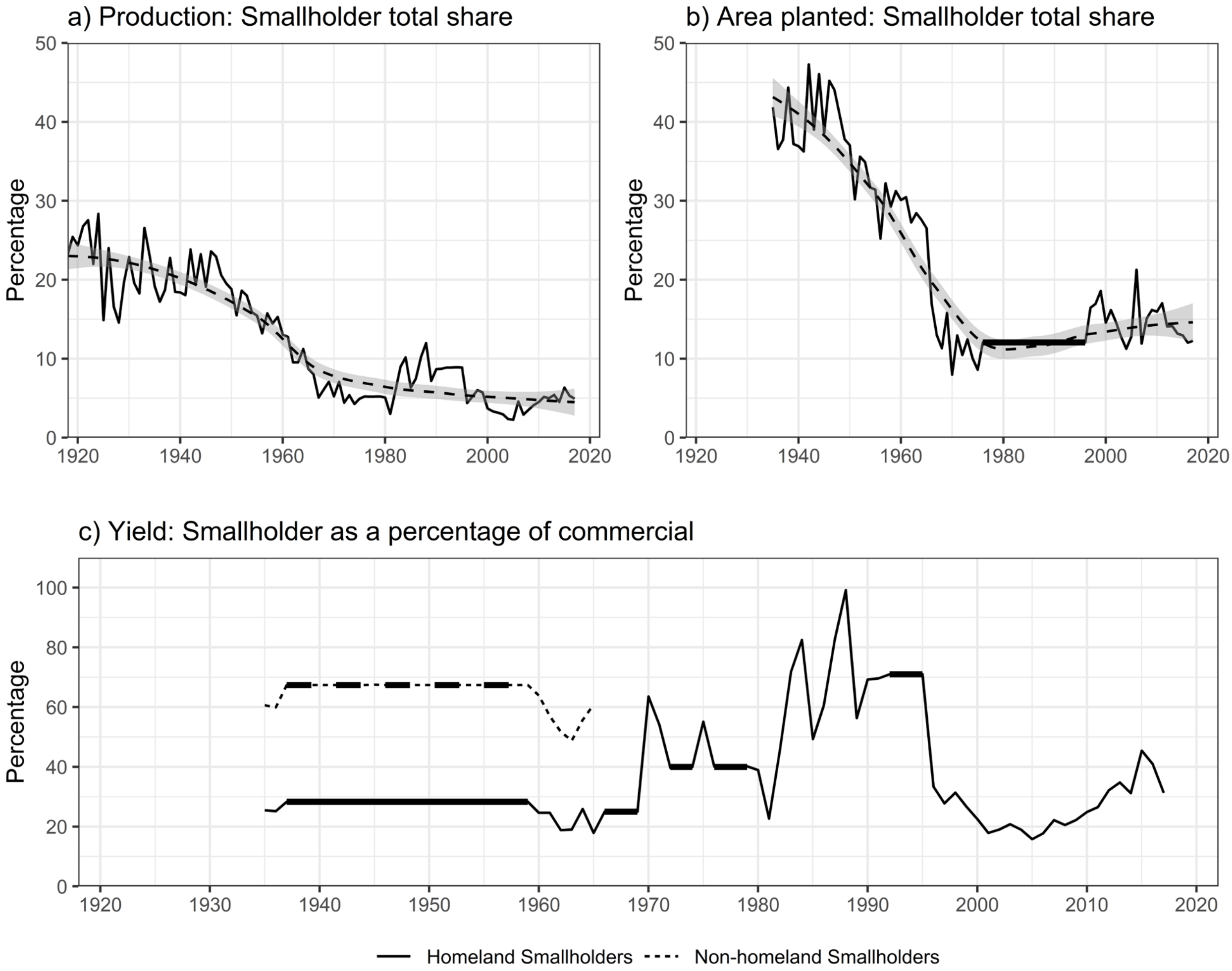

Figure 2.3: Relative smallholder production, area planted and yield

Source: *Authors estimates based on data summarized in Appendices A and B.*
Notes: *See Figure 2.1. The dotted line in Panels a and b shows a fitted loess regression, with the grey area around the fitted function indicating the 95 per cent confidence interval. The thickened parts of the plotted data in Panels b and c indicate invariant shares reported in the source statistics.*

The relative decline in the smallholder share of total South African maize production, most notably during the 1945–1980 period, appears principally due to a contraction in the relative area planted to smallholder versus commercial maize.[7]

Figure 2.2, Panel b shows smallholder maize area increasing from 1935 to 1944 by an average of 3.2 per cent per year, much faster than the corresponding area planted to commercial maize (which grew by an average of just 1.5 per cent per year).[8] This was partially the result of the 1936 Land Act that enabled the homelands to expand their area by 25 per cent by 1952

[7] Not only did the maize area planted by smallholders contract, but Wilson (1971), Wolpe, (1972) and Simkins (1981) observed that the quality of this land (in terms of nutrient and organic matter content, among other attributes) also deteriorated given a lack of nutrient inputs and limited adoption of improved soil management practices.
[8] Annualized growth rates calculated from five-year-centred moving averages.

(Tomlinson Commission, 1955: 84). Smallholder maize area declined thereafter by an average of 4.8 per cent per year from 1945 to 1970. In contrast, commercial maize area continued expanding until 1968, and although it then trended downward, its overall 1945-1970 growth rate averaged 1.7 per cent per year. This was higher than the corresponding smallholder rate, and so the balance of maize area shifted in favour of commercial farms during these decades, even though both commercial and smallholder maize area was contracting during this period. After 1970, the smallholder area share stabilized, and even showed some signs of a small trend increase beginning in 1970 when taking the area relativities in Figure 2.3, Panel c at face value.

The smallholder-to-commercial yield relativities plotted in Figure 2.3, Panel c are revealing, even after setting aside the reported primary data that appear to be concocted by various (and changing) rules of thumb (see the questionably invariant thicker portions of the plotted yield relativities). Prior to 1960, the maize yields of smallholders operating in homeland areas averaged just 28 per cent of the corresponding yields of commercial farmers. Notably, during this same period the yields of smallholder producers operating on land outside the homelands were much higher, averaging 67 per cent of the corresponding commercial yields. If true, this begs the question, why this marked difference in yield relativities? Did smallholders operating in non-homeland areas tend to be more educated, more skilful and more entrepreneurial than their homeland counterparts? Did they have access to better land, better roads and storage infrastructure, better credit and better technologies and knowhow? For instance, perhaps non-homeland farmers, during the period they were able to retain access to land, benefited from being in close physical proximity to an economically dynamic commercial farmers.[9] Or were there other factors in play, including measurement issues? For example, it may have been easier for statistical agencies to obtain a more complete assessment of the quantity of production (and planted area) of those operating in non-homeland areas versus those operating in homeland areas with less formal marketable surpluses and relatively more subsistence production which, by its consumed-where-grown nature, is intrinsically more difficult to measure. For example, the Tomlinson Commission (1955: 84) noted the possibility of measurement error in their production estimates since smallholders typically consumed some of their crop as green maize (corn on the cob), and it is uncertain if green maize production was included in the reported estimates.

[9] Notably, not all commercial (white) farmers were “progressive” with respect to the adoption of the new technologies and farming practises (see, for example, Schirmer, 2005); however at least elsewhere in the world there is clear evidence of a proximity effect when it comes to the speed of adoption of improved production practices (e.g., Lindner, Pardey & Jarrett, 1982).

The trend in the reported yield relativities over the past several decades, if true, opens up another, important, and policy-relevant, line of inquiry for later work. The decline in relative smallholder yields during the period 1995–2005 reflect growing commercial yields versus declining smallholder yields over this period (an annual increase of 2.7 versus a decline of 6.7 per cent, respectively, derived from Appendix A and B). The growth in commercial yields during this period coincided with the dismantling of the agricultural marketing schemes and the liberalization of international trade. Vink et al. (2018) argue that at least some of the substantial rate of growth in (national) average commercial yields during this time may well have been the result of a reduction of maize planted in more marginal production areas, which was then planted to pastures or alternative crops such as sunflower and soybeans. Notably, my new data compilation (Figure 2.5, Panel b) shows a substantial contraction of maize area in the relatively drier, and relatively lower yielding, Northwest province.

2.4.3 White and yellow maize

Not only is South African maize production bifurcated between commercial and smallholder producers, it is also divided into white and yellow maize production, each with its own distinctive supply and demand dynamics. White maize is predominantly used for human consumption (74 per cent in 2015), while yellow maize is largely used for animal feed (88 per cent), particularly poultry and beef (Grain SA, 2018a). Notwithstanding the distinctive end use and other economic and food security implications of white versus yellow maize, production data that distinguishes between these two types of maize are only available for commercial farmers.

The annual data used in this sub-national (provincial) compilation are compatible with the corresponding national data, all of which are sourced from Breitenbach & Fényes (2000) for the period 1986–1988, and SAGIS (2017) for the period 1989 to 2015. Data that distinguish between white and yellow maize production for the South African commercial sector prior to 1986 are especially limited. Nonetheless, I was able to compile such data for three census years—namely 1960, 1971 and 1976 — from the *Agricultural Census* reports. I standardized the spatial representation of the entire 1960 to 2015 series using the present (nine) provincial boundaries that came into force in 1994.[10]

In 1960 commercial maize farmers planted 56.9 per cent of their total maize area to white maize (Figure 2.4, Panel a). With white maize yields at this time around 20 per cent higher than

[10] See Greyling, Senay & Pardey, (2018) and Senay et al. (2018) for details on the methods we developed and deployed to spatially standardize these production data. Note, prior to 1994 there were only four provinces in South Africa.

the corresponding national average yellow maize yields (Figure 2.4, Panel c), this meant that 60.7 per cent of commercial maize production was white maize. Indeed, for all of the post–1960 period plotted in Figure 2.4, Panel a, the commercial area planted to white maize exceeded the area planted to yellow maize, However, the data suggest that the (relative) area planted to white versus yellow maize areas went through two distinct phases. During the period 1960 to 2005 the commercial area planted to both yellow and white maize declined. However, the yellow maize area contracted at a faster rate than the white maize area, such that the relative area planted to yellow maize declined. During the decade after 2005 for which I have data, the area planted to white maize stabilized (albeit with significant year-on-year variation around the decade average area) while the area planted to yellow maize increased slowly, especially after 2011. Thus, in more recent decades, the balance of commercial maize area has shifted in favour of yellow maize. For example, in 2003 a contemporary peak of 70.1 per cent of the commercial maize was planted to white maize, which dropped steadily to just 54.6 per cent in 2015 (Figure 2.4, Panel a).

The move towards yellow maize production (Figure 2.4, Panel b) has been even more pronounced than the move towards yellow maize area. This is because yellow maize yields have been rising faster than white maize, part of a long-run trend since at least the 1960s, such that by 2015 the three-year centred average yellow maize yield was 4.9 tons per hectare, 1.0 ton (20 per cent) more than the corresponding white maize yield, which averaged 3.9 tons per hectare.

Several structural economic and technological factors are likely at play here. On the demand side, the shift in favour of yellow versus white maize reflects part of a broader change in dietary preferences. Whereas direct human consumption of white maize is still a significant source of calories in South Africa (FAO, 2018), in more recent years calories from white maize have given way to a preference for bread, rice and potatoes as per capita incomes have grown and urbanization has increased. In addition, the increase in meat consumption, and especially poultry consumption (Ronquest-Ross, Vink & Sigge, 2015; BFAP, 2017), has in turn increased the demand for livestock feed, and especially yellow maize as a major ingredient in livestock feed rations.[11]

[11] For example, (DAS, 2017) reports that the 76 per cent increase in South African per capita poultry consumption from 2003 to 2015 has spurred a growth in the demand for yellow maize, which constitutes between 40 and 60 per cent of poultry rations.

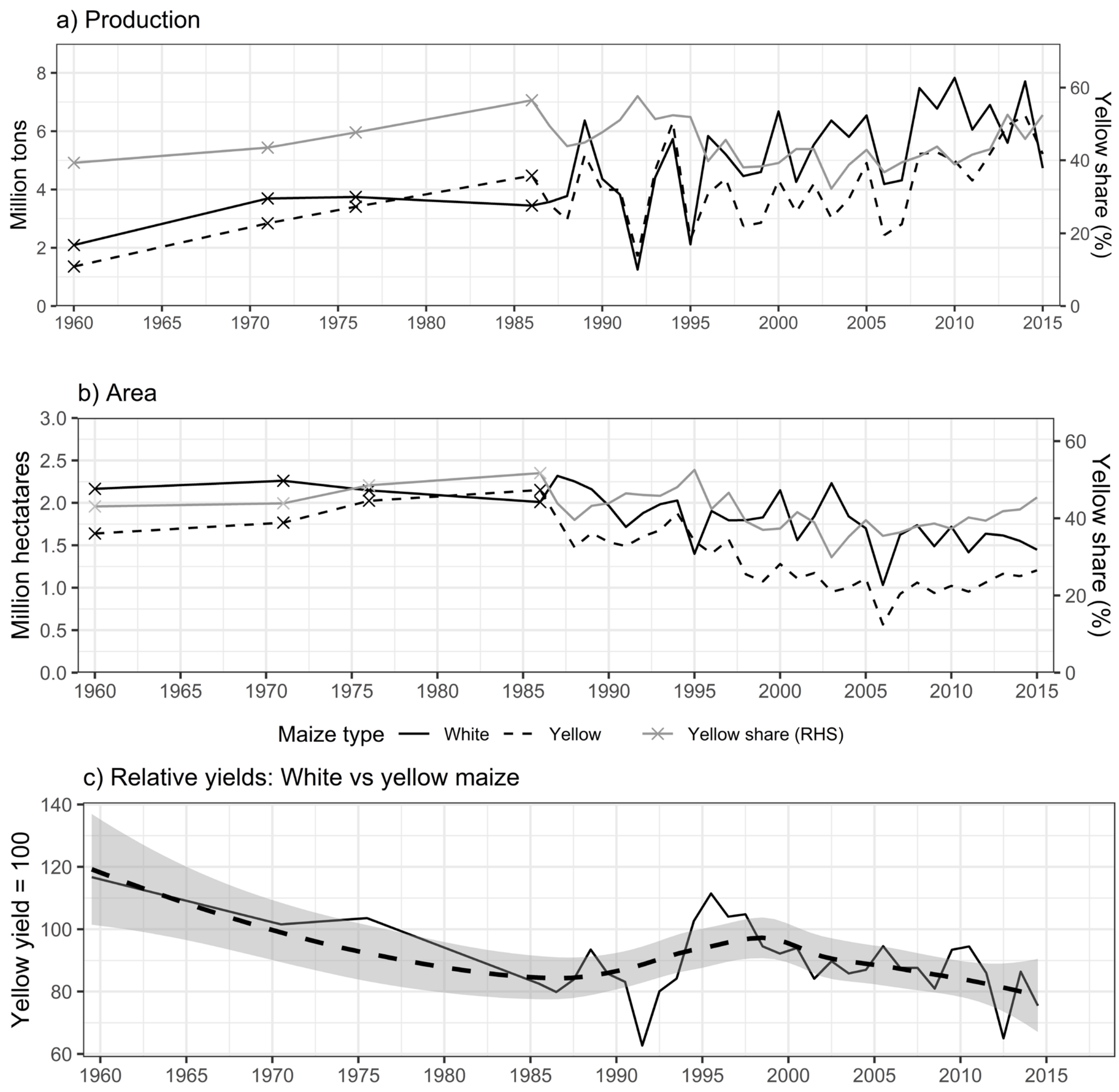

Figure 2.4: Yellow and white maize production from commercial farms

Source: 1960, 1971 and 1976 from Agricultural Census; 1986–1990 from Breitenbach & Fényes, (2000); and 1991–2015 from SAGIS (2017)

Notes: The dotted line in Panel c shows a fitted loess regression with the grey area around the fitted function indicating the 95 per cent confidence interval. The plotted lines joining the census data points delineated by an 'X' in Panels a and b in the earlier part of the data series represent a linear interpolation by the authors.

A shift of demand in favour of yellow versus white maize is concordant with two supply-side responses. One is the recent rebound in the area planted to yellow maize (Figure 2.4 Panel b). The other is the faster rate of gain in the yields of yellow versus white maize, especially in the post–2000 period. In 1960 white maize yields averaged 116.7 per cent of the corresponding yellow maize yields, whereas by 2015 white maize yielded just 75.5 per cent of the corresponding yellow maize average.

Figure 2.4, Panel c shows that yields of both types of maize have been rising; however yellow maize yields have been increasing at a faster rate (4.0 per cent per year) than white maize yields (3.0 per cent per year) for much of the past half century (specifically 1960–2015).

There are a complex set of factors that affect these yield relativities, including where in South Africa these two types of maize tend to be grown and the technological (including genetic) and management practices used to grow each crop. Differences between white and yellow maize in terms of the availability of new maize varieties is one stark point of technological distinction between the two crops. Hassan, Mekuria & Mwangi (2001) reported that in 1998, South African maize farmers had access to 44 improved yellow varieties compared with only 24 new varieties of white maize. In part this is because 96 per cent of the hybrid seed varieties used by South African farmers in 1992, for example, was developed by U.S. based companies where yellow maize dominates (South African Maize Board, 1993).[12] Figure 2.5 provides a sub-national perspective on the location of white versus yellow maize production throughout the country. The figure includes three major maize producing provinces—specifically the Free State (FS), North West (NW) and Mpumalanga (MP)—that in 2015 collectively accounted for 83 per cent of all the maize produced in South Africa, and 87 per cent of the total area planted.

Since 1960, white maize production has tended to be greater than yellow maize production in the Free State and the Northwest, but the reverse has been true for Mpumalanga (Figure 2.5, Panel a). The area planted to both yellow and white maize has declined in the Free State and the Northwest, especially since the mid–1980s, while the area planted to both types of maize in Mpumalanga is now similar (for white maize) and greater (for yellow maize) than it was 50 years ago. All three regions have shown solid, but erratic, growth in crop yields, but again Mpumalanga is the exception, with its yields for both types of maize growing faster than in the other two provinces. Combining these relative area and yield trends, Mpumalanga's share of both white and yellow maize production in South Africa grew considerably over the past half century.

[12] Although the U.S. is the world's biggest maize (corn) producer, white maize production in that country is negligible. FAO (2017) reports that the U.S. produces around 400 million tons per year, only three per cent of which is typically used for direct human consumption. Hansen (2012) noted that white maize represents just one per cent (around 120,000 tons) of the 400 million ton U.S. total.

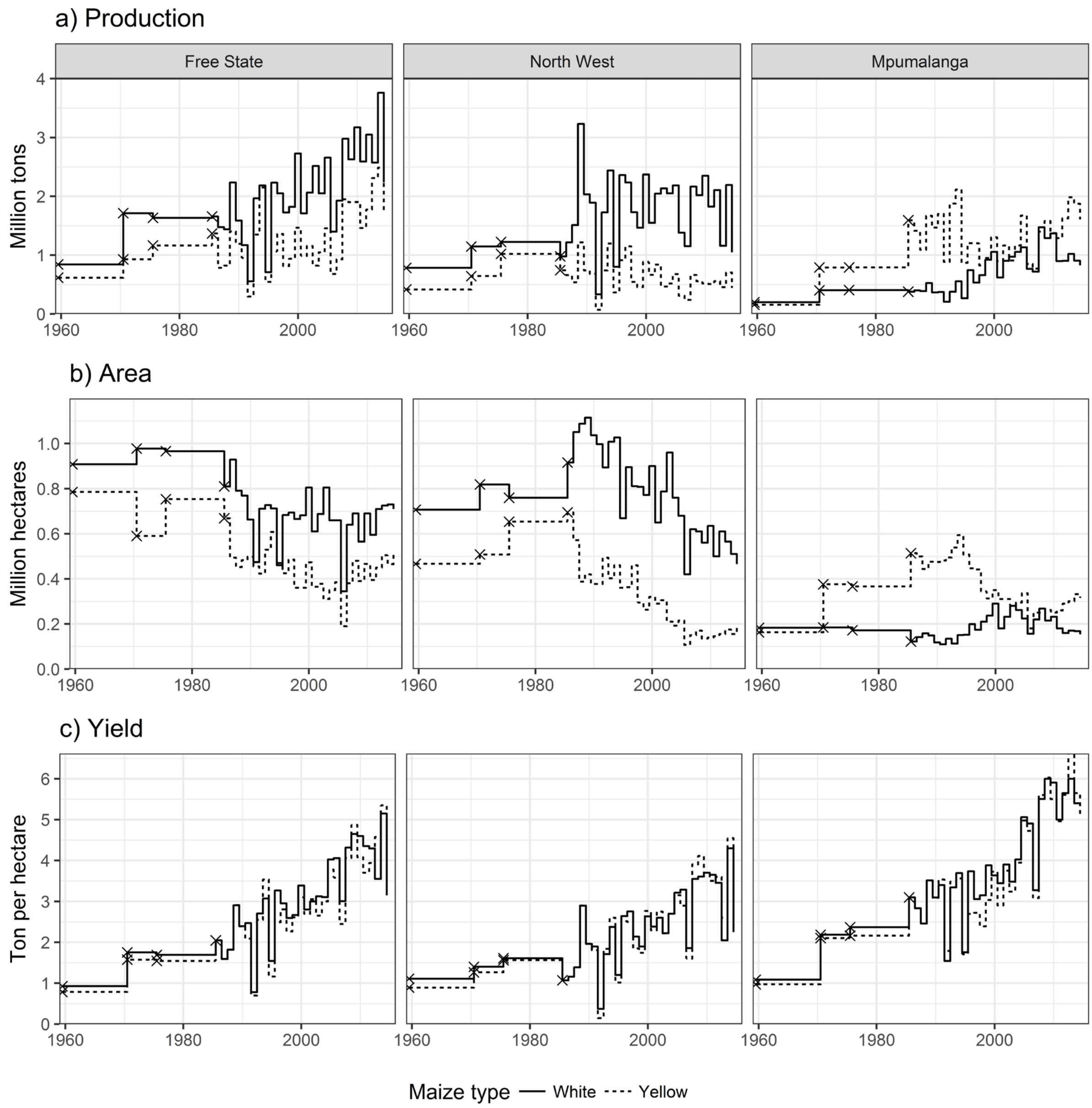

Figure 2.5: Provincial shares of commercial maize production, by type

Source: 1960, 1971 and 1976 from Agricultural Census; 1986–1990 from Breitenbach & Fényes (2000); and 1991–2015 from SAGIS (2017). The plotted lines joining the census data points delineated by an 'X' in Panels a and b in the earlier part of the data series represent a linear interpolation by the authors.

The province now accounts for about one-third of the country's entire yellow maize production and around one-fifth of the white maize output. In contrast, the Northwest province lost ground, and now accounts for a significantly smaller share of South Africa's production of both crops. Among these three provinces, the Free State is still the dominant maize producer, accounting for almost half the country's white maize production and one-third of its yellow maize output in 2015. Maize production in the Northern Cape province also warrants attention. In 2015 this province accounted for only 3.8 per cent of South Africa's total yellow maize area but produced 12.3 per cent of the national yellow maize crop. The 2007 Agricultural Census reports that 83 of the province's maize production was grown under irrigation (Stats SA, 2010). Consequently, in 2015, farmers in the Northern Cape averaged yields of 13.6 tons per hectare, 4.2 times larger than the average yield for farmers in the Free State.

2.5 Conclusion

Over the past century, South African maize production underwent some remarkable changes. As the 20th century dawned, in 1904, South Africa produced 328,000 tons of maize. By 1935 that had grown to 1.68 million tons, increasing to a three-year average of 11.26 million tons centred on 2015.[13] This 6.1-fold increase in maize production from 1935 to 2015 was achieved with an overall 35.7 per cent decline in maize area (from 4.14 million hectares in 1935, peaking at 5.59 million hectares in 1964, then falling to a three-year average of 2.9 million hectares centred on 2015). What made this possible was an 8.6-fold increase in average maize yields from 1935 (0.5 tons per hectare) to the 2015 three-year centred average of 4.2 tons per hectare.

The new historical compilation of maize data I developed and described here, enable me to dig behind these aggregate trends to reveal some equally dramatic developments in terms of what types of maize are being produced, by whom, and precisely where in the country the production took place. The data suggest that smallholder producers (both those operating within the former homeland areas and those operating elsewhere in the country) were once a substantial source of maize production. In 1942, smallholders accounted for 20.6 per cent of the total (i.e., smallholder plus commercial) maize production and 40.6 per cent of maize area. Now, in 2015, production from smallholders is a much smaller share of the respective totals (13.0 per cent of area and 6.3 per cent of output).

With the preponderance of production coming from commercial operations, I was able to decompose that production into its white and yellow maize components. I show that over the past half century for which data were available, the production of white maize has been steadily losing ground to yellow maize. This was due to both an area effect and a yield effect, wherein the area planted to commercial white maize production fell as a share of total maize (from 60.7 per cent in 1960 to 47.6 per cent in 2015), and the relative yield of white to yellow maize also fell substantially (from 116.7 per cent in 1960 to 75.5 per cent in 2015). These compositional

[13] 2015 is an atypical year to use as a terminal production value for this long-run series. There were exceptionally adverse weather conditions that year, which particularly affected production in the western part of the country where drought conditions were severe and widespread. Hence, we opted to report a three-year average, deeming it to be more representative of the terminal production value in this series.

developments represent a complex combination of changing consumption preferences and technological and locational production practices. I broach some of those elements, but there is surely much more that can be done to understand the drivers of these trends, and hopefully these new data will spur such studies.

Maize will no doubt continue to be a dominant food and feed crop in South Africa for some time to come. However, significant shares of the crop are now grown in areas that are subject to new, and spatially-sensitive, production pressures. In Mpumalanga the land used for maize production is competing against alternative uses of that same land—specifically, economic and policy pressures to use the land for open-cut coal mining (BFAP, 2012) . A major share of the national maize crop is grown in the drier Northwest province, a region which has the highest climate vulnerability in Southern Africa according to the IPCC (2014). [14] In addition a sizable share of the national maize crop is now grown in the Northern Cape, which is heavily reliant on irrigation (Stats SA, 2010). As pressures to use that water for other purposes mount, this significant source of production is also increasingly at risk. Continuing to expand, deepen and further nuance my measures of South African maize production in the decades ahead will be a necessary, but far from sufficient component of improving the myriad and consequential policy and production choices that lie ahead.

[14] One of the IPCC (2014) predictions has the average precipitation during the growing season (December – February) decreasing by up to 18 per cent (80mm) along with an increase of 3.1°C increase in the average temperature.

Chapter 3:
Maize and Gold: Transitioning from suppression to support (1886–1948)

3.1 Introduction

This chapter traces the progression from 'suppression to support' of South African agriculture during the early twentieth century (1886 to 1948), revisiting the early part of the development of the South African agricultural sector from the perspective of the structural transformation framework. To this end the nature of the alliance between 'gold' and 'maize' (as coined by Trapido, 1971), and its subsequent disintegration (as documented by Morrell, 1988) is re-examined. The focus is on the evolution of political tensions stemming from the converging and diverging interests of groupings within the mining and agricultural sectors, specifically how this facilitated the transition from 'squeezing' a large but marginalised group of smaller white farmers as well as black farmers in general, to the reluctant 'squeezing' of the mining industry by the state and the eventual complete marginalisation of black farmers.

The chapter contributes to the recent extension of the structural transformation literature that stresses the importance of taking underlying country fundamentals into account with development policy formation. The South African case illustrates the complexity of the political tensions created during the transformation process and their long-term impact, since these played a significant role in putting the country on the path to grand apartheid. In addition, a newly compiled long-term dataset on agricultural prices, output and public spending is provided, to add a quantitative perspective to the ability of either party to capture the state and a more precise estimate of the timing of the disintegration of the alliance. Two previously underemphasised aspects of stakeholder interactions at the time are also explored, namely the nature and policy impact of the interaction between white and black farmers and the mines within the context of shared and conflicting interests, and the changes in the nature and extent of support to white farmers during this period.

In what follows, section two provides an overview of the structural transformation literature, while section three expands on the historical background and state capture. The fourth section describes the measures put in place by white farmers to stem the competition from black farmers. This is followed by a closely related discussion on the land and labour market interventions by the state. In sections six and seven the transition to the controlled marketing of maize and other agricultural produce, and increased direct subsidies to the commercial farming sector are discussed, followed by a brief discussion of the post–1948 consolidation of support and its eventual decline towards the 1990s. The ninth and last section provides a summary and conclusion.

3.2 The structural transformation

The structural transformation of economies during development has shown itself to be a 'remarkably uniform' process through the work of Clark (1940), Lewis (1954), Kuznets (1966) and Chenery & Syrquin (1975). This transformation is paramount since it is regarded as a defining characteristic of economic growth, both as cause and as effect (Syrquin, 2006).

The trajectory of the transformation that industrialised economies transition through can be summarised as follow (Timmer 1988): Prior to the structural transformation the economy is dominated by farming, largely subsistence farming, since it constitutes the bulk of economic output and the labour force. During the initial stages of development, the productivity of the agricultural sector is required to increase sufficiently for the sector to be able generate surpluses. These surpluses enable the sector to meet the domestic demand for food, produce exportable surpluses, release labour to the rest of the economy, and serve as a source for capital and a market for manufactured inputs and consumables (Johnston & Mellor, 1961). At this point some countries could opt to 'squeeze' the agricultural sector through depressing commodity prices or increased taxation to raise greater surpluses from the sector, since these could earn a greater return if employed by non-farm industries with a greater productivity (Timmer 1988). Examples include the suppression of peasants in the USSR (see for example Allen 1996).

Collectively these enable faster productivity growth in the non-farm economy relative to the farm economy, thereby resulting in farm incomes that increasingly fall behind incomes earned in the rest of the economy. "This lag in real earnings from agriculture is the fundamental cause of the *deep political tensions generated* by the structural transformation" (Timmer 2009, p6, emphasis in original). Given sufficient political influence the sector can lobby for policy interventions directed at narrowing the earnings gap – mostly through import protection, price support measures and direct transfers to farmers (Lindert, 1991). Finally, the agricultural sector transitions to the last phase in the transformation process following the removal of price interventions and other support measures, and continued agricultural productivity growth. At this point the agricultural sector is fully integrated into the rest of the economy given indistinguishable productivity levels (Timmer, 1988). The income disparity between farm and non-farm labour also starts to converge and is eventually equalised (Barrett, Carter & Timmer, 2010).

While this constitutes the general trajectory of the transformation, the heterogeneity in the underlying fundamentals of individual countries results in different productivity expansion paths and development outcomes (Timmer 2007). This sentiment is also shared by the authors of a five-year World Bank study on the structural transformation of late developing African countries. They stress the importance of taking national characteristics such as '…country assets, market functionality, business climate, institutional arrangements, overall governance, and political stability…' into account when formulating policy since these determine the constraints faced by households who are struggling to escape poverty (Losch, Fréguin-Gresh & White, 2011: xxii). Ultimately these determine the timing and extent of the eventual convergence of the urban-rural productivity and income gaps, where successful countries such as China and South Korea achieve a classic transformation, while progress is stunted in others such as India or fails as with South Africa (Binswanger-Mkhize, 2014).

3.3 Historical background and capturing the state

Subsistence farming dominated South Africa's agricultural landscape for most of the 19th century, with the exception of the wool and wine exporting settler farmers of the Cape (Ross, 1986). After starting their migration to the interior with the *Great Trek* (migration) of 1838, the newly established settlers of the northern interior could not readily join their exporting Cape compatriots given a coastline straddled by mountains and the lack of navigable rivers.

The discovery of diamonds at Hopetown near Kimberley in 1866 and gold at the Witwatersrand in 1886 put this initial steady state in flux. While this development posed an economic and political threat to the predominantly farming community of the newly established Boer republics of the Free State and South African Republic (later Transvaal), the fortunes of some farmers were greatly improved through the substantial and growing market for agricultural produce in the interior.

By the 1890s a 'marriage of convenience' had developed between wealthy mine owners of the Witwatersrand and some of the larger farmers of the interior, especially those of the eastern Transvaal. Likened to the union of 'iron and rye' of Imperial Germany (Trapido, 1971), the marriage between maize and gold rested on two main pillars. One, because the gold mines took responsibility for housing and feeding mine workers, there was a mutual interest in a regular supply of, and dependable market for maize. Two, the two sectors had a shared interest in the creation and maintenance of a constant supply of cheap black labour (Trapido, 1971; Wolpe, 1972; Morrell, 1988).

The development and prosperity that came with the mines was followed closely by the struggle for the control of the Boer Republics. Conflict manifested itself in the Jameson Raid (1896) that the Republics managed to subdue, ultimately culminating in the Second Anglo Boer War (1899–1902) from which Great Britain emerged as victor (Davenport & Saunders, 2000).

The 'scorched earth' strategy employed by Britain towards the end of the war wiped out the livestock that were the main source of traction and transport for farmers, and brought agriculture in the two Boer republics to its knees. After the war, Lord Alfred Milner as Governor of the Orange River and Transvaal colonies was tasked with the reconstruction efforts of the agricultural sector. This took the form of the provision of credit for buying land and equipment, as well as loans to import expensive cattle, but these efforts were directed at the larger farmers who were deemed to have a greater ability to repay loans and the potential to provide the gold mines with produce (Morrell, 1988).

With smaller farmers left unsupported, this gave rise to a class of so-called '*Boer notables*' who employed modern production techniques and made use of hired labour. At the time, a second group of prosperous Transvaal farmers established themselves as major actors in the industry. This emergent group of mostly English speaking 'progressive' farmers consisted of immigrants or former Rand businessmen whose social capital offered them greater access to financing, the mining market and land from landholding companies (Morrell, 1986).

While the larger farmers played a dominant role in supplying the mines, the balance was supplied by rivalling smaller white and black farmers. At the time land and labour served as the major production inputs, with a sufficient supply of labour the greatest hurdle faced by white farmers. Conversely, black farmers faced major challenges in accessing land[15].

In dealing with the convergent and conflicting interests, both the mining and broader agricultural interest groups lobbied the State to turn its machinery in their favour. During the early part of the twentieth century, most of the larger farmers in Transvaal supported Botha and

[15] The market competition between black and white farmers and the land challenges faced by black farmers have received relatively little attention within the context of the maize and gold debate, hence this will be expanded upon in Section 3.4.

Smuts' *Het Volk* party, which favoured the mining interests. *Het Volk* amalgamated with the Cape Colony's South African Party (SAP) after the formation of the Union in 1910 and became the party of the progressive Afrikaner farmers who supported the policy to restore relations between the historically estranged Boers and British. By 1911 the structural transformation of the economy had progressed beyond its agrarian roots to one where the agricultural sector represented 22 per cent of GDP and mining 27 per cent (Nattrass & Seekings, 2010: 4).

In reaction to the South African Party's pro-British and pro-mines stance, Hertzog established the National Party (NP) in 1914 to promote Republicanism and Afrikaner Nationalism, and secession from Britain for the two former Boer republics. The party was particularly popular amongst smaller white farmers who felt left behind by Smuts. The National Party's victory in 1924 through a coalition with the (White) Labour Party served as a turning point in the popular imagination as the era of a "…white workers government antagonistic to the interest of mining capital…" (Davenport & Saunders 2000:300). Morell (1988) argues that this victory added momentum to the disintegration of the maize and gold alliance already in motion.

Figure 3.1 provides a visual summary of the main stakeholders as well as the resource and influence flows. The main stakeholders, namely the white and black farmers, the mines and the state, are showed at the extremities. Maize is at the centre of this system, with both black and white farmers competing to supply the commodity. All three parties competed for both black labour and land, while only white farmers and the mines could lobby the state, as represented by the dotted lines. The nature of this lobbying warrants further exposition since at least four distinct groupings can be found in this process. These include the larger farmers and the mine owners, amongst whom the informal alliance emerged, the initially disenfranchised smaller farmers and the often-overlooked blue-collar white mine workers.

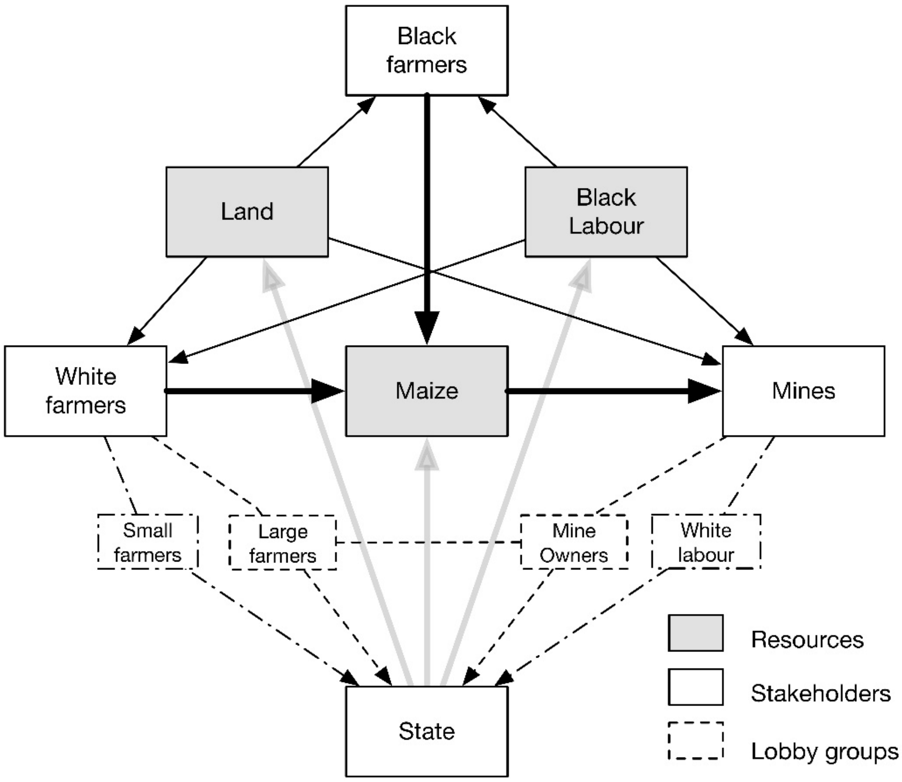

Figure 3.1: The stakeholders with their resource and influence flows

3.4 Stemming the competition from black farmers

The impact of the discovery of diamonds and gold was not limited to white farmers. In the rush to supply these new markets, African farmers proved themselves more than capable of producing substantial surpluses. For example, their output in Natal expanded two-and-a-half fold between 1867 and 1894, resulting in a nearly doubling of average per capita output (Lenta, 1983). Numerous examples of similar patterns can be found in other parts of South Africa (Wilson, 1971a; Bundy, 1972; Morris, 1976; Trapido, 1978; Beinart, 1982; Lacey, 1982; Keegan, 1986).

The success of these farmers created a problem for the white farmers. With simple technology and relatively abundant arable land, labour was the critical production factor. Capital-constrained settler farmers found it difficult to offer wages that were high enough to attract indigenous labour, resulting in labour shortages in many regions of the country. They tried to resolve this by persuading the colonial government to limit African competition through the creation of reserves, to bring about an artificial land shortage using measures such as livestock, hut and poll taxes; road rents; location, vagrancy and pass laws; and confinement to the reserves. In the process they invoked a Nieboer-Domar system of serfdom, given the context of an abundance of land and a shortage of labour (Nieboer, 1900; Domar, 1970).

In response to the pressure to reduce such competition, the state intervened in the land rental market and sought to reduce the number of rent-paying African tenant farmers, with the Glen Grey Act of 1894 the precursor of things to come (e.g. Thompson and Nicholls 1993). It attempted to levy a labour tax on all men living in the reserves, and banned the sale, rental or subdivision of land by introducing a perverted form of communal tenure. While Africans could not access land through official channels during this period, many bought land as individuals and in groups as land syndicates. No exact information is available regarding the amount of land bought, but there was some speculation that Africans would succeed in buying back all that they had lost during the colonial wars (Plaatje, 1987).

From the perspective of the maize and gold alliance, the parties faced the usual mix of shared and competing objectives. Both parties had an incentive to suppress black farmers since black self-subsistence posed a threat to the maintenance of the cheap labour system (Marcus, 1989). Conversely, the mines had an incentive to act in favour of black farmers for two reasons. One, the mines and other land speculation companies owned vast tracts of land and favoured leasing to black tenants who were deemed more dependable with rent payments. The amount of land accessed in this way is substantial given that landholding companies alone owned more than 1 300 farms in the Transvaal at the turn of the century with a single tribe renting more than 22 of these (Bundy, 1972). Secondly, the mines had a possible (probable?) incentive to support some black farmers since their competition weakened the bargaining position of white farmers, thereby lowering commodity prices.

White farmers were opposed to black farmers in principle given the competition they posed for accessing land, cheap labour and the disposal of produce. Conversely, capital constrained farmers at the turn of the twentieth century opted for various tenure arrangements that enabled black families to access land and produce crops since access to labour was the most constraining production factor.

3.5 Land and labour market interventions

The existing racial discrimination in access to land was consolidated by the Land Act of 1913, which made it explicit that 'natives' were only allowed to buy, rent or acquire by other means land from other 'natives', and white farmers from other whites, thereby creating parallel land markets and outlawing other forms of contract such as labour tenancy and sharecropping. This caused much disruption to the farm production of the black peasantry (Keegan, 1981;

Matsetela, 1981; Willan, 1984; Plaatje, 1987). The main intention of the law, which was ‘almost exclusively the basis of the country’s future policy of apartheid’ (Wilson 1971), was to transform tenants into wageworkers for the mines, thereby earning it the title of the “…law made for the mining houses…” (Davenport 1987). The law was also intended to “curb black farming practices at a time when white farming was beginning to pick up ... to check black sharecropping ... and to prevent the purchase of land by syndicates of blacks who ... were beginning to move ahead fast” (Davenport 1987).

The immediate effect of the law was to force those African families, who were formerly independent farmers on sharecropped land, to accept wage labour and give up their equipment. The longer-term effect was to end African farming above the subsistence level and to degrade the reserves to ‘dormitories’ (Hendricks, 1990) for a cheap African labour force. The results were catastrophic: by 1918 agricultural production in the reserves covered at most 45 per cent of subsistence requirements, declining to 20 per cent in the 1950s (Simkins, 1984), while increasing population pressure caused African households in the reserves to spend 60 per cent of their income on food by the 1920s.

Appointed under provisions of the Land Act, the Beaumont Commission reported that land scheduled for African occupation in terms of the Act was only sufficient for about half of the native population, and recommended that further land be released, specifying the areas which should be added. As indicated in Table 3.1, the reserves were limited to 7.8 per cent of the total land area before 1936. Outside the reserves, Africans owned only 0.7 per cent of the land and lived on state and European-owned lands (another 3.6 per cent); thus the total land technically available for their use was 12.1 per cent, excluding the mission reserves. This remained unchanged until the establishment of the Native Land Trust by the Native Trust and Land Act No. 18 of 1936. The Trust was meant to release a further 6.2 million hectares (later to be known as ‘released land’) and add it to the original Scheduled land to increase the size of the reserves to 13.7 per cent of the country.

Table 3.1: Land areas by land tenure systems, 1916

Tenure system	Area (hectares)	Percentage
Native reserves	9,538,300	7.8
Mission reserves	460,000	0.4
Native-owned lands	856,100	0.7
Crown lands occupied	805,100	0.6
EOL1: Occupied by Europeans	90,314,000	73.7
EOL1: Occupied by Africans	3,550,900	2.9
Vacant Crown land2, reserve3 and other	17,002,400	13.9
Total:	122,526,800	100.0

Note: 1: EOL: European-Owned Land; 2: Now called State Land: mountains, beaches, etc. where ownership is not allowed; 3: Nature reserves.

Source: Beaumont Commission, 1916, pp. 3 and 4; DBSA, 1990, pp. 34. Excludes Walvis Bay.

3.6 Towards controlled marketing

Having traced the initial ‘squeeze’ and eventual marginalisation of black farmers, I now turn to the remaining stakeholders, namely the State, white farmers and mine owners, and show the multiple complexities of structural transformation in South African agriculture’s progression ‘from suppression to support’.

South African maize farmers, both black and white, made rapid strides towards achieving domestic maize self-sufficiency after the Second Anglo Boer War. Production more than doubled from 360 to 860 000 tons between 1904 and 1911, and continued to trend upwards to reach a high of 2.9 million tons by 1948 (Panel a, Figure 3.2).

With neither the mines nor the greater Southern African market able to absorb the expanding harvest, farmers were forced to seek alternatives for their crop. For this they turned to the State, under whose supervision just over 42 000 tons were exported to the United Kingdom in 1907 and 1908 (Panel b, Figure 3.2). These exports were in part facilitated by the proclamation of ‘Government grades’ for maize that ensured the exportability of the 463 000 bags of 200 pounds each (Bosman & Osborn, 1924: 42). Maize exports took off in earnest during the First World War, given the substantial premium that South African farmers could earn on the world market, panel b Figure 3.3.

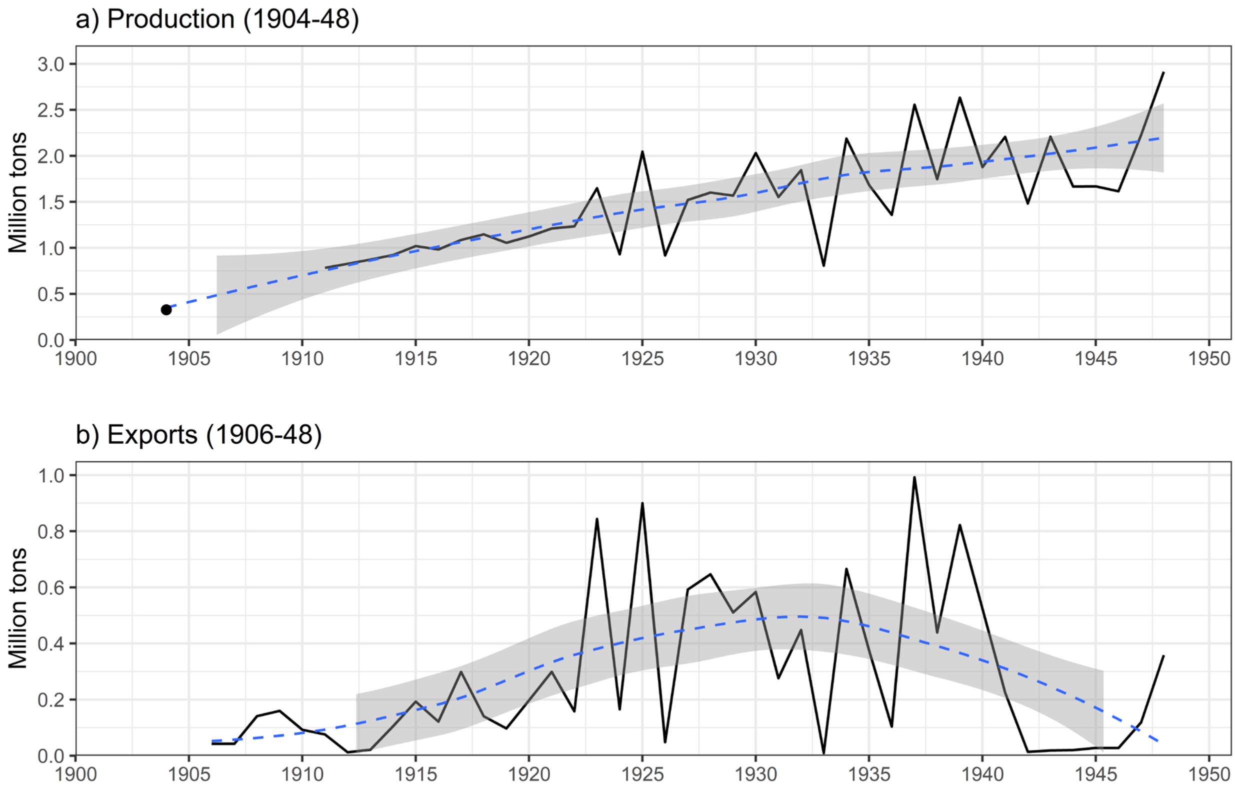

Figure 3.2: South African maize production, area planted and exports

Source: *See Greyling & Pardey, (2018b) (Chapter 2)*
Notes: *The dotted line shows a fitted loess regression with the grey area around the fitted function showing a 95 per cent confidence interval for each plot.*

The first cooperatives were established in 1908 and jointly formed the Central Agency (CA) for the marketing of their maize. The mines supported the establishment of the Central Agency since they hoped that it would facilitate effective marketing and promote efficiency in general, and the evidence suggests that they were indeed well served by the Central Agency (Morrell 1988). It was also hoped that such an agency would strengthen the bargaining position of cash-strapped small farmers who had to accept the price offered by their local merchant or traveling buyers (Brits, 1969). Cooperatives did not buy or sell the maize on their own account but merely acted as agents on behalf of their members. Farmers were paid an advance by the cooperatives upon delivery, and received the balance at the end of the marketing season once the relevant costs were deducted. This practice proved problematic since cooperatives often found themselves in a difficult financial position because of either paying out over-generous advances and/or inefficient management and administration. As a result, the cooperative movement struggled to gain traction among bigger farmers: by 1922 membership totalled some 6 300 farmers who sold but 10 per cent of the total crop (Brits, 1969).

The export expansion failed to support the South African maize price during the War, however, since it trailed the U.S. price by more than 42 per cent ($250 per ton) at its 1916 peak. South African farmers struggled to gain traction on the world market given their low yields and limited infrastructure: South African farmers averaged a yield of 0.7 ton per ha nationally in 1925, with their counterparts in Argentina and U.S. achieving more than double that at 1.6 and 1.5 respectively (Saunders, 1930). While the main rail lines from the ports to the interior had been completed by 1902, most of the branch lines critical for exports on a substantial scale were only added between 1905 and 1930. The expansion was substantial with 12 460 km of track added during this period, representing 64 per cent of all the lines built in South Africa up to that point (De Swardt, 1983). The construction of grain silos (elevators) along the railway lines in the main maize producing regions followed during the 1920s. Four elevators had been completed by 1925 in the eastern Transvaal towns of Bethal, Balfour, Kinross, and Middelburg (De Swardt, 1983; Morrell, 1988). Attempts were also made to stimulate exports through preferential rail rates to the ports and subsidised ocean freight rates. The state went so far as to task a Union Government representative in London with marketing all unsold maize handled through the Railway authorities (Brits, 1969).

South African maize prices trended continually downwards during the 1920s to reach a low of $160 per ton by 1932 following the onset of the Great Depression (see first panel of Figure 3.3). In fact, the South African price declined by 28 per cent and 50 per cent relative to 1931 and 1929 respectively, 68 per cent below the high of 1921. This hardship was amplified by the 1933 drought that reduced total production by 56 per cent or a million tons (1.73 vs 0.76) relative to the previous year.

Given their limited market power, South African farmers got the short end of the stick during the First World War by losing out on the resulting commodity price boom (Figure 3.3). However, South African farmers were somewhat sheltered against the decline pursuant on the Great Depression, but they also missed out on the post-depression boom.

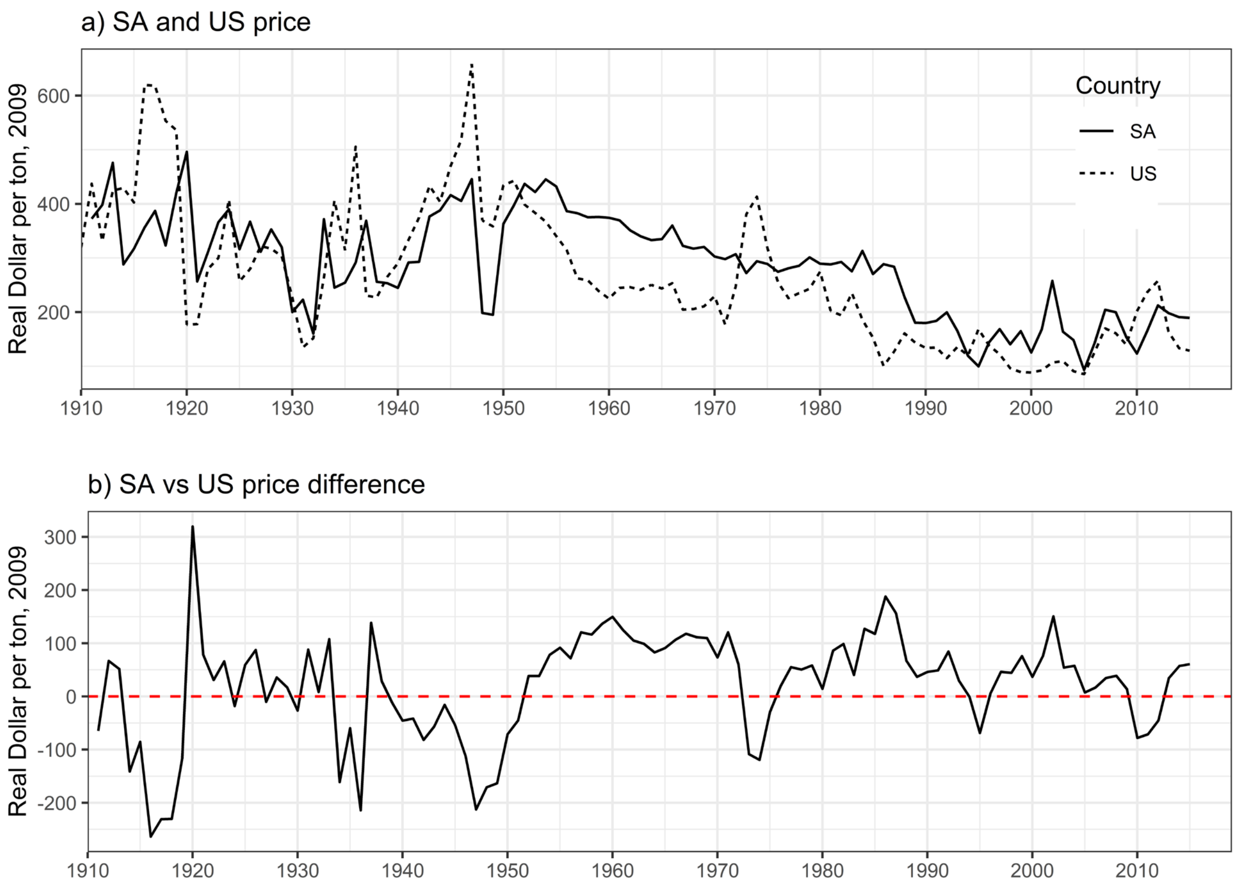

Figure 3.3: Real maize prices: South Africa vs United States

Source: South African Data: Abstract of Agricultural Statistics (1970, 2018) and SAGIS (2018); deflated by the South African Reserve Bank 2009 GDP deflator and exchange adjusted with average 2009 South African exchange rate as published by The World Bank Databank, 2016
U.S. Data: USDA, 2016 and deflated with the U.S. deflator as published by Barro, 2010

Having failed to benefit from the First World War price increases and a growing impatience with the inability of the Central Agency to counter the continued price decline, farmers lobbied the State through the South African Agricultural Union (SAAU) for support and domestic price controls, while mine owners opposed the move in the interest of profitability (Morrel 1988). The National Party government, as the torch bearer of the small farmer, was in favour of protecting domestic production and promoting self-sufficiency, as evidenced by a 1926 report which described agricultural protection as a 'necessary evil' required to stimulate production in a stagnating economy (Department of Agriculture, 1926: 12)

The Central Agency was rendered obsolete by the Marketing act of 1931 that expanded state involvement in the maize market, and the Agency was dissolved in 1934. This was followed by the promulgation of the Marketing Act of 1937 that established the (pro-farmer) state as the sole buyer and seller of numerous agricultural commodities, including maize. So influential and far-reaching were the effects of the 1937 Act that it was at one point described as the "Magna Carta of agriculture in South Africa" (Stanwix 2012: 8). Morell (1988) regards the promulgation of the 1937 Act as marking the final stage of the breakdown of the maize and gold alliance since (progressive) farmers no longer required the mines to ensure their success. This Act followed on the back of a growing divide between the mines and the progressive farmer group who increasingly cast their lot with that of the smaller farmers (Morrell, 1988). This manifested itself in the growing prominence of the farmer cooperative movement (cooperative societies that facilitated the collective marketing of maize, of which membership grew to 86,700 by the mid–1930s (Department of Agriculture, 1934: 478)).

According to Morris (1976) the 1924 National Party victory tipped the scales in the farmers' favour and the 1937 Marketing Act decoupled their success from that of the mines. Morrell (1988) does not provide a specific date for the solemnisation of the divorce of the maize and gold alliance. Such a definite separation was not possible given the state's unwillingness to "…sacrifice mining profitability for agricultural viability" (Morrell, 1998:634). Davenport & Saunders (2000) also stress the importance of maintaining mining profits, specifically for the sake of both white and blue-collar workers who made a crucial contribution to the National Party at the polls. Trapido (1978) adds to this by emphasising the importance of mining tax revenue to the State. The above therefore strengthens Davenport and Saunders' (2000) position that the NPs 1924 victory was not as important to the farming community as has often been argued, especially if viewed from a marketing perspective.

3.7 Towards direct subsidies

Stanwix (2012:1) describes South Africa's agricultural history as a "marathon of government intervention". Built around the cornerstone provided by the 1937 Marketing Act, South African agricultural policy transitioned into its second phase after the Second World War. Various policy instruments set the scene for the almost total segregation of agriculture and for a comprehensive system of support measures to white farmers. Between 1910 and 1935, 87 Acts were passed in the Union Parliament rendering permanent assistance to farmers (Minnaar, 1990). State support to white farmers also came in the form of disaster relief, the construction of irrigation infrastructure, water subsidies, soil conservation, research, consumer price subsidies and soft interest rates.

Table 3.2 provides an overview of the various leases and purchases granted to white farmers in 1916. Between 1910 and 1936, an average of about 700 farmers were settled per year and supported by substantial state subsidies. Loans were also made to help white farmers obtain working capital and farming requisites. One result of this period of strong government support was the growth of the number of white farms from 81 432 in 1921 to a peak of 119 556 in 1952 (Union of South Africa, 1916-54).

Table 3.2: Allotment of agricultural holdings during 1916

	No. of Holdings	No. of Settlers	Area (hectares)	Amount (£)	Rent (£)
Land Settlement Act, 1912	141	210	168 636	110 053	-
Crown Land Disposal Ordinance (TVL)	123	134	90 557	58 215	-
Crown Land Disposal Ordinance 1903 (TVL)	26	26	21 414	10 654	-
Act 15 of 1887 (Cape): Sales	12	13	4 356	993	-
Act 26 of 1891 (Cape): Leases	24	25	19 291	-	523
Act 26 of 1891 (Cape): Sales	2	1	7 621	395	-
Natal Proclamation	36	35	28 711	13 026	53
Irrigation Settlement Act 31 of 1909	22	22	120	3 353	-
Act 13 of 1908 (OFS): Leases	3	7	2 085	-	145
Total Land Alienated	389	473	322 791	196 689	721

Source: Union of South Africa, 1916 as the South Africa Year Book of that year TVL: Transvaal province, OFS: Orange Free State Province, Cape: Cape Province

Figure 3.4 shows changes in the different forms of state support to farmers over the period 1910 to 1994[16]. It is clear from both the first and second panel that the agricultural sector enjoyed limited support prior to 1924, with expenditure on the sector averaging close to 2.5 per cent of total public outlay.

The early growth in non-subsidy and research spending (the dotted line of the first panel of Figure 3.4) can be explained by the establishment of the Land and Agricultural Development Bank (or 'Land Bank') in 1912.[17] The bank was not created with a commercial aim, but rather to use public funds to promote agriculture, *inter alia* by making capital available to white farmers

[16] Prior to 1910, agricultural policy was managed by each of the four provinces separately.

[17] Still in existence today, the institution is now governed by the Land and Agricultural Development Bank Act 15 of 2002, with land redistribution, food security and agricultural growth as its primary objectives.

at below-market rates (Bertelsmann et al., 2008: 645). As the NP came to power in 1924, subsidy and assistance spending increased in 10 years from zero to R24 million (2005 values).

Public support of the agricultural sector only took off in earnest with the drought of the mid-1930s that accompanied, as a result the sector's public expenditure share reached an all-time high of close to 20 per cent. Droughts played a significant role in the level of state support at different times. Unsurprisingly, in response to the Great Depression and a severe drought that lasted three years, Hertzog's government increased state support to agriculture substantially from 1929 onwards, as shown in Figure 3.4. Assistance and subsidy spending increased 72-fold between 1932 and 1933. In the following year, subsidies more than trebled from R504 million to R1 836 million (2005 values). Subsidy and Assistance spending on the sector declined immediately thereafter but remained at historically high levels throughout the 1930s and 1940s.

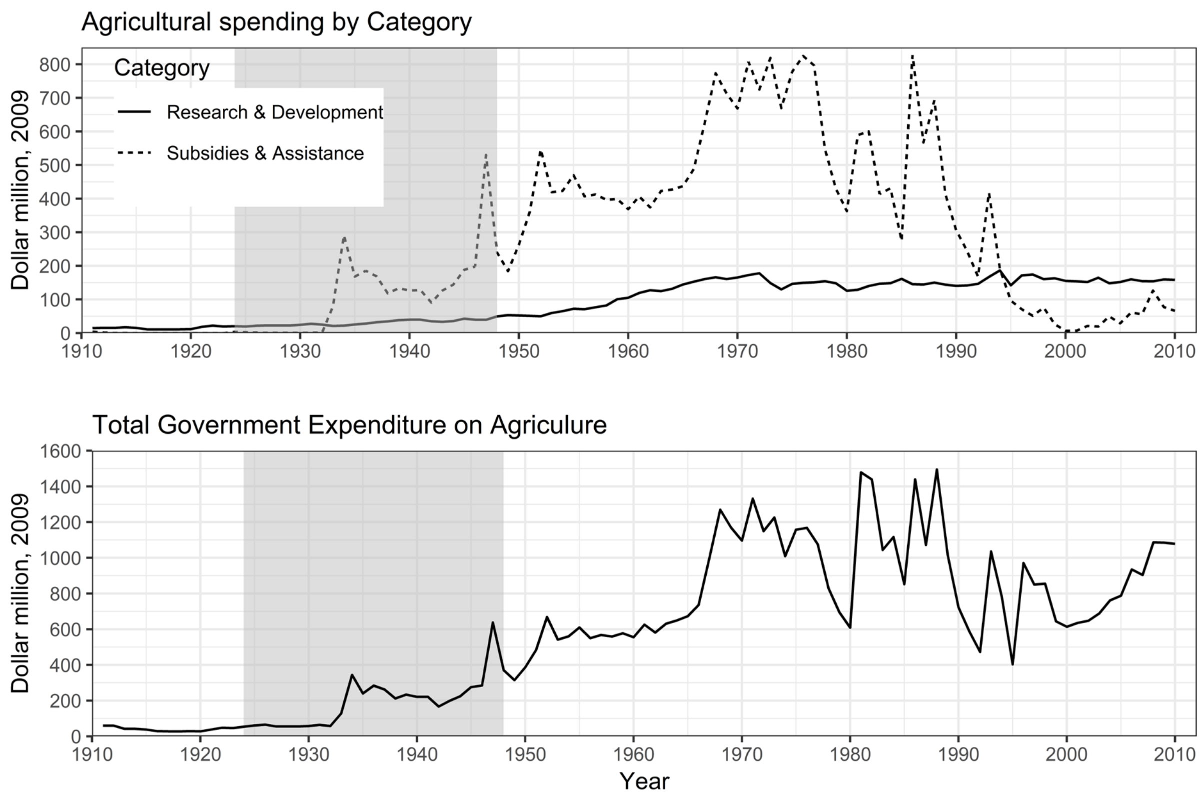

Figure 3.4: Government Expenditure on Agriculture

Source: Liebenberg, 2012.

3.8 Post–1948 support consolidation and eventual reversal

Built around the cornerstone provided by the 1937 Marketing Act, South African agricultural policy transitioned into its third phase after the Second World War. The sector, or at least the white farmers, enjoyed far higher levels of direct and indirect support relative to the pre-1940 period, lasting until around 1983 (see Figure 3.4). Examples of direct support measures include disaster relief, the construction of irrigation infrastructure, water subsidies, soil conservation, research, consumer price subsidies and soft interest rates. Indirect measures took the form of greater control over the marketing of agricultural commodities through the Marketing Act of 1968 (Vink and Kirsten, 2003; Van Zyl, Fényes, and Vink 1992). On the other hand, black maize farmers were doubly affected by these marketing measures since they were excluded from accessing urban markets to the extent that they were forced to sell their produce through a white farmer as an intermediary, while most (95 per cent) small scale producers had to buy maize at a premium since they were not self-sufficient (Van Zyl & Coetzee, 1990). The introduction of the interest rate subsidy, in conjunction with the ability to write off capital purchases in the year of acquisition, also contributed to the rapid adoption of combine harvesters during the 1960s and 1970s. This resulted in significant productivity increases but at the expense of employment (see for example De Klerk 1984; Van Zyl, Vink, and Fényes 1987).

These measures stayed in place until the 1980s, after which agricultural policy was gradually restructured towards lower subsidies, market-related interest rates and the deregulation of controlled marketing schemes (Van Zyl, Fényes & Vink, 1992b; Kirsten, Edwards & Vink, 2009). This process was hastened by the split in the National Party in 1983 that saw the farmers siding with the breakaway Conservative Party, rendering them vulnerable to increased subordination by corporate agribusiness and their 'own' farmer cooperatives (Bernstein, 2004). The restructuring process was only completed by the late 1990s and resulted in substantial efficiency gains through the removal of marginal land from production and greater access to international markets (Vink and Kirsten 2000).

3.9 Discussion and conclusion

At first glance the structural transformation of the South African economy during the late 19th to mid-20th century seems to fit the textbook example: Farming in the South African interior initially faced numerous challenges in the absence of sizable markets, transport networks and sufficient labour supply. This status quo was disrupted by the discovery of diamonds and gold, which kick-started commercial farming through increased productivity and eventually an expansion to food exports. This resulted in substantial gains for some farmers, but the mining industry was initially effective in 'squeezing' the broader sector through suppressing maize prices given their position as major buyer and the weak international integration of the maize market. This, together with growing competition for labour and land between white and black farmers on the one hand, and white farmers and the mines on the other, gave rise to growing tension between maize and gold. Ultimately the growing political influence of farmers following the election victory of the National Party in 1924 enabled them to apply the state machinery to their benefit through various forms direct and indirect support measures.

The South African case illustrates in the complexity of stakeholder interactions and resource flows that give rise to the political tensions experienced during the structural transformation. Shortly after the discovery of gold on the Witwatersrand, a strategic alliance developed between the gold mines and a group of larger 'progressive' maize farmers. This followed from their mutual interest in the maize market and the securing of black labour. However, this relationship showed a gradual deterioration over time because of the depression of maize prices by the mines, thereby forcing the 'progressive' farmers to increasingly cast their lot with that of their smaller compatriots. Eventually this broader white farmer grouping managed to gain control of the State with the support of blue-collar mineworkers, thereby bestowing direct support upon themselves and product price support through the centrally controlled marketing of most agricultural products. These farmers also applied the state machinery to help stem competition from black farmers by increasing control over their access to land and to produce markets. South African agriculture enjoyed high levels of direct and indirect support until the 1980s, but these lasted only until the early 1980s.

Chapter 4:

Hybrid maize adoption in South Africa during the 20th century: Policy failures and climate adaptation successes

4.1 Introduction

South African maize yields increased 9.4–fold[18] between 1920 and 2015, with almost three quarters of the long-run gain in yields occurring during the second half of the century (Greyling & Pardey, 2018), a timing that concords with a surge in the rate of multi-factor productivity growth for South African agriculture as a whole, Figure 4.1 (Liebenberg, 2012; Liebenberg & Pardey, 2012, Table 4). There is a reasonably extensive and heavily cited economics literature on the uptake of hybrid maize in the United States during the 20th century (see for example, Griliches, 1957a & b, 1960 & 1980; Dixon 1980; and Sutch 2011). In contrast, and notwithstanding the importance of maize in the South African agricultural economy, comparatively little economic attention has been paid to the uptake of improved (hybrid) maize varieties in South Africa.[19] Rusike (1995) conducted an institutional analysis of the Southern African maize seed industry that included South Africa, while Kirsten & Gouse (2003) and Gouse et al. (2005, 2009) examined the production, uptake and economic consequences of bioengineered maize varieties in South Africa since 1998 (the first year of approval for use of bioengineered maize variety in South Africa).[20]

In the United States, hybrid maize technology was first commercialized in 1924–25 (Brown 1983, p. 172, Sutch 2008, p. 2) drawing directly on the research conducted by George Schull (Cold Springs Harbor) and Edward East (Connecticut Agricultural Experiment Station) on hybrid vigour (heterosis) in maize (and especially the findings that occurred in the period 1909–1912), and Donald Jones' 1918 discovery of breeding double-cross hybrids (Fitzgerald, 1990). South African researchers were quick to catch on. Numerous United States and other improved maize varieties

[18] Based on centred five-year moving averages, commercial production only.

[19] Greyling and Pardey (2018b) noted that "Between 1970 and 2015 an average of 57 per cent of the commercial area in field crops was dedicated to the production of maize. In addition to being a major South African feed and food staple, over this same period an average of 25 per cent of the country's maize crop was exported, mostly to Southern African neighbours."

[20] Other studies of the economics of improved maize varieties, that include references to maize varietal improvement in South Africa, include Hassan et al. (2001) and (Byerlee, 2018).

were tested in South Africa during the 1920s and a dedicated hybrid breeding programme was launched at the Potchefstroom experimental station in 1925 (Saunders, 1942). While South African scientists were early adopters of hybrid maize breeding methods, as I show in this paper, South African farmers lagged well behind their U.S. counterparts. I examine the likely reasons for this considerable lag.

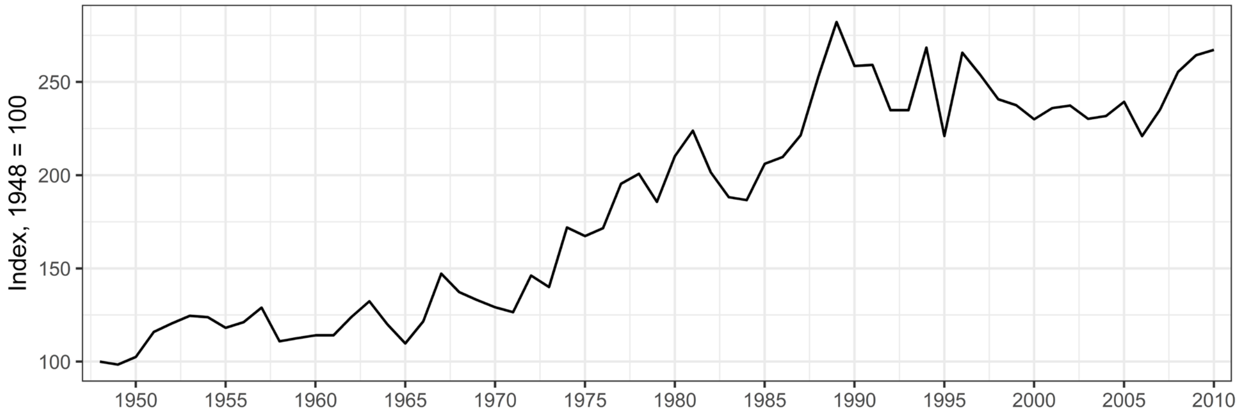

Figure 4.1: TFP index of South African agriculture, 1948 to 2010

Source: Liebenberg (2012)

In addition to quantifying the overall historical pattern of hybrid maize adoption in South Africa, I also compile and assess evidence on the uptake of hybrid maize for seven maize growing regions throughout the country. Like the U.S. adoption evidence presented by Griliches (1957a, b), Dixon (1980) and, especially Griliches (1960), I find substantial geographical differences in the initial uptake (origin) and subsequent rate and ceiling level of adoption of hybrid maize. In contrast to a sizable body of contemporaneous sociological literature on the determinates of technology adoption, Griliches emphasized the role of economics in accounting for these observed geographical differences.[21] He used differences in regional market sizes to account for differences in the 'date of availability' (or origin) of hybrid maize among regions, and differences in the relative profitability of hybrid varieties vis-à-vis open pollenated varieties (OPVs) to account for the 'rate (or speed) of acceptance' of hybrid varieties within each region. He also argued that differences in the 'equilibrium (or ceiling) level' of adoption in each region—that is, differences in the fraction of acreage within each region ultimately devoted to hybrid maize—

[21] Prior the Griliches the adoption of hybrid maize received attention in the sociology literature most notably by Ryan (1948) and Ryan & Gross (1950)

were "… explained by differences in the *average* profit to be realized from the shift to hybrid seed (Griliches 1960, p. 279)."

A later study by Dixon (1980) showed the differences in the ceiling (or equilibrium) level of adoption among regions were largely a data truncation artefact. Using a longer time series of adoption data than was available to Griliches, Dixon revealed that all the regions eventually equilibrated at higher—and often more similar (complete or almost complete)—levels of adoption of hybrid varieties than Griliches reported. However, access to longer time-series data raises questions as to whether or not a symmetrical logistic curve is the best representation of the historical time path of hybrid maize adoption in the United States. Dixon found in favour of a Gompertz curve that can accommodate non-symmetries (in this case positive skewness) in the time path of adoption. In my own efforts to choose functional forms that best summarize the South African hybrid maize adoption data, I was also sensitive to these distributional asymmetries. Griliches (1980) acknowledged this point in his reply to Dixon's 1980 paper, while also noting that opting for 'goodness of fit' considerations comes with a loss of 'interpretability' (Griliches 1980, p. 1463).

More recently, Sutch (2008 & 2011) revisited the underlying yield differential evidence used by Griliches to quantify the profitability differences between OPV and hybrid varieties and account for differences in the rate of uptake of hybrid varieties (and conversely the rate of abandonment, or disadoption) of OPV varieties. He reports that in the early years of commercial use (prior to 1937) the relative yield-cum-profitability advantages of hybrids over OPVs were in fact not supported by the available data, and that superiority of hybrid yields only became apparent post–1937 as private seed companies ramped up their R&D investments in the development of new hybrid varieties.

According to Sutch (2011, p. 219), what did give hybrid maize varieties their advantage, and thus spurred their adoption in the early 1930s, was their actual, and widely reported (Fitzgerald 1990), 'resistance to drought.' This was revealed during the Dust Bowl droughts of the 1930s and its aftermath. In this paper I assemble and deploy a spatialized set of rainfall data to also explore the yield differential versus drought resistance explanations for the geographically distinct patterns of hybrid maize adoption I observe in South Africa.

4.2 The South African and U.S. seed industries, in brief

To set the scene for my analysis, I begin with a brief overview of the basic principles of hybrid maize breeding and contrast the development of the United States and South African maize industries. A special emphasis is placed on the institutional structures that underpinned the development of the respective industries as means to explain why the South African adoption lagged the United States by almost two decades.

4.2.1 The U.S. hybrid seed industry

Charles Darwin was among the first scientists to experiment with inbred and cross-pollinated maize, culminating with the publication of his findings in 1876 that inbred maize plants—resulting from forced self-pollination—were generally inferior to cross-bred maize plants.[22] He concluded that in-bred plants suffered from an 'inbreeding depression' while cross bred (or out crossed) maize plants exhibited a 'innate constitutional vigour' (Sutch, 2011, p.208). These findings inspired William J. Beal at the Michigan Agricultural college to experiment with inbred pure lines[23] and to become the first to cross these to illustrate the value of hybrid 'vigour.' This work was furthered by George Shull and Edward East, who developed the first systemically produced single cross hybrids in 1908 (Olmstead & Rhode, 2008). However, at the time many maize breeders were sceptical about their practical usefulness. The poor vigour and low seed yields of the inbred lines required for hybridisation made it comparatively costly and time consuming to produce sufficient hybrid seed for extensive commercial use (Griliches, 1957a; Hallauer & Miranda, 1981).

The possibility of widespread hybrid use moved a step closer to reality in 1917 after the development of double cross hybrids by Donald Jones (Alston et al., 2010). As a cross between two highly productive single cross hybrids it increased seed yields dramatically. During the 1920s this newly found promise of commercialisation spurred a substantial expansion in the development of inbred lines, which provided the impetus for the establishment of the first private seed companies. Henry A. Wallace[24] founded the Pioneer Hi-Bred seed company in 1926 after becoming the first to market a private hybrid variety in 1925. But early success was limited,

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[22] Darwin was by no means the first maize breeder. Genetic and archaeological evidence show that modern maize traces its existence back to the domestication and continued improvement of the wild Mexican grass teosinte (*Zea mays ssp. Parviglumis* or *spp. Mexicana*) 5 to 10,000 years ago in the Balsas river valley in Mexico (Wang et al., 1999; Ranere et al., 2009).

[23] Inbred maize varieties are obtained by forcing self-pollination which reduces vigour and increases uniformity. Pure lines are varieties that have been inbred for a sufficient number of generations, usually six to seven, to deliver an offspring that "breeds true" since they exhibit complete uniformity and does not suffer any further reduction in vigour (Saunders, 1940).

[24] Later U.S. Secretary of Agriculture and Vice President of the United States (Culver & Hyde, 2001)

with a mere one per cent of the total U.S. maize acreage planted to hybrid varieties ten years later (Olmstead & Rhode, 2008). While double cross hybrids put commercialisation of the technology within reach, it also brought with it a different set of challenges, principally stemming from the fact that not all double crosses out-yielded their open pollinated competitors. Hence the optimal selection of the combination of pure and single-cross hybrids became of the utmost importance as the sheer number of unique crossing combinations rendered the trial and error breeding methods of the time impractical. For example, a mere 20 pure lines (South Africa tested several hundred by the 1920s) could theoretically have 190 unique single cross combinations, which in turn make possible 14,535 unique double cross combinations (Hallauer & Miranda, 1981).

During the 1930s substantial progress was made with the development of predictive breeding techniques that enabled improved pre-trial hybrid screening. One of the first was the realisation that the performance of a so-called 'top cross'—a cross between a pure line and a common tester variety (typically an OPV)—gives breeders a good indication of the pure line's hybridisation potential. The second was the development of statistical methods that could be applied to the data from single cross hybrids to predict their performance as double crosses, thereby reducing the number of double crosses to be tested in field trails (for more detail see Hallauer & Miranda, 1981). Taken collectively, Griliches (1957) argues these developments did not result in the invention of hybrid maize as such, but rather resulted in the invention of a new way of inventing which could then be applied by both public and private entities. This enabled Pioneer Hi-Bred and DeKalb[25] to develop their own research and development programmes to supply U.S. farmers. This, in combination with innovative farmer-dealer contract arrangements, enabled these companies to dominate the U.S. seed industry at an early stage, and eventually, overseas markets as well. While U.S. breeders could not patent maize varieties under the Plant Patent Act of 1930, their intellectual property investments were still protected by trade secrets laws. These enabled them to protect the identity of the pure lines and breeding procedures used to breed their hybrids. This was also aided by the seed certification programmes that formalised the industry during the 1920s (Rusike, 1995).

During the 1930s and 1940s the number of formal breeding programmes increased in both scope and number, and so too did the number of double cross hybrids available to farmers. By 1943 Iowa became the first state to plant its entire area to hybrid maize, with the whole of the

[25]Founded by Charlie Gunn in DeKalb, Illinois.

United States following suit by 1960. However, this was not achieved without continued varietal improvements. During the 1950s, breeders became increasingly concerned that yield growth would begin to wane since double cross hybrids were perceived to be approaching their yield plateau. However, this concern was misplaced following advances in pure line breeding methods that enabled the commercialisation of single cross hybrids. This was achieved through increased pure line vigour following continued breeding and improved cultivation practices such as the application of fertiliser, herbicides and pesticides. As a result the use of single cross hybrids increased from close to zero in 1960 to 85 per cent by 1980 (Hallauer & Miranda, 1981).

4.2.2 The South African hybrid seed industry

Scientific maize breeding in South Africa was initiated in 1904, shortly after the Second Anglo-Boer War, at the Potchefstroom Experimental Station by the then Transvaal Department of Agriculture. By the 1920s government researchers had introduced and tested several hundred open pollinated varieties from the United States, Canada and Australia, but only a handful of U.S. varieties proved suitable for local conditions. These included varieties such as *Hickory King, Iowa Silver Mine, Champion White Pearl*, and various others.[26] Early success came in 1910 following the chance discovery of *Potchefstroom Pearl,* the product of an accidental hybridisation between *Champion White Pearl* and either *Hickory King* or *Iowa Silver Mine*. This variety was widely distributed during the 1920s and 1930s, and continued to be used as a breeding line, yielding the blight tolerant *Natal* and *Pretoria Potchefstroom Pearl* variants (Saunders, 1930). The variety *Natal Potchefstroom Pearl* would later serve as the cornerstone of the early hybrid maize industries in South Africa, Zimbabwe, Zambia, and Malawi (Rusike, 1995).

The first hybrid maize breeding experiments in South Africa were conducted by A.R. Saunders at the Potchefstroom and Kroonstad experimental stations in 1925 and 1928 respectively. At the time the programme focussed on traits of "resistance to drought, strength of the root system, moderately early maturity, fairly large size of grain and other minor properties which appear desirable to have in any variety" (Saunders, 1940, p. 311). As a result, the early hybrid breeding programme prioritised adaptability and drought tolerance above yield potential, opting for the development of 'synthetic'[27] varieties such as the *Synthetic Potchefstroom Pearl* developed by 1932 (Saunders, 1942). Progress was slow however, with maize yields only

[26] This includes *Chester County, Golden Beauty, Reid Yellow, Leaming* and *Boone County White.*

[27] As a precursor to single and double cross hybrids, synthetic hybrids are open pollinated varieties (OPV) bred through the intercrossing of pure lines that are maintained through selection procedures within isolated populations (Lonnquist, 1961).

increasing at an average of 0.7 per cent per year between 1920 and 1949 (Greyling & Pardey, 2018b).

The establishment of the South African Maize Board following the Agricultural Marketing Act of 1937 marked a key event in the local hybrid maize industry. While primarily tasked with the controlled marketing of maize (see Greyling, Senay & Pardey, 2018), in 1947 the Board initiated a Hybrid Maize Scheme (hereafter Scheme) in collaboration with the Department of Agriculture, with the former being responsible for seed multiplication and distribution, and the latter tasked with hybrid breeding. The first thirteen bags of the hybrid maize were sold to farmers in 1949, all of which was the variety *PP×K64*, a top cross between the synthetic variety *Potchefstroom Pearl* and the imported Kansas strain *K64*. Described by Laubscher (1970, p. 3) as a "diamond in a pile of gravel," *K64* would form part of numerous hybrids developed in subsequent decades.[28] At the time *PP×K64* out-yielded the popular open pollinated varieties by an average of 25 to 30 per cent, depending on agro-ecological realities (Kuhn & Gevers, 198, p. 69). In addition to its other responsibilities, the Scheme was also tasked with setting the price of hybrid seed, which it seems to have gotten wrong. Following a research visit to South Africa in 1950 under the auspices of the FAO, Jenkins (1951)[29] as one to the central figures of the U.S. breeding programme, argued that the Scheme set the hybrid seed price too low to encourage private investments in hybrid development. Referencing the price of U.S. hybrids, Jenkins proposed that South African hybrid seed prices should be increased by at least 50 per cent to encourage private seed companies.

Given the substantial yield increases and affordability, the Board was unable keep up with the demand, and by 1954 seed multiplication and distribution had to be outsourced to contract farmers, farmer cooperatives and seed merchants (Laubscher, 1970). Seed supplies were in such short supply during the 1952–53 season that the Department of Agriculture encouraged farmers to plant second generation hybrid seed saved from their previous harvest, stressing that this should only be done as a temporary measure. Trials conducted by the department showed that second-generation, farm-saved hybrid seed still out-yielded open pollinated varieties by an average of 18 per cent (Laubscher et al., 1954, p.130). Despite the release of various subsequent varieties such as *SA4, SA5* and others, the Scheme achieved limited success during the first

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[28] A variant of this cross as *NPP×K64* and *PP×K64* was still being marketed in 1974 (Maize Board, 1975).

[29] Byerlee (2018, p. 4) noted that "Merle T. Jenkins (PhD Iowa State 1928) … led the USDA's mid-west cooperative corn improvement program when it was established at Iowa State in 1925 and produced the first widely adopted maize hybrids for the Corn Belt. From 1934 to 1958 he headed the USDA's maize breeding work, based in Beltsville near Washington DC, and would play a leading role after the War in transferring hybrid technology to Europe and South Africa."

decade of its existence, primarily because the pedigrees of these various varieties were closely related to *PP×K64* (Kuhn & Gevers, 1980).

Although the first private seed companies were established in 1958, the South African private seed market was only formalised after the promulgation of the Seed and Foundations Act in 1963. The Act established the legal framework for the registration of new varieties and set standards for varietal trials, seed certification. It also outlined the procedure for the approval and registration of seed merchants, established control over seed imports and exports, and launched the South African varietal list. Only varieties on the list could be sold to farmers, and to be listed, new varieties had to achieve prescribed performance standards in government-organised trials, most notably indicators of agricultural value, uniformity and genetic stability.

In addition, the act also gave the Seed Inspection Service (established in 1944) the authority to prosecute and punish seed companies that violated seed quality standards or misrepresented their products through false advertising. The Seed Inspection Service commenced operations in 1963. The number of inspection visits to the premises of seed sellers and cleaners increased tenfold between 1964 and 1974, while the number of transgressions declined in response to substantial penalties imposed on transgressors. In 1968 the most common transgressions were seed sold in deficient containers (34.8 per cent), a lack of sufficient record keeping (15.2 per cent), the selling of unregistered varieties (15.2 per cent), and selling seed under false pretences (13 per cent) (Rusike, 1995, p. 105). It is conceivable that these actions may have reduced the availability of hybrid seed during the mid–1960s as the newly formed Seed Inspection Service stepped up its efforts.

One of the major institutional impediments to private investment in hybrid development was removed with the proclamation of the Plant Breeders' Rights Act of 1964. The act enabled breeders to secure intellectual property rights over varietal innovations, and exclude others from unauthorised selling of protected cultivars. This aligned the South African legislation with that of the United States and Europe, and saw South African seed companies establishing strategic alliances with U.S. seed companies, thus giving them access to elite international breeding material. Examples include the partnership between Sensako[30] and DeKalb Genetics Corporation, and Pannar[31] and Pioneer Hi-bred International. The first proprietary South African

[30] Sensako was established in 1959 by the Central Western Agricultural Cooperative, North Western Agricultural Cooperative, and the Eastern Transvaal Cooperative to fulfil the Maize Board contract of multiplying and distributing hybrids released by way of the national breeding programme (Rusike, 1995).

[31] Pannar was founded in 1958 by Mr Bill Wall, a Natal (Greyton) farmer who was contracted to multiply and distribute hybrids developed by the Natal breeding programme (Rusike, 1995).

maize variety was registered in 1965, with Pannar registering their first four varieties in 1968 (Rusike, 1995).

While the Department of Agriculture continued breeding so-called ‘S.A. varieties’ (e.g., *S.A.9N, S.A.5,* and *S.A.100*), rapid progress was made with privately developed ‘elite varieties’, to the extent that the latter out-yielded the former by an average of 41 per cent during the 1977 and 1978 seasons (Kuhn & Gevers, 1980). As a result, the public (S.A.) hybrids were replaced by privately bred varieties within just 15 years (1981) of registering the first public hybrid (see Section 4.5). As the uptake of improved hybrid varieties expanded, in tandem with the adoption of other, largely complementary, technologies (Bennie, Hoffman & Coetzee, 1995; Liebenberg & Pardey, 2012) the pace of maize yield increase picked up: these enabled maize yields to expand at an annual average rate of 3.5 per cent per year between 1949 and 1981. This slowed thereafter to an annual increase of 2.1 per cent, accelerating to a 3.1 per cent increase between 1999 and 2015 following the deregulation of agricultural marketing in 1998 (Greyling & Pardey, 2018b)

4.3 South African versus U.S. rates of varietal adoption

4.3.1 Measuring adoption rates

Griliches (1957) observed that U.S. hybrid maize adoption exhibited an S-shaped curve that can be described mathematically using three parameters; a beginning (origin), rate of adjustment (slope parameter), and its equilibrium (ceiling parameter). While various functional forms can and have be fitted to adoption data, Griliches opted for a logistic growth function as a summary device for his hybrid maize data given its fitting ease and interpretation. Revisiting Griliches’ study using a longer time series, Dixon (1980) improved the goodness of fit of the logistic function by using a weighted ordinary least squares (OLS) or iterative nonlinear least squares procedure. He also used a Gompertz curve as an alternative functional form since it can accommodate asymmetrical adoption paths. In response Griliches (1980) conceded the relevance of new econometric techniques to improve the fit of the logistic function. But he contests the use of the Gompertz functional form, arguing that a ‘decent’ fit would require a three-parameter specification, but this would come at the expense of interpretability. Thus, Griliches concludes that the logistic growth function still offers the optimal balance between accuracy and interpretability and hence I proceed with this function. The logistic growth function is mathematically represented by:

$$P_{it} = \frac{K_i}{1 + e^{-(a_i + b_i t)}} \quad (1)$$

where P_{it} represents the hybrid adoption rate expressed as the percentage share of hybrid maize in total seed sales or area planted in region i at time t. As t tends toward infinity, P will tend towards K as the ceiling value. The parameter a positions the curve on the time scale while, b represents the rate of hybrid acceptance or adoption (P).

4.3.2 Adoption data and results

In his foundational 1957 study, Griliches used USDA survey-based data reporting the annual percentage of maize area planted with hybrid varieties for 31 U.S. states for the period 1933–1956. Dixon (1980) used the same data from the same source, now spanning the longer period from 1933 to 1960, the year collection of these statistics was discontinued.

To assess the robustness of my results, logistic growth functions (i.e., equation 1) were fitted to the South African and U.S. data using (1) a weighted OLS procedure[32], (2) a weighted generalised linear method (GLM), and (3) a non-linear least squares (NLS) approach. The model results are summarised in Table 4.1, with the actual and fitted (NLS) data shown in Figure 4.2.

Table 4.1: Adoption rate estimates, South Africa and United States

	(1) Weighted Logit		(2) Weighted binomial generalised linear (GLM)		(3) Non-linear least squares (NLS)	
	b_1	Adj. R^2	b_2	R^2	b_3	R^2
South Africa	0.31(0.03)	0.85	0.24(0.02)	0.89	0.28(0.04)	0.94
U.S.	0.28(0.02)	0.85	0.25(0.01)	0.94	0.33(0.02)	0.99

Source: See Figure 1.
Notes: All are statistically significant to the 99 per cent level.

Given that both South Africa and the United States effectively achieved full adoption within thirty years of its initial commercial release[33], the national average rates of hybrid maize

[32] Weighted in accordance to Berkson (1953) and employed by Dixon (1980), the weights associated with P_{it} are inversely proportional to $n_{it}P_{it}(1 - P_{it})$ with n_{it} as the number of observations at each point in time, t.
[33] SA: 1949-1979, US: 1933-1964. Technically the first U.S. hybrids were introduced in 1923 but the adoption only reached 0.1 per cent by 1933.
…

acquisition or uptake are similar for both countries. However, like Dixon (1980), I find that the respective fitting techniques deliver substantially different estimates of the adoption rate (b_i).[34]

All the specifications fitted the trend in the adoption data quite well, although the non-linear least squares method (3) delivered the best overall fit for both countries given its iterative procedure. The slightly worse fit in the South African instance may be attributable to the sharp, off-trend dip in hybrid maize adoption during 1966 (from 65 to 51 per cent) and 1967 (from 51 to 47 per cent) seasons (Figure 4.2). While hybrid maize use recovered to 68 per cent in 1968, it was still lower than projected and remained so for some time. While the exact cause of this lower than projected uptake of hybrid maize is not ascribed in the literature, a possible contributing factor may have been the activities of the Seed Inspection Service that commenced its duties in 1964 and expanded it efforts thereafter. Regulatory actions against seed companies that violated seed quality standards and misrepresented their products may have reduced overall hybrid availability or removed relatively affordable but dubious hybrids from the market.

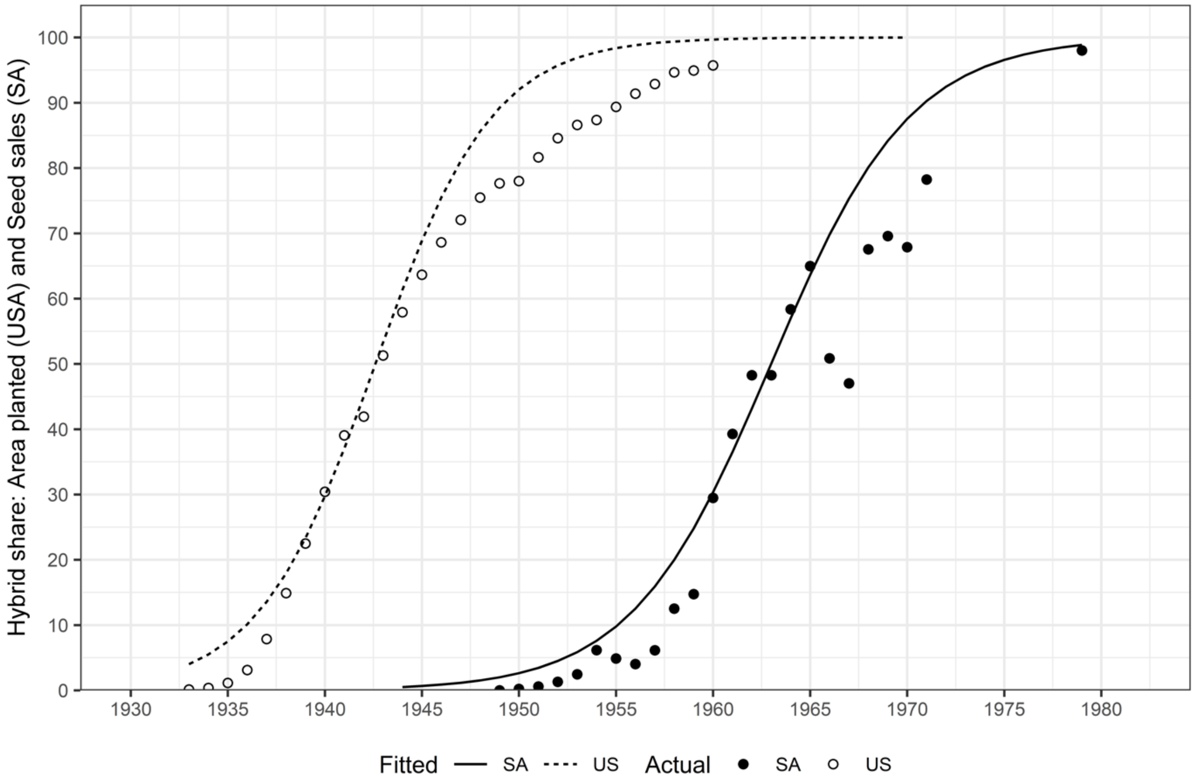

Figure 4.2: Hybrid adoption: South Africa vs United States

Source: *Compiled from: South African Maize Board Annual Reports (1951–1994); U.S.: USDA (1975)*
Notes: Fitted values as per NLS model (3).

[34] Unlike Griliches (1957) and Dixon (1980), we do not restrict my analysis to observations above 10 and below 95 per cent of the ceiling level of adoption since we do not face the same computational constraints. Also, not only does the removal of these cut-off thresholds remove a source of arbitrariness from my study, including all the available data improves the goodness of fit for both countries.

4.4 Regional hybrid adoption

The data published by the Maize Board on the regional (i.e., sub-national) uptake of hybrid maize is less comprehensive (years 1961–1971) than the corresponding national estimates, but informative nonetheless. The data were reported by maize region, as composites of magisterial districts, but sadly are also afflicted by inconsistent reporting. However, it was possible to standardise the data according to the ten[35] maize regions shown in Figure 4.3.

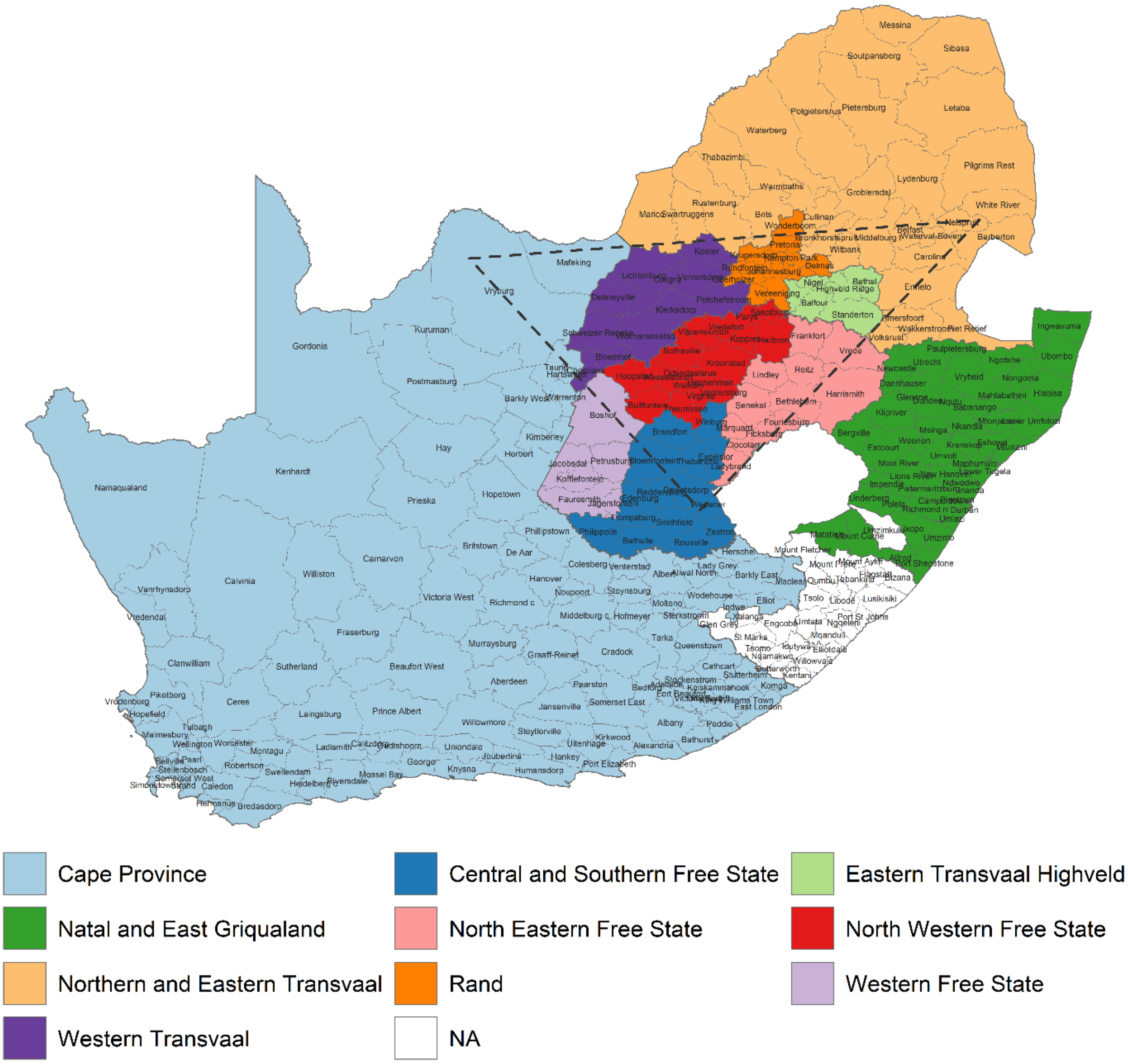

Figure 4.3: Maize region map (1981)

Source: Maize board (1982)
Notes: Maize triangle represented by dotted lines. NA includes Lesotho, Transkei and Ciskei

[35] To do so we had to combine the Western Free State with the Central and Southern Free State regions. In addition, the data observations on the Cape as well as the Natal and East Griqualand regions were inconsistently reported. Hence seven regional observations are available for this 11 year period.

Although this process increased the number of temporal observations, the standardisation came at the expense of cross-sectional observations, but with the added advantage of ensuring the spatial concordance between the hybrid adoption and public/private hybrid data discussed in Section 4.5. To develop summary estimates of the trend path in adoption, I followed the curve fitting exercise I undertook at the national level. Unfortunately the NLS model failed (most likely because of the limited number of observations (11)), and so an unweighted GLM model (5) was fitted instead.[36]

Sub-national hybrid adoption in South Africa, as in the U.S., showed wide regional differences in both the origin (or initial uptake) and the rate of adoption, Table 4.2 and Figure 4.4. For example, the Rand region (includes Delmas, Vereeniging and Krugersdorp, see Figure 4.3) is the smallest maize region by area planted (denominated in thousands of hectares below the district name in Figure 4.4) was the first to reach full adoption (98.6 per cent) by 1966. The Western Transvaal (WT: Bothaville, Kroonstad, Viljoenskroon), the second largest maize region followed suit in 1970, while the Eastern Transvaal Highveld (ETHv: Bethal, Standerton, Nigel) was the last district to cross the full adoption threshold before the Maize Board ceased reporting.

Table 4.2: Regional hybrid adoption rates, growing season rainfall and projected adoption

Region		(5) Generalised linear (GLM) b_5		Rainfall: Season average *mm*	Projected adoption *Year 75 per cent*
4: Central and Southern Free State+	(C&SFS)	0.04	(0.05)	435	
8: Eastern Transvaal Highveld	(ETHv)	0.15	(0.08)*	607	1967
10: Northern and Eastern Transvaal	(N&ET)	0.14	(0.05)**	607	1975
6: North Eastern Free State	(NeFS)	0.09	(0.03)***	573	
5: North Western Free State	(NwFS)	0.09	(0.06)	502	
9: Rand	(Rand)	0.25	(0.09)**	628	1963
7: Western Transvaal	(WT)	0.26	(0.09)**	489	1964

*Notes: Significance codes: 0.001 '***' 0.01 '**' 0.05 '*', standard errors shown in brackets*
+ Includes the Western Free State region

4.4.1 Hybrid availability

Griliches (1957) noted that both hybrid maize supply and demand factors affect the pattern of uptake of this varietal technology. The supply side phenomena he dubbed 'availability,'

[36] Unweighted logit and OLS models were also fitted for comparative purposes, see Appendix E for these model results.

referring to the idea that profit maximizing private firms were likely to target their varietal development efforts according to market size, with hybrid seed being made available to larger maize seed markets ahead of smaller ones.

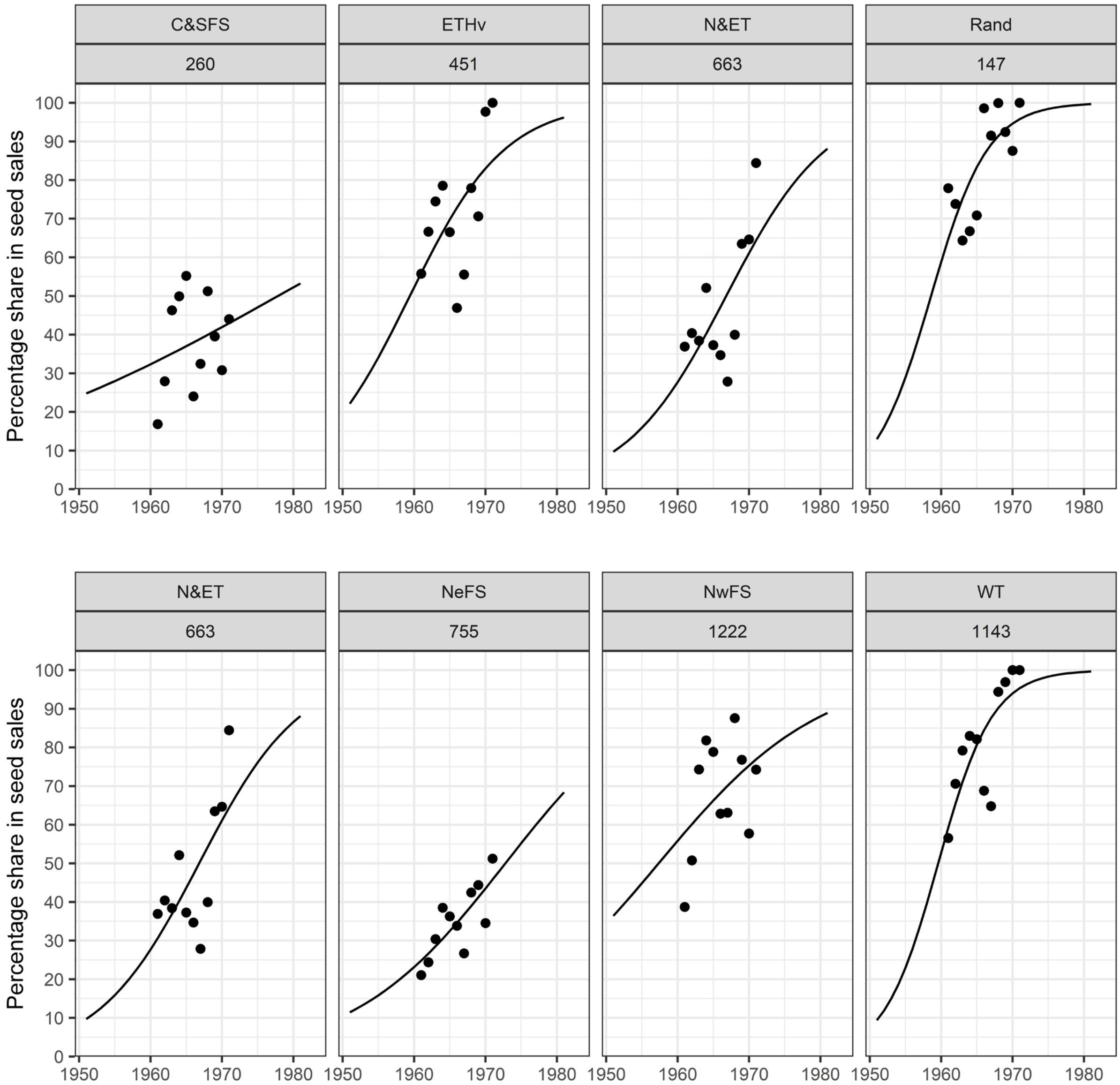

Figure 4.4: Hybrid adoption by maize region – actual and fitted

Source: Maize Board (1962–1994)

Notes: Total area planted (1 000 hectares) in 1971 shown below district abbreviation. District abbreviations as follow, see Figure 4.1 for spatialization. Cape and Natal and East Griqualand districts excluded due to inconsistent reporting.

C&SFS:	*Central and Southern Free State (includes the Western Free State)*	*NwFS:*	*North Western Free State*
ETHv:	*Eastern Transvaal Highveld*	*Rand:*	*Rand*
N&ET:	*Northern and Eastern Transvaal*	*WT:*	*Western Transvaal*
NeFS:	*North Eastern Free State*		

The South African regional adoption model results are presented in Table 4.2. It shows that early adopting districts reported the fastest adoption rates. However, if the total area planted per region is an indicator of its relative importance, then the availability argument is not as applicable in the South African case since the smallest and second to largest districts were the first to adopt the technology as reflected in Figure 4.4. It shows both the actual and predicted values with relative importance of the region shown below its label as the area planted to maize in 1971 as the last year of data available.

A possible contributing factor to this outcome is the structure of the South African seed market as discussed in Section 4.2.2, specifically the limited involvement of private seed companies prior to 1965. This constrained overall R&D investment and limited access to international breeding material, thus slowing the overall rate of release of new hybrid varieties. The public sector nature of the market may have also muted the tendency (evident in the private led U.S. case) to prioritize larger (and thus more lucrative) maize seed markets over smaller ones. In fact, political pressures may have pushed in the direction of 'equal treatment' such that one part of the country was not in fact prioritized ahead of another, or at least the priorities were less evident or less effective. The development of *PP×K64* provides a case in point: While it offered a significant advantage over the OPVs grown at the time of its release, progress slowed thereafter since the genetic pedigrees of subsequent derivative varieties varied little from the original release (Kuhn & Gevers, 1980). In addition to challenges with the availability of genetically suitable hybrids, early adoption was also constrained by challenges in physical availability following the Scheme's inability to meet seed demands. It is uncertain if all districts were affected equally.

4.4.2 Hybrid acceptability and revealed drought tolerance

On the demand side, Griliches emphasized 'acceptability,' positing that the rate of uptake is a function of the yield superiority of hybrid varieties over the OPV alternative(s) they replaced. He concluded that hybrid varieties, on average, provided a 20 per cent yield advantage over the OPVs they replaced.[37] This is in line with the South African estimates where *PP×K64* out-yielded OPVs by between 25 and 30 per cent. However, this showed wide regional differences with some districts reporting an increase of up to 60 per cent. In addition, the yield gap was more

[37] Specifically Grilches (1957, pp. 58-59) noted that "As [a] … measure of the longer run cross-sectional differences in the superiority of hybrids, I used the average pre-hybrid yield of corn. This is based on the widespread belief that hybrids represent a constant per centage gain of about 15 to 20 per cent over open pollinated varieties. Hence, differences in average pre-hybrid yields will imply differences in the absolute gain in yield due to the use of hybrids. Usually an average for the ten years before an area reached 10 per cent in hybrids was used as the estimate of the average pre-hybrid yield. For states, the source was Agricultural Statistics. For crop reporting districts, various published and unpublished data from the AMS and from State Agricultural Statisticians were utilized."

pronounced in lower rainfall areas (Kuhn & Gevers, 1980) and more importantly, during dry seasons (Laubscher et al., 1954: 129). This provides a segue into Sutch's (2011) hypothesis that early adoption (prior to 1940) was not driven by absolute yield gains since these were too small relative to hybrid seed cost, but rather by its relative yield advantage during droughts. Using a simple scatter plot of 43 yield observations from an unspecified number of trial locations during four seasons (1935-1938), Sutch shows that the relative yield of advantage of hybrids was greatest when yields were depressed due to drought.

This can also be tested for South Africa since comparative trial data is available for the early adoption period, 1951 to 1954. It encompasses the results of between six and ten trial locations but unfortunately their results were averaged to report annual variety averages. Fortunately, this period included both drier (1951 & 1952) and wetter (1950 & 1953) years, as the growing season average rainfall (November to April) across trial locations[38] calculated from the Lynch (2004)[39] rainfall database of Southern Africa. A comparison of aggregate hybrid and OPV yields (Table 4.3) during these seasons suggests that Sutch's hypothesis also holds for the South African case since the hybrid advantage was greatest when yields were depressed during drier seasons.

Table 4.3: Annual average yield hybrid and OPV and growing season rainfall

	Average yield all trails (t/ha)		Hybrid advantage	Growing season rainfall
Year	Hybrid	Open pollinated	*(OPV = 100)*	all trail locations *(mm)*
1950	2.0	1.5	133.7	662.2
1951	1.6	1.1	140.4	520.8
1952	1.6	1.3	126.7	463.7
1953	2.1	1.7	123.7	628.1

Source: See text, own calculations.

To improve the robustness of this preliminary conclusion and extend Sutch's analysis, I exploit the fact that the average yield of up to eight hybrids and eleven OPVs were reported[40] during for four-year period, hence these can be combined into 199 unique hybrid-OPV combinations. These are plotted in Figure 4.5, with OPV yields represented by the horizontal axis and the vertical axis showing the hybrid to OPV yield differential expressed as an index of the

[38]Nine of the ten locations were included since the location of the tenth was not reported. Districts included: Potchefstroom, Delmas, Bethal, Standerton, Klerksdorp, Coligny, Bothaville, Kroonstad, Bethlehem.

[39]Lynch's (2004) database includes daily rainfall observations from 12 153 weather station across South Africa between 1850 and 2000.

[40] Not all included each year, number of hybrids and OPVs each year: 1950:2, 4; 1951: 3, 5, 1952: 8, 11; 1953: 8,11

OPV yield. The growing season is indicated by the point type while the point colour shows the hybrid variety used in the relative yield comparison.

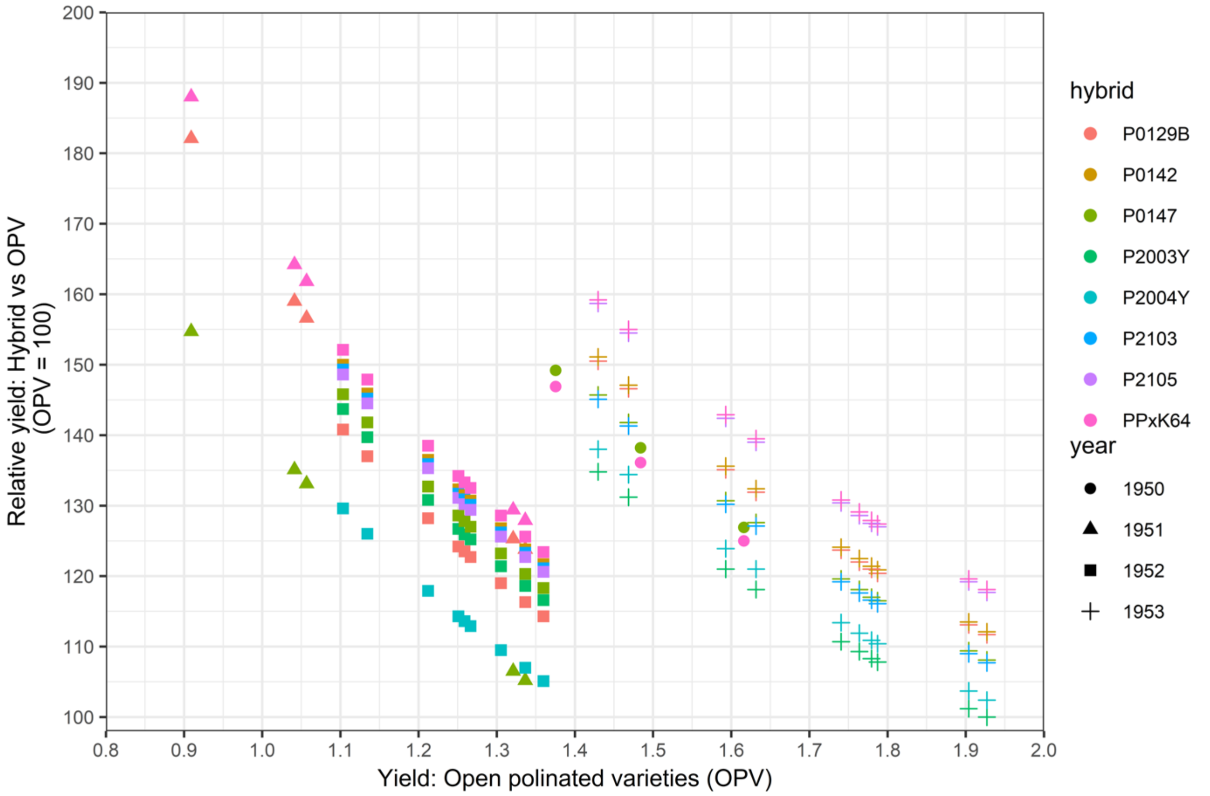

Figure 4.5: Relative advantage hybrid to OPV

Source: Laubscher et al. *(1954: 131)*

Two observation clusters are evident as the low and high yield observations because of drier (1951 & 1952) and wetter (1950 & 1953) seasons. If viewed collectively it is evident that the greatest yield differentials were observed when OPV yields were most depressed. Furthermore, this relationship is polynomial and convex with respect to the origin, hence the yield advantage of hybrids over OPVs increases at an increasing rate as OPV yields become more depressed. In other words, the advantage of hybrid over open pollinated maize is the greatest when rainfall is low, but the advantage diminishes as rainfall increases. This is also true when comparing individual hybrids and OPVs. To confirm the presence of the observable polynomial trend a simple OLS model was devised:

$$Y_{it} = \frac{H_{it}}{O_{it}} \times 100 = \beta_0 + \beta_1 O_{it} + \beta_2 O_{it}^2 + c_i + \varepsilon_{it} \qquad (2)$$

Where Y_{it} is the hybrid to OPV yield index of the hybrid-OPV combination i during year t, β_0 is the intercept, O and O^2 is the OPV yield and OPV yield squared, c_i are fixed effects if included and ε_{it} is the error term. Fixed effects for the OPVs and Hybrids were included in the model to isolate the impact of their time-invariant characteristics on the relative yield index. In other words, by including them as fixed effects within the model it removes the impact of their characteristics that does not change over time from the model, thereby allowing me to study their nett effect on relative yields.

The model results (Table 4.4) show that the inclusion of the OPV and/or hybrid fixed effects does not have an impact on the statistical significance of the predictor variables, but the inclusion of both improves the adjusted R squared, as the indicator of goodness of fit, from 0.329 to a respectable 0.742. As expected, the function is convex with respect to the origin since the coefficient of OPV yield is negative and the squared term thereof positive, thus confirming that the relative yield advantage of hybrid maize increases at an increasing rate as yields are depressed because of drought.

Table 4.4: Relative yield advantage model, hybrid vs open pollinated varieties (OPV)

	Dependent variable:			
	Relative hybrid to OPV yield			
	(1)	(2)	(3)	(4)
OPV yield	-132.311***	-154.592***	-124.748***	-145.070***
	(38.535)	(34.857)	(33.861)	(27.180)
OPV yield squared	34.314***	45.386***	32.074***	42.621***
	(12.895)	(11.699)	(11.322)	(9.115)
Constant	245.341***	247.953***	239.769***	240.614***
	(28.097)	(25.702)	(24.623)	(19.997)
OPV FE?	No	Yes	No	Yes
Hybrid FE?	No	No	Yes	Yes
Observations	199	199	199	199
R^2	0.329	0.555	0.505	0.742
Adjusted R^2	0.322	0.526	0.481	0.714
Residual Std. Error	11.824 (df = 196)	9.885 (df = 186)	10.340 (df = 189)	7.673 (df = 179)
F Statistic	47.979*** (df = 2; 196)	19.311*** (df = 12; 186)	21.427*** (df = 9; 189)	27.074*** (df = 19; 179)

Note: *p<0.1; **p<0.05; ***p<0.01

4.4.3 Adoption rates and rainfall

To test whether drier regions were earlier or quicker adopters of hybrid maize, I compare regional hybrid adoption rates and the 75 per cent adoption thresholds with the corresponding regional growing season average rainfall. To do so I overlay Lynch's (2004) rainfall database with the spatialised maize region boundaries (shown in Figure 4.2) to allocate the respective weather stations[41] to maize regions. Thereafter I restrict the observations to the growing season (November to April), I then calculate the average rainfall observed per region between 1918 and 2000. Seeing that only three regions had reached full adoption when reporting was ceased in 1971, I project adoption levels forward by ten years to establish when the respective regions first reaches a 75 per cent acceptance level. The projected year in which the acceptance exceeds 75 per cent is shown in the last column of Table 4.2. Missing observations are either the result of statistically insignificant adoption rates or the fact that the projected adoption threshold did not exceed 75 per cent at the end of the projection period.

Rainfall does not show an apparent relationship with either the adoption rate or the timing of adoption as the projected 75 per cent threshold. It is possible that such a relationship is simply non-existent, especially since the Rand and Western Transvaal are both the earliest and quickest adopters but also the highest and lowest rainfall areas respectively. But it goes without saying that the analysis is also hampered by the small number (7) of regional observations of differing sizes. Another limitation stems from the fact that the adoption and rainfall indicators represent regional averages, but both are location specific. In other words, production and rainfall is not distributed evenly across regions. Hence more granular data would be required for such an analysis.

However, other studies have shown that farmers in lower rainfall areas are more likely to adopt improved maize varieties. For example, Kaliba et al. (2000) showed that Tanzanian smallholders who farm in the relatively drier lowland areas of the country were 25 per cent more likely to adopt improved maize varieties.

4.5 Private hybrid adoption and rainfall

As stated earlier, the elite private hybrids replaced the public hybrids in rapid succession after their introduction in the mid-1960s. Although the share of public hybrids declined from 89.3 to a mere 1.4 per cent between 1970 and 1981, public hybrids saw a brief resurgence thereafter to peak at a 29.5 per cent share by 1986, before declining to an average of 3.2 per cent between 1990 and 1993 (Figure 4.5, panel a). The replacement of public by elite private hybrids can be disaggregated by maize type: In 1970 the share of white to yellow public S.A. hybrids was substantially higher at 93.8 versus 82.7 per cent, whereas both showed a concordant decline

[41] Note the number of weather stations vary across time.

thereafter, the white-yellow order was reversed post 1981. By 1986 the white public hybrids represented 24.6 per cent of total hybrid sales compared to a 33.9 share of yellow. This reversal between white and yellow carried through until 1993 with a share of 1.5 and 4.7 per cent for white and yellow public hybrids respectively.

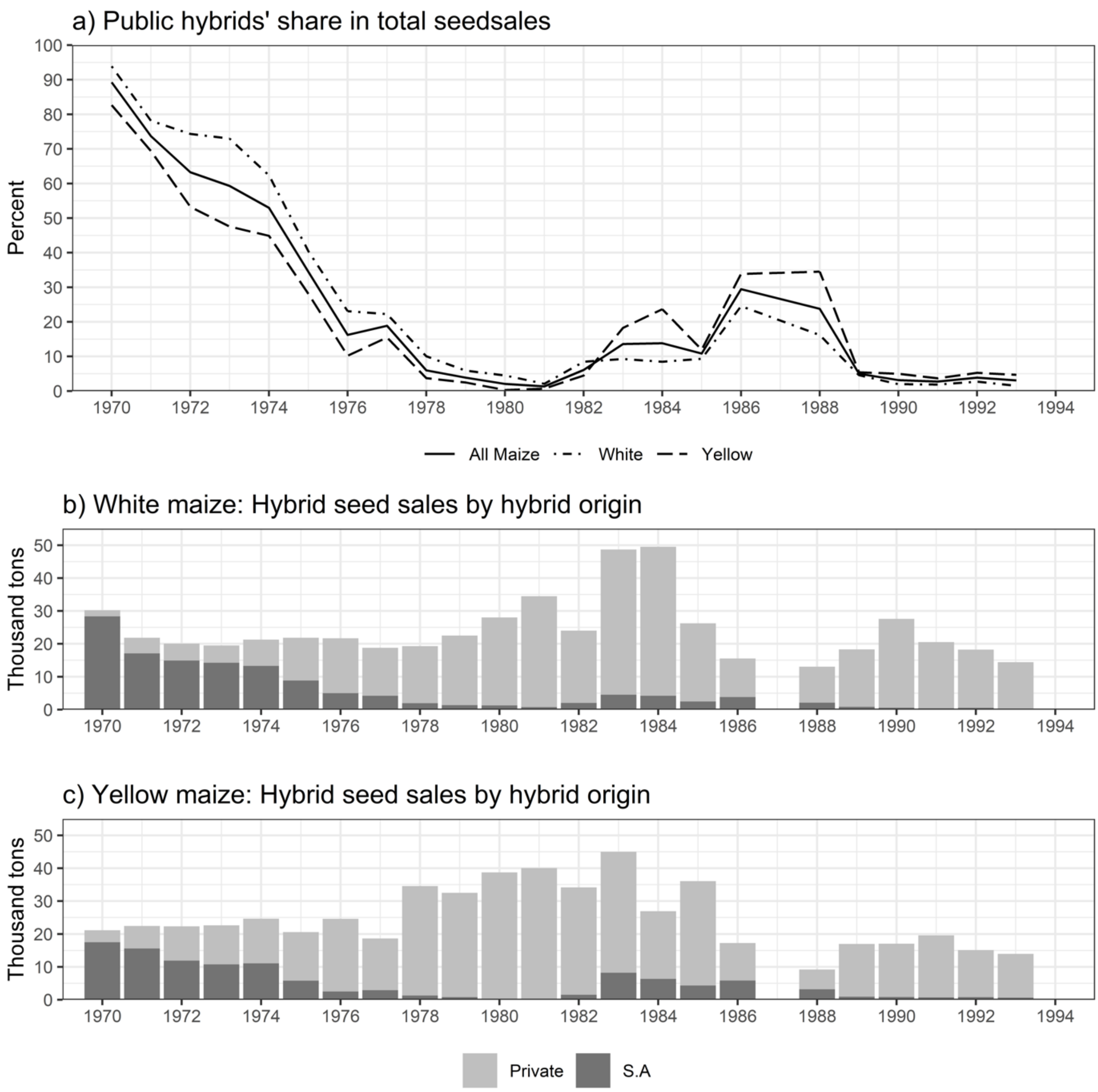

Figure 4.6: Share of public (S.A.) hybrids in total seed sales

Source: Maize Board Annual Reports (1972–1994)
Notes: No data reported for 1987

The exact cause of the brief reversal in the relative importance of public hybrids during the early 1980s is uncertain. It is worth noting that the period 1981 to 1985 was exceptional in the sense that the above average yields that propelled South African maize production to a high of 14.87

million tons in 1981 (only surpassed by 2014, 14.92 million tons) was followed by consecutive droughts (Greyling & Pardey, 2018b). A possible explanation is that the older public hybrids could have been more suitable under drought conditions, or farmers simply opted for the older public varieties as a cost saving measure. However, it could also have been a matter of seed supply since the resurgence in public hybrids also coincided with increases in total seed sales as shown in Figure 4.6 panels b and c. These increases were substantial, for example between 1982 and 1983 the demand for white hybrids showed a more than two-fold increase, while the demand for yellow hybrids increased by 34.1 per cent.

It is worth noting that the South African seed industry experienced substantial changes during the 1980s, with the number of private companies declining from ten to six, the state ceased to control the price of hybrid seeds and started to shift its duties of laboratory seed testing and seed certification to the private sector (Rusike, 1995). This took place in the context of a South African economy and agricultural sector in turmoil following the depreciation of the rand and increase in interest rates from 10.1 to 21.8 per cent between 1983 and 1984. As a result, interest payments became the single largest production cost to farmers. In addition, farmer support spending declined by 50 per cent after 1987, in part because of the partial deregulation of maize marketing in 1988 (Kirsten, Van Zyl & Van Rooyen, 1994).

Figure 4.7 provides a disaggregated perspective on the regional public hybrid displacement with the region name and growing season average rainfall shown on the right. It shows that farmers in drier districts were quicker to adopt the elite private hybrids and were also less likely revert to public hybrids during their resurgence in the 1980s. In fact, the lower the average rainfall of the region, the more subdued the public resurgence, with the lowest rainfall districts showing almost none. This suggests that relative drought tolerance was not a driver of the resurgence of public hybrids given the popularity of elite private hybrids in drier production regions; hence an alternative explanation should be sought for the resurgence of public hybrid use.

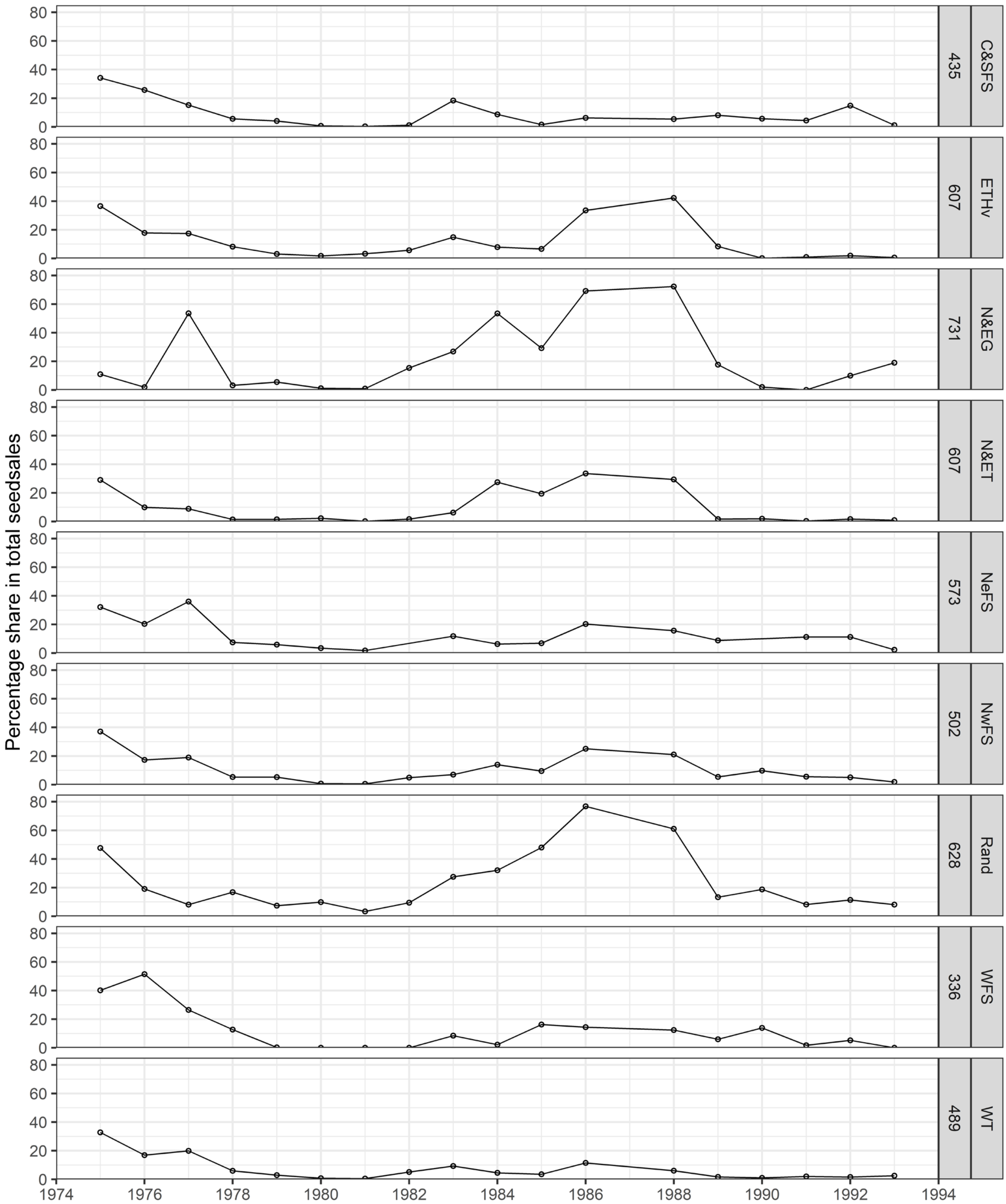

Figure 4.7: Share of public hybrids in total seed sales by maize region

Source: See text

Notes: See Figures 4.2 and 4.3 for meaning of abbreviated district names. Growing season average rainfall indicated to the left of region labels.

4.6 Measuring rainfall productivity

At this stage I know that the relative yield advantage of hybrid to open pollinated maize was greatest during droughts, but I cannot say whether drier regions adopted hybrid maize at a quicker rate or earlier date. But I do know that drier regions adopted elite private hybrids at an earlier data and were more steadfast after switching to it. Seeing as the selection for drought tolerance was a core objective of the early breeding programme, I attempt to estimate how successful they were in achieving this objective. To do so I calculate a simple rainfall productivity indicator as the yield per unit of rainfall:

$$IW_{it} = \frac{y_{it}}{R_{it}} \quad (3)$$

where IW_{it} is the rainfall productivity index of municipal district i during census year t, while y and R are the relevant average yield and growing season rainfall respectively.[42] The district level yield observations were obtained from the spatially standardised agricultural census data prepared by Greyling, Senay and Pardey (2018).[43] The average district level growing season rainfall is calculated using a spatial overlay with the Lynch (2004) data, but now I use the 2007 ADM 3 municipal boundaries to ensure that the boundaries agrees with the yield observations.[44] I exclude the Cape province as a predominantly winter rainfall area since most of the crop in this region is irrigated.[45] To ease the interpretation of my rainfall productivity indicator I transform it to a simple single unit index with 1950 as base year since it was the last census year before the adoption of hybrid maize. To summarise the temporal change in my index, I fit a Generalized Additive Model (GAM) with integrated smoothness estimation (see Wood, 2018; Wood, Pya & Säfken, 2016) to the indexes calculated.

Figure 4.8 shows the fitted model results with the shaded area showing the 95 per cent confidence interval around the estimate. It shows that rainfall productivity showed little change between 1918 and 1950 but increased sharply thereafter before levelling off at a 4-fold increase

[42] This is similar to the Rainfall Use Efficiency (RUE), which also takes into account the pre-season rainfall and the change in the soil profile water content between consecutive harvests (Bennie, Hoffman & Coetzee, 1995). The pre-season rainfall was excluded due to differences in soil water retention and management practises, while change in the soil water balance is unknown. While these assumptions would not invalidate the analysis, they could result in an overestimation of rainfall productivity.

[43] Agricultural censuses included: 1918, 1922, 1930, 1937, 1946, 1950, 1956, 1960, 1965, 1971, 1976,1981, 1983, 1988 and 1993. These were reported according to magisterial district boundaries (or ADM2, administrative district 2 boundaries). The production and area data were disaggregated to a five-arc minute cell or pixel that represents an area that is 10km^2 using the 2005 SPAM dataset (You et al. 2017) and re-aggregated to the 2007 ADM 3 municipal boundaries.

[44] The 2002 and 2007 censuses could not be included given the time period covered by Lynch (2004). Attempts were made to obtain more recent data from the South African Weather Service but without success.

[45] District level irrigation data is only reported in the 2002 and 2007 censuses.

by 1981 (relative to 1950) whereafter it inched upward to a 4.2-fold increase by 1993. The slowdown after 1981 can be contributed to various factors. From the figure it is clear that the growth in rainfall productivity accelerated during the 1970s, possibly because of the adoption of the elite private hybrids as discussed in Section 4.5. However, this process was completed by the early 1980, which could have contributed to the slowdown in yield growth. Adverse weather could also have been a contributing factor. While 1981 was characterised by exceptionally good yields, the same cannot be said for 1983 and 1993 since these census years coincided with droughts wherein they received 60 and 80 per cent of their respective long term (1918–1993) growing season average (Lynch (2004), own calculations), thus explaining the decline in the index.

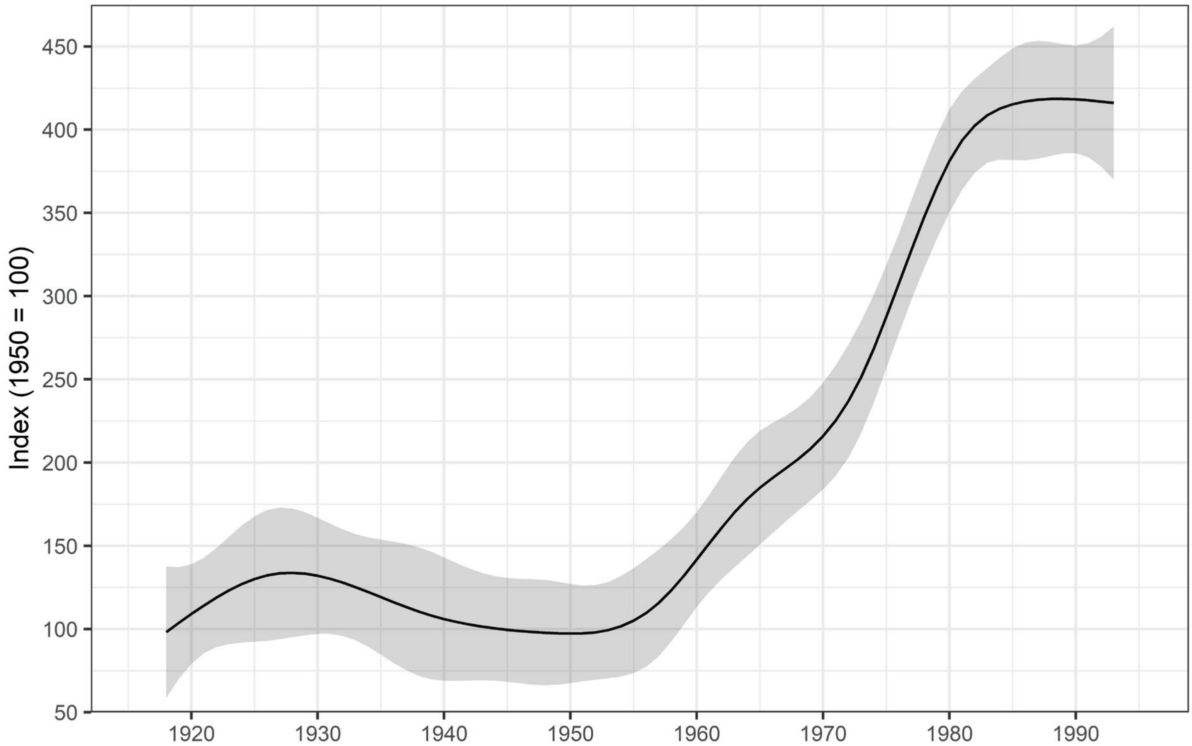

Figure 4.8: Rainfall productivity

Source: *See text*
Notes: *Base year, 1950*

Although the post–1950 increase in water-use efficiency coincides with the adoption of hybrid maize, in cannot be regarded as the sole driver thereof since it also coincided with the adoption of other yield increasing technologies such as fertiliser, pesticides, herbicides and others (see Liebenberg and Pardey 2012; Liebenberg 2013). During this time farmers also benefitted from research on improved farming practices that maximised rainfall utilisation in dryland production, especially maize and wheat. This includes research on the benefits of deep tillage practices whereby sandy soils are mechanically loosened to a depth of 1,200mm to ensure root penetration of up to 2,000mm, thereby enabling greater access to soil water and thus increased production and resistance to drought. Subsequent research also showed the advantages of combining this with a controlled wheel traffic and strip tilling production system. Herein equipment only traverses the field on established 'tramlines', thereby limiting compaction to these areas, which can be easily corrected during or after the season. In addition, the maize is planted in wide row widths of between 1,500 to 2,100mm[46] on the same strips each year, with only the soil underneath each row loosened prior to planting (Bennie & Botha, 1986; Bennie, Hoffman & Vrey, 1994; Bennie, Hoffman & Coetzee, 1995).

Albeit caveated, the objective of the hybrid breeding programme to improve drought tolerance seems to have been successful. This was also the case with the elite private hybrids given the continued increase in rainfall productivity following their adoption during the 1970s and their popularity among lower rainfall regions as discussed in Section 4.5.

4.7 Conclusion

The seven-fold increase in South African maize yields between 1950 and 2015, largely due to the adoption and continued improvement of hybrid maize, is remarkable. However, the fact that South African hybrid maize adoption lagged the U.S. by more than twenty years is surprising given the early efforts to import U.S. breeding techniques and material. A distinguishing difference between the two is the extent of private involvement in hybrid development and distribution. Unlike the U.S., where private seed companies played a central role from an early stage, the South African government curtailed private seed companies during the early stage of hybrid adoption. In addition to taking responsibility for hybrid breeding, multiplication and distribution, the State through the Hybrid Maize Scheme also set the price of hybrid seed too low to incentivise private investment. This was exacerbated by the fact that, unlike the U.S. where breeders enjoyed early protection of intellectual property and a formalised seed market, the same rights were only extended to South African breeders by the 1960s. This resulted in supply shortages, decreased overall research and development spending (as evidenced by the limited progress during the first decade of the Scheme's existence) and prevented private seed companies from accessing international breeding material prior to the protection of biological

[46] For comparative purposes 86 per cent of US maize is planted at 762mm with the remainder being planted at between 381 to 1000mm (Jeschke, 2018)

property rights. This study therefore echoes the findings of studies that stress the importance of plant variety protection for the securing of private research funding (Perrin, Kunnings & Ihnen, 1983; Knudson & Pray, 1991).

Collectively these factors delayed the initial hybrid development and adoption, and the limited progress of the Scheme slowed the rate of adoption once it got underway. However, the formalisation of the seed market in 1963 and the protection of biological property rights in 1964 enabled South African seed companies to access superior breeding material through strategic partnerships with U.S. seed companies. While the first 'elite' private hybrids were only registered in 1965, by 1978/9 they out-yielded the public hybrids by 41 per cent and consequently replaced their public counterparts by 1981. I also show that drier production regions adopted the elite private hybrids at an earlier date and were less likely to revert back to public hybrids thereafter.

The sub-national adoption of hybrid maize in South Africa, as in the U.S., showed wide regional differences both in the timing and rate of acceptance. Unlike the U.S. this cannot be attributed to differences in the relative importance of regions, since the smallest and second largest South African maize regions were the first to adopt hybrid maize, possibly due the more democratic allocation of research funding. I also cannot find a link between climate and the timing or speed of adoption, but I do find evidence that the hybrid advantage was greatest when yields were depressed during drought. In addition to confirming Sutch's hypothesis, I extend it by showing that this relationship is polynomial, hence the yield advantage of hybrids over OPVs increases at an increasing rate as OPV yields become more depressed.

Lastly, I test whether breeding efforts directed towards drought tolerance came to fruition by constructing a rainfall productivity indicator as an index that reflects the yield per unit of growing season rainfall. I find that while rainfall productivity was largely unchanged between 1918 and 1950 as the period prior to hybrid adoption, it showed a 4.2 -fold increase between 1950 and 1993. While not entirely attributable to public R&D spending, it contributes yet another example to those highlighted by Alston et al. (2010) of how the persistence in such spending pays.

The South African hybrid maize breeding programme provides pertinent example of how drought focussed research efforts can deliver transformative results. The finding that the relative advantage of hybrid maize is greatest during droughts, and that this advantage increases at an increasing rate as yields become more depressed, is especially important when devising climate adaptation strategies for smallholder farmers. This suggests that the use of hybrid maize should be promoted among smallholder farmers, not only to increase overall productivity but also to mitigate climate risk, thereby increasing their overall climate resilience and thus food security. This is currently under-emphasised within the climate change literature; in some studies it is included as one several adaptation strategies (see for example Stringer et al., 2009), but others disregard it completely (see for example Morton, 2007; Cooper et al., 2008). An notable exception is Hellin et al (2014), who recommend the adoption of heat and drought stress-tolerant improved maize varieties as a means whereby smallholders can adapt to clime change. They continue that such a strategy is not without challenges, in Mexico the adaption has been low since smallholders prefer their local land races because of culinary, agronomic, and cultural considerations. Hence, they suggest that public institutions should focus on both the promotion of improved maize varieties and improving landraces themselves.

Chapter 5:
Politics, production and productivity: 20th century farm policies and the spatial consequences for maize production

5.1 Introduction

For much of the 20th century, South African agriculture took place in the presence of a potent, albeit evolving, package of distortionary farm (and broader economic and social) policies. The policy foundation for the transition from suppressing to supporting the agricultural sector took place well before the start of overt Apartheid, with these policies being put into practice beginning with the Malan government in 1948 (Greyling, Vink & Van der Merwe, 2018). These ushered in a golden age of support wherein South African agriculture operated under a host of policy and institutional instruments that favoured agriculture relative to other sectors of the economy. These sectoral policy distortions occurred in the context of other policies that either de facto or de jure favoured commercial (mostly white) over smallholder (largely black) farmers. Discriminatory policies against smallholder agriculture included restrictions on precisely where in the country these farmers could grow their crops, the total amount of land accessible to black farmers, and limits to their access to markets and agricultural support measures (see for example Bundy, 1988; Van Onselen, 1996; Vink, Kirsten & Van Zyl, 2000). Policies that favoured commercial producers included subsidised long-term credit, farmer settlement programmes, controlled marketing and capital tax concessions (see for example Brits, 1969; De Klerk, 1983; Vink, 1993; Letsoalo & Thupana, 2013).

Although the racially-based (discriminatory) Apartheid policies persisted for decades, they were eventually dismantled, beginning during the early 1980s and accelerating with the de Klerk government in 1991–92 that ushered in the Mandela government with the 1994 election, the first under universal suffrage in the history of South Africa. 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 (i.e., post–1994) liberalization of international trade and deregulation of domestic agricultural marketing programs, processes that were all largely complete by the late–1990s (Vink et al. 2017).

I show that the changing orientation of these farm policies had a profound effect on the structure of production agriculture in South Africa. I 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 per cent of the 3.67 million hectares sown 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 & Pardey, 2018b). It is also an important source of calories, accounting for 28 per cent of the country's 3,022 calories consumed per capita per day in 2013 (FAO 2018).[47]

To assess the policy-production-productivity interactions, I compiled a timeline of policy prescriptions and practices that waxed and waned over the course of the 20th century. For extended periods of time, albeit less so of late, these polices provided substantial targeted support to production agriculture (including maize), and for much of that time favoured commercial (largely white) over smallholder (mainly black) farming interests. I juxtaposed that policy timeline against a time-series decomposition of a new, historical (1904–2015) compilation of maize production statistics—specifically maize area planted and grain yields—and relative domestic versus international farm gate prices.

An additional, and especially hard won, feature of my compilation is the spatial disaggregation of maize production indicators (i.e., yield, planted area, and output) to a spatially standardized set of municipal boundaries. Given the complex interactions between spatially variable environmental factors (including soil, temperature, rainfall, and pests and diseases) and crop genetics, the realized yield and output performance of a crop are closely linked to these environmental fundamentals. Thus, cropping agriculture is an intrinsically location specific production process, but these locational choices are also subject to distortionary policy influences.

To presage my main findings, I show that the shifting orientation of distortionary farm polices accord closely with changes in maize production patterns. The period during which the South African policy landscape most favoured agriculture —beginning in the late 1930s and

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[47] Maize is also the most important staple food crop throughout much of sub-Saharan Africa (hereafter Africa), accounting, on average, for 18 per cent of the region's per capita calorie consumption (of 2,556 calories per person per day) in 2013 (FAO 2017). A large share (17 per cent) of the region's maize production occurred in South Africa.

tailing off by the 1990s— was when the area under maize production expanded markedly and yield growth took off. Notably, during this same period, maize marketing interventions resulted in domestic maize prices that generally exceeded a reference external (specifically a United States average) maize price. As these farm-favourable policies were gradually abandoned, beginning in 1983, the area under 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[48]. The rate of growth in maize yields began to accelerate during the mid–1990s as the policy bias towards agriculture diminished. The internal–external price differentials also gradually diminished so that by 2015 the price received by South African farmers was 3.9[49] per cent above that of U.S. farmers, compared to an average of 31.1 per cent above the U.S. price between 1948 and 1998 (see Figure 2).

Notably, my new spatial production data reveal another important, and hitherto little studied (at least by economists), policy-induced distortion in the location of agricultural production. The favourable production policies also induced a substantial expansion of the physical footprint of production in those areas that had hitherto supported little (if any) maize production. I show that the policy-induced expansion of maize area drew in new locations with relatively lower maize yields than the areas that supported the bulk of the country's maize production prior to these policy distortions. In other words, the policies sufficiently undermined environmentally-based spatial comparative advantages to spur production in these less-favourable parts of the country. 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. The exceptions to this post-reform area reallocation are the irrigated areas along the Vaal and Orange Rivers, and to a lesser extent the Western and Southern Cape region. Government support to the instillation 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.

[48] Commercial maize area.

[49] As a 5-year centred average, see Section 5.2 below for the sources.

5.2 Data: Measuring maize

5.2.1 Aggregate production

Quantifying the historical pattern 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 my series spanning the period 1918–2015, often reflecting shifts in prevailing policy and political norms. The data problems I 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 inconsistencies, I endeavoured to cross-reference my 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.

For my time-series analyses I 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 & Pardey (2018) for more specific details). South African maize production comes from both commercial and smallholder producers. Unfortunately, the smallholder production (specifically planted area and average yields) data are less comprehensive (and less reliable) than data on commercially grown maize, and so my formal assessment of the time-series properties of South African maize production relies only on my commercial maize compilation. Nonetheless, for the period 1935–2015 in which I compiled both commercial and total (inclusive of smallholder) production, the series closely track each other.[50]

My time-series decomposition of maize price differentials used the average price received by South African farmers (primarily taken from Abstract of Agricultural Statistics (1970, 2018) and SAGIS (2018)) and average price received by U.S. farmers (taken from USDA (2018)). Both price series were deemed representative of the national average maize price received by farmers. The U.S. price is measured in real (2009) U.S. dollars, the South African price in real (2009) Rand,

[50] For example, a linear regression of the form $y = \alpha + \beta x$, where y is total maize production (in tons) and x is the commercial maize production, the $R^2 = 0.9986$, $\beta = 1.02$(and is statistically indistinguishable from 1.0), and $\alpha = 343\,158$ (close to the period average area sown to smallholder production of 374 238 tons). My estimates suggest that the smallholder share of total South African production peaked in 1924 at 28.4 per cent, declining to 13.0 per cent of total national production by 1960, 4.3 per cent in 1974, and recovered to 6.3 in 2015 (Greyling and Pardey 2018b, Figure 3, Panel a).

converted to 2009 U.S. Dollars after deflation using the period average official exchange rate as published by The World Bank (2018).

For my assessment of the spatial production implications of the spatialized South African maize output, area and yield data used in this paper I primarily drew on 17 national agricultural censuses conducted by Statistics South Africa and its prior variants; the first agricultural census in my sample reports data for the agricultural year ending in 1918 and the last ending in 2007.[51]

5.2.2 Spatializing measures of maize production

To assess the historical performance of the South African maize sector from a spatially explicit perspective required compiling and standardizing a spatial representation of sub-national production, area planted and yield data. From the *Agricultural Censuses* I extracted tabulated, subnational (specifically magisterial district) data for 17 census years beginning in 1918.[52] 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, 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.

Using a slightly 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 several printed map sources spanning the years 1918 to 2007, as described in detail by Senait et al. (2018). Then all the district data were mapped to the district boundaries for the closest available year, and each of the districts were subsequently divided into arrays of five arc-minute pixels.[53] 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

[51] The discrepancy between the total production and area planted reported in the 2002 and 2007 Censuses, and the totals reported in the Abstract of Agricultural Statistics and other sources such as SAGIS is well known. Since this paper concerns itself primarily with differences in the spatial allocation of the area planted and yield, these discrepancies are deemed less important if the error is equal across all districts, but it is uncertain if this is the case. This will have to be tested in future research.

[52] Specifically, the agricultural censuses report on 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. Thus, 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 (ADM 3), thus they represent a set of "ADM 2.5" boundaries.

[53] 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

area obtained from the 2005 SPAM dataset (You et al. 2017). This does not imply that the pixels' share of the district's production and area was invariant between 1918 and 2007 but rather that the maize suitability of each was invariant.

Finally, the raster data were then re-aggregated according to year–2007 district boundaries, resulting in a standardized panel of production and harvested area data, all mapped to the 2007 ADM 3 municipal district boundaries.

5.2.3 A chronology of South African maize policies

Maize has not always been such a dominant (food) crop in South Africa.[54] Burtt-Davy (1914, pp. 13–14) writes that maize found its way to South(ern) Africa by way of Portuguese seafarers, prior to the establishment of the Cape of Good Hope settlement of the Dutch East India Company in 1652, but remained principally a (semi-)subsistence food crop until the middle of the 19th century.[55] 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;Gilbert 1933; 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,' with the towns of Carolina, Mafeking and Ladybrand located in the central north-eastern part of the country forming the corners of this triangle (Saunders 1930).

South African (white and yellow, all farmers) maize production totalled just over 327,000 tons in 1904 (Saunders 1930, Table 4), increasing substantially thereafter to around one million tons by 1915 (Greyling & Pardey, 2018b), and 2.1 million tons[56] by 1925 (Saunders, 1930, Table 4).[57] While impressive, the expansion of maize production during the early decades of the 20th century was hampered by a policy regime that favoured mining interests over those of the broader agricultural sector (Greyling, Vink & Van der Merwe, 2018). A raft of support policies and

[54] The principal crops grown in South Africa prior to the expansion of maize production were sorghum and millet (Burtt-Davy, 1913).

[55] Other commentators have other opinions about the early introduction of maize to South(ern) Africa. Goodwin (1953, p. 13) dated the earliest cultivation of maize on the African continent to 1554 (at Takoradi on the Gold Coast) but reports that "[maize] had not reached the Cape by 1652… [and that] Van Riebeeck [a Dutch navigator and colonial administrator who founded Cape Town in 1652] asks that specimens of Indian Corn … be sent to the Cape for local experiment." Jeffries (1967) claims it was introduced into Southern Africa much earlier by the Nguni people about 1400 and later by the baVenda. For further commentary on early maize production in (South) Africa see also Miracle (1966), Brits (1969), McCann (2001) and Bernstein (2004).

[56] See Greyling and Pardey (2018b) for an exposition on the reported and aggregated production and area totals.

[57] Bosman and Osborne (1924) and the Union Statistics (1960) report a similar 1904 production total of 361,169 tons.

government managed marketing practices introduced during the 1930s and 1940s shifted the policy landscape from one of suppressing to supporting agriculture (Jayne & Jones, 1997; Greyling, Vink & Van der Merwe, 2018), with the nominal rate of assistance peaking at 31 per cent between 1980 and 1981 (Kirsten, Edwards & Vink, 2009). The major policy events during this and subsequent periods are summarised in Table 5.1. These are also classified with respect to the distortionary and discriminatory nature of their objective, with the latter subdivided into *de jure* and *de facto* to serve as an indication of whether the discrimination against black farmers was explicit or implicit.

The area under maize continued to expand, peaking at 5.6 million hectares in 1964 (Greyling & Pardey, 2018b). It shrunk steadily thereafter to just 3.0 million hectares in 2015. Despite this decline in maize area, production continued to grow during the latter half of the 20th century as average yields continued to increase, with production peaking at 14.87 million tons in 1981. This record was superseded only 33 years later in 2014, albeit marginally so at 14.93 million tons.

All these changes in maize production occurred in tandem with, and often in response to, the changes in government policies and practices summarised in Table 5.1, along with changes in grain milling and rural transportation infrastructure, plus research- and policy-enabled changes in input use (including irrigation, improved seed and mechanization). In addition to the large changes in the national area and output totals (and, implicitly, national average yields), this constellation of policy, technological, and logistical factors had hitherto unstudied consequences for the location of agricultural production in South Africa and its production cum productivity implications.

Table 5.1: 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 Long term loans to farmers who could not access credit from commercial banks	Vink Ortmann & King	1993 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 per cent of the sale price; and the provision of advances for production costs. 2) Standardized the acquisition, exchange, and disposal of state lands for white settlement	Letsoalo & Thupana The World Bank	2013 1994	299 52
1913	Land Act	X	X		Restricted black farmers to 7.3 per cent 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 per cent 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 Vink	1969 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
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	

Year	Name	Distor-tionary	Discri-minatory		Description	Source		
			De jure	De facto		Author	Year	Page
1962	Orange river scheme				Initiation of the Orange River scheme that would eventually expand the irrigated area in South Africa by 40 per cent	Water Wheel	2010	21
1966	Agricultural Credit Act	X			WHY NO DESCRIPTION OR SOURCES LISTED HERE?			
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
1996	Marketing of Agricultural Products Act, No. 47				Deregulation of agricultural marketing starting 1998	Vink et al.	2018	338
2005	Cooperatives Act				Modernises existing cooperatives act	Ortmann & King	2007	47

5.3 The nexus between policy, production and productivity

5.3.1 Discriminatory policies: Smallholder–Commercial dualism

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, Vink & Van der Merwe, 2018). To stem competition from black farmers, various 'apartheid' policies were enacted by the state in favour of the interests of white farmers. These discriminatory policies led to the establishment of a dualistic agricultural system, wherein 'white agriculture' enjoyed the benefits of agricultural support programmes, subsidised credit and controlled marketing. Not only were black farmers excluded from accessing these income support and marketing arrangements, their direct access to land was also restricted to just 14 per cent of the available farmland in South Africa by way of the 1913 Land Act (and its successor laws).[58] To circumvent these land access restrictions, black farmers opted for various (informal) tenure, sharecropping, 'squatting' and other arrangements, all of which the state endeavoured to thwart over the years (see, for example, (Trapido, 1971; Bundy, 1972; Morris, 1976; Marcus, 1989; Van Onselen, 1996; Greyling, Vink & Van der Merwe, 2018). Nonetheless, efforts to work around blatantly discriminatory policies were substantial; at its peak during the 1950s more than half of smallholder maize was produced on areas outside the former homeland reserves (Greyling & Pardey, 2018b).

Ultimately these policy measures succeeded in establishing 'two agricultures;' one characterised by a relatively small (in numbers) group of mostly white 'commercial farmers,' the other characterised 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 that are central to the spatially explicit analyses in this paper. Nonetheless, Greyling and Pardey (2018b) estimated that while smallholders accounted for approximately 30 per cent of total maize output in 1911, that share dropped to about 20 per cent by the late 1930s and fell further to around 10 per cent by the mid–1960s, where it remained until the end of apartheid in 1994. Despite the repeal of all racially based land measures 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

[58] 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.

per cent by 2007 (Greyling & Pardey, 2018). 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 their uptake of modern crop varieties and other agricultural technologies. Another manifestation of this agricultural dualism is that the maize yields of smallholders were estimated to be around 41 per cent of the yields realized by commercial farmers in 1935 falling to just 18.2 per cent of commercial yields by 2003, but then widening again to 37.3 per cent by 2015 (Greyling & Pardey, 2018).

This agricultural dualism also extends to the type of maize produced. White maize, which is predominantly consumed by humans as porridge (called mieliepap in Afrikaans, or phutu in Zulu), represents a major component of the South African maize market. It constituted around 56 per cent of total commercial maize production during the period 1960–2007 (Greyling & Pardey, 2018).[59]

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 per cent of total production in the decade ending in 2007 (and 86 per cent of production over the entire 1918–2007 period).

5.3.2 Commercial production overview

Figure 5.1 shows the production (solid line, panel a), area planted (panel b) and yield (solid line, panel c) of commercial maize production in South Africa between 1918 and 2015. Commercial maize output increased dramatically over this 89-year period, from just 0.9 million tons in 1918 to a peak of 14.4 million tons in 1981.[60] From 1918 to peak production in 1981, commercial harvested area increased less than 3-fold (compared with an 11-fold increase in production), from about 1.8 million hectares to 4.3 million hectares, while average yields increased just over 4-fold (from 0.5 to 2.1 tons per hectare). Peak area occurred earlier than peak

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[59] 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 2018b).

[60] The 2014 commercial maize total of 14.3 million tons came close to that 1981 record. However, the 2014 figure was an anomalous total for its time (where the five year average for the period 2012-16 was 11.2 million tons), attributable to an exceptionally favourable growing season in 2014 (USDA, 2014).

…

production (1968 versus 1981), given that maize yields continued trending up over the entire period, albeit with varying rates of growth over time (Greyling & Pardey, 2018). An average of 12.1 million tons was produced in 2015, and although this is less than the 1981 peak, it nonetheless represents a 7.5-fold increase over 1937 production levels. [61]

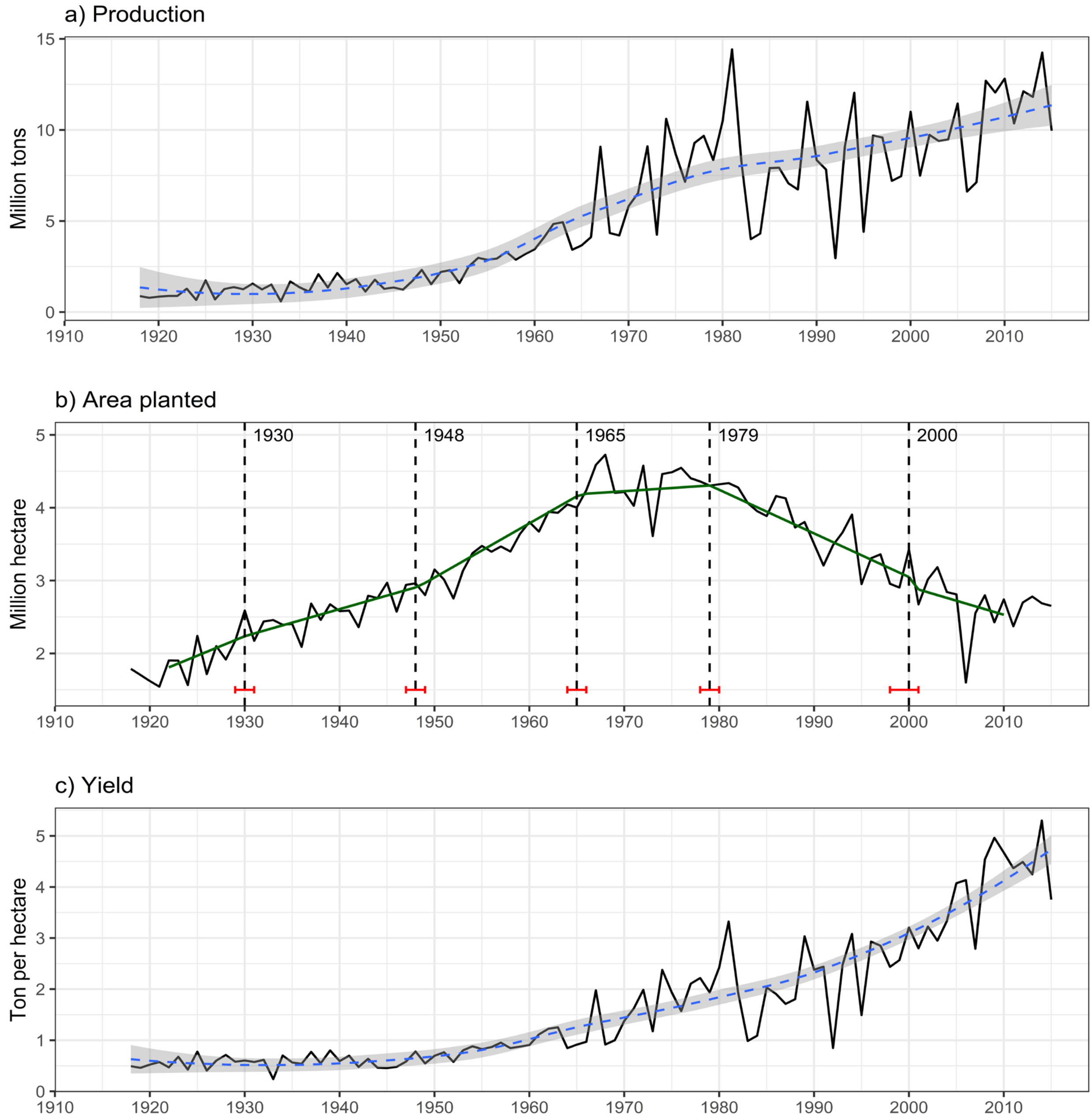

Figure 5.1: Commercial maize production, area planted and yield, 1918–2015

Source: Panel a) and c): See Greyling and Pardey, 2018b. Panel c): See text

Notes: Panel a) and c): The dotted line shows a fitted loess regression with the grey area around the fitted function showing a 95 per cent confidence interval for each plot.
Panel b): The fitted trend is shown in green with the estimated break date indicated by the vertical dotted line. The 95 per cent confidence interval around the break is shown in red.

[61] Five-year average centred on 2015.

5.3.3 The temporal concordance of policy and production in the commercial sector

Empirical strategy

To test the temporal concordance of policy and production, I compare the policy timeline above with empirically identified structural breaks in the maize area planted and real price series by using the procedures devised by Bai & Perron (1998, 2003a,b). This technique is novel in allowing for the endogenous detection of both the number and location of structural breaks. In other words, the number and location of breaks need not be specified beforehand since it is computed from the data provided. To this end, the technique uses a dynamic programming approach that applies the Bellman principle. In addition, the procedure enables the computation of confidence intervals around break points using a distribution function.[62]

I examine the maize price breaks by regressing the real maize price on a constant to determine the time varying changes in the intercept (δ) of the price function (1), thereby estimating the average real dollar price received by farmers during each break period. The price function is specified as follow:

$$P_t = \delta_j + u_t, \qquad t = t_{j-1} + 1, \dots, t_j, j = 1, \dots, m + 1 \qquad (1)$$

Where P_t is the real dollar (2009) price of maize during period t, δ_j is the intercept of the respective estimated break periods and u_t is the error term. Since the breakpoints are unknown, the objective of the analysis is to determines both their number m and location $t_j (j = 1, \dots, m)$. By convention $t_0 = 0$ and $t_{m+1} = T$. In addition to the above, a break parameter (h) must be set for the estimation of the breakpoints. It defines the minimum break period length, either in absolute terms as the minimum number of years or relative terms as the percentage share of all observations per segment. A relative share of between $h = 0.1$ and $h = 0.15$ is typical (Zeileis et al., 2002), but can be set as high as $h = 0.2$ if serial auto-correlation is allowed (Bai & Perron, 2003a: 15).

Similarly, I the test for the area breaks by regressing the log of area planted (a_t) on time (tt) to establish the break period average area growth rate (β_j) and break period intercept (α_j). The error represented by ε_t. The model is specified as follow:

$$a_t = \alpha_j + \beta_j tt + \varepsilon_t, \qquad t = t_{j-1} + 1, \dots, t_j, j = 1, \dots, m + 1 \qquad (2)$$

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[62] We implement my analysis in R using the "*strucchange*" package developed by Zeileis et al. (2002). It implements the Bai & Perron (2003a,b) procedure but does not allow partial break models. For more information see Zeileis & Kleiber (2005). I also want to thank Achim Zeileis for his help with the implementation.

Table 5.2: Maize price breaks (1911–2015) (2009 dollars)

Coefficient estimates four breaks ($h = 0.1$)				
$\hat{\delta}_1$	$\hat{\delta}_2$	$\hat{\delta}_3$	$\hat{\delta}_4$	$\hat{\delta}_5$
1911–29	1930–42	1943–62	1963–87	1988–15
359.17 **	265.69**	399.91**	302.35**	168.72**
(12.54)	(4.12)	(13.83)	(6.59)	(10.55)
Corresponding breakpoint estimates				
$\hat{t}_1$	t_2	$\hat{t}_3$	$\hat{t}_4$	
1929	1942	1962	1987	
(1924–1934)	(1941–1945)	(1961–1963)	(1986–1988)	
Adjusted R^2	0.98			
F (5,100)	1098.00**			

Notes: In brackets the standard errors (robust to serial correlation) for $\hat{\delta}_i = (i = 1, \ldots, 5)$ *and the 95 per cent confidence intervals for* $\hat{T}_i(i = 1, \ldots, 4)$
Breaks were endogenously chosen based on the Bayesian Information Criterion (BIC)
***Denotes statistical significance at the 5 per cent level*

The price break model results are shown in Table 5.2. I find four statistically significant price break points ($\hat{t}_i$) in 1929 1942, 1962 and 1987 with the 95 per cent confidence interval around the respective breaks shown in brackets. The incept estimates ($\hat{\delta}_i$) represent the period average price received by farmers with the robust[63] standard errors showed in brackets. With respect to area (Table 5.3, Figure 5.1), I find five statistically significant area breaks ($\hat{t}_i$) as 1930, 1948, 1965, 1979 and 2000, with the 95 per cent confidence interval also in brackets. The coefficient $\hat{\beta}_i$ shows the average annual area growth per break given the log specification of the model; the robust standard errors are also shown in brackets. These results are incorporated within the discussion below to show the concordance between them and the changing nature of distortionary farm policies.

[63] Wald tests of estimated coefficients using the Newey–West estimator

Table 5.3: Area breaks as logged 10 year centred moving average (1923–2011)

Coefficient estimates five breaks ($h = 0.1$)					
$\hat{\boldsymbol{\beta}}_1$	$\hat{\boldsymbol{\beta}}_2$	$\hat{\boldsymbol{\beta}}_3$	$\hat{\boldsymbol{\beta}}_4$	$\hat{\boldsymbol{\beta}}_5$	$\hat{\boldsymbol{\beta}}_6$
1922–30	1931–48	1949–65	1966–79	1980–00	2001–11
0.029**	0.014**	0.022**	0.002**	-0.017**	-0.013*
(0.001)	(0.000)	(0.000)	(0.001)	(0.000)	(0.005)
Corresponding breakpoint estimates					
$\hat{t}_1$	$\hat{t}_2$	$\hat{t}_3$	$\hat{t}_4$	$\hat{t}_5$	
1930	1948	1965	1979	2000	
(1929–1931)	(1947–1949)	(1964–1966)	(1978–1980)	(1998–2001)	
Adjusted R^2	0.98				
F (3,86)	73.58**				

Notes: In brackets is shown the standard errors (robust to serial correlation) for $\hat{\boldsymbol{\delta}}_i = (\boldsymbol{i} = \mathbf{1}, \dots, \mathbf{5})$ and the 95 per cent confidence intervals for $\hat{\boldsymbol{T}}_i(\boldsymbol{i} = \mathbf{1}, \dots, \mathbf{4})$
Breaks were endogenously chosen based on the Bayesian Information Criterion (BIC)
**Denotes statistical significance at the 5 per cent level*
***Denotes statistical significance at the 1 per cent level*

5.3.4 Policy and price concordance: Implementation and reversal of controlled marketing

While most of the policies highlighted in Table 5.1 affected the maize industry, State interventions in commodity markets served as the cornerstone of support. In this regard four policy events shown in are of special interest, namely the promulgation of the Agricultural Marketing of 1937, the election of the pro-farmer National Party in 1948, the partial deregulation of maize marketing in 1988 and the implementation of the Marketing of Agricultural Products Act of 1996 that resulted in virtually complete deregulation by 1998.

Pre-regulation

The first step towards 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', as the cooperation between the mines (as a major maize buyer) and maize farmers (Trapido, 1971; Morrell, 1988; Greyling, Vink & Van der Merwe, 2018) was styled. However, the cooperative movement only started to gain traction as a result of growing discontent within the hegemony of maize and gold that drove bigger farmers to cast their lot with their smaller compatriots (see

Greyling, Vink & Van der Merwe, 2018). This 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 cooperatives increased from 54 to 416, with their total membership expanding from 12 800 to 85 600. By 1932 the Central Agency (CA), as their overarching collective marketing body, controlled 60 per cent of all maize sold nationally during that year (Brits, 1969). Morrell (1988) argues that the CA was ineffectual in ensuring better prices for farmers; this is illustrated by the break model, which shows a decline in the average maize price from 359.17 dollar per ton between 1911 to 1929, to 265.69 dollar per ton between 1930 and 1942 (Table 5.2). This also concords with a slowdown in the area expansion from an annual average of 2.9 per cent realised between 1922 to 1930, to an average of 1.4 per cent between 1931 and 1948.

The regulated maize market

The objective of collective marketing was realised with the promulgation of the Marketing Act of 1937, which replaced the CA. Hailed as the 'Magna Carta of South African agricultural policy during the 20th century' (Stanwix, 2012), the Act and its subsequent extensions eventually controlled the marketing of 90 per cent of agricultural output during most of the 20th century (Brits, 1969). In broad terms the Act had the objective of ensuring the 'orderly marketing' of agricultural produce through the establishment of 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 fixed price system that established the Board as the sole maize buyer and seller of all maize in South Africa in accordance with a pan-seasonal and pan-territorial price. In other words, throughout the season the Board purchased maize at fixed prices irrespective of delivery and sold it at fixed price[64] throughout the season irrespective of purchasing location. The Board also had the monopoly on all maize exports and imports (Brits 1969). The Board determined the price of maize before the start of each season through farmer surveys, with the price set at the average surveyed production cost plus an allowance for operator's earnings[65] (Brits, 1969). For storage and handling the Board appointed

[64] As the producer price plus transport, storage and handling costs. Pan territorial pricing was enabled by the cross subsidization of transport costs by producers close to consumers and vice versa. The system also rendered the MB as the sole importer and exporter of maize, as stabilization was used to capture profits or losses of exports (Vink, 2012).

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

local agents to act on its behalf; this was mostly entrusted to farmer cooperatives, thereby establishing them as regional monopolies (Kassier Committee, 1992; Vink, 2012).

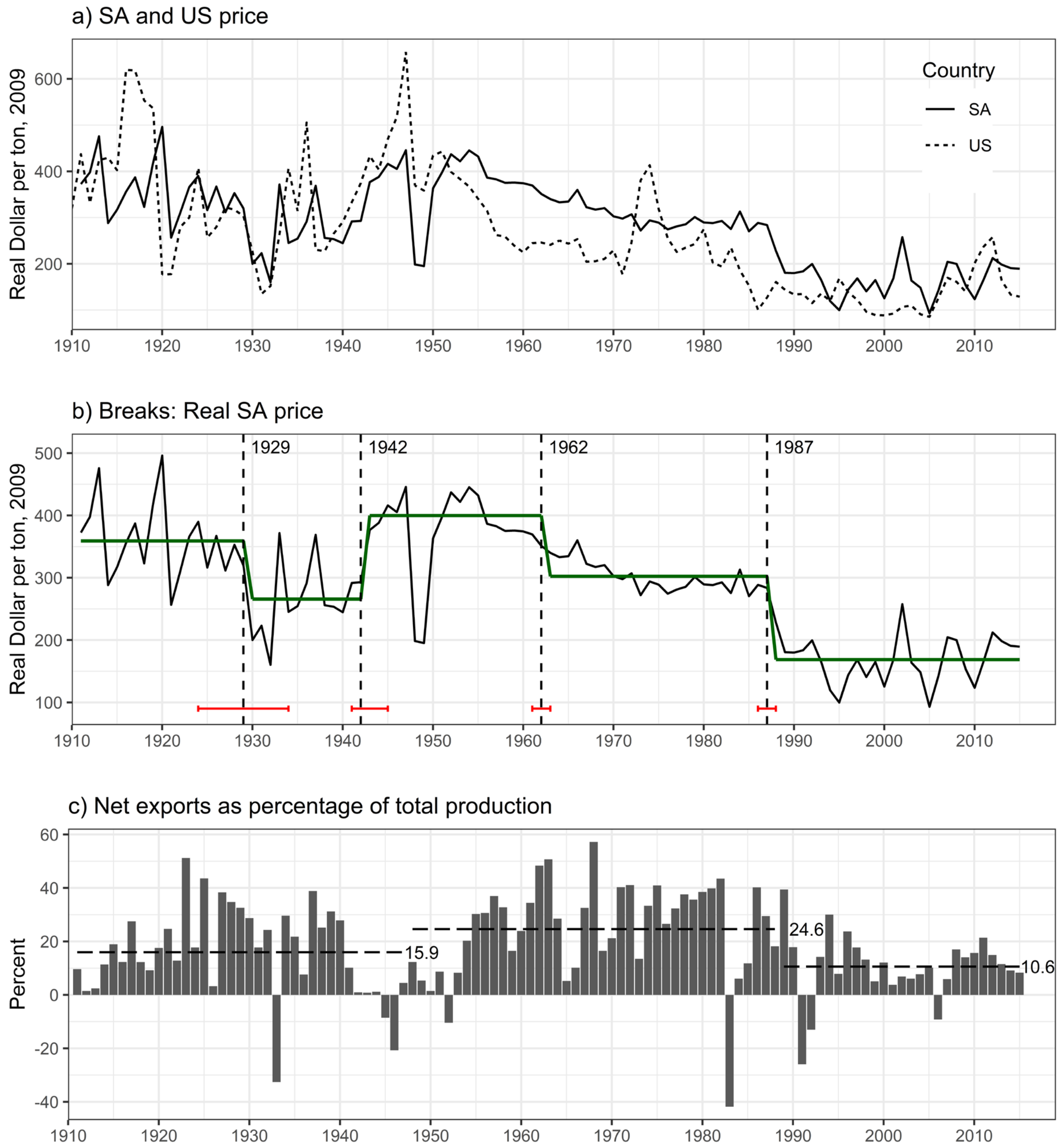

Figure 5.2: Prices and trade: SA vs U.S., SA price breaks and net trade share

Source: *See text*

Notes: *Panel b): The fitted trend is shown in green with the estimated break date indicated by the vertical dotted line. The 95 per cent confidence interval around the break is shown in red. Panel c): The period average net export share is shown by the dotted horizontal line. Periods: 1911–1948, 1948–1988, 1989–2015*

The implementation of the Act is reflected in the price break analysis given the increase in the average price from $266 per ton during the preceding period to $400 per ton from 1942 to 1962 (Table 5.2, Figure 5.2 panel b). While somewhat slower to respond, the average rate of area expansion accelerated from 1.4 per cent per annum between 1931 and 1948 to 2.2 per cent from

1949 to 1965 (Table 5.3, Figure 5.1 panel b). Greyling, Vink & Van der Merwe (2018) argue that the Act was only leveraged to the farmers' advantage after the pro-farmer National Party came into power in 1948. This is evidenced by the fact that South African maize price was consistently above the world price during most years in the second half of the nineteenth century, as shown in Figure 5.2 panel b.

The inflated price was inevitable if allowed by the state 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[66] (Brits, 1969; Vink, 2012). 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 maize price (Brits, 1969; Vink, 2012). This incentivised the expansion of production into marginal regions (see for example Brits, 1969; Van Zyl, Fényes & Vink, 1992; The World Bank, 1994; Vink, 2004, 2012) and resulted in the production of substantial surpluses. Net exports as percentage of total production increased from 19.9 per cent before 1948 to 24.6 per cent between 1948 and 1988 (Figure 5.1 panel c). All the while the South African farm gate price was mostly maintained above the U.S. farm gate price; hence these surpluses had to be exported at a loss, with the taxpayer having to foot the bill because the export stabilisation fund was continually in arrears.

The reduction in the average maize price from $400 per ton to $302 per ton between 1963 and 1987 cannot be attributed to any specific policy event but rather follows the decline in the U.S. (global) price (Figure 5.2, Table 5.2). The decline in the real price predates the stalling in the area expansion of just 0.2 per cent between 1966 and 1979. After 1979 the marginal area expansion transitions into an annual average decline of 1.7 per cent that persisted until 2000.

Post-regulation

The first step towards the deregulation of 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 not be carried over to the next financial year. This effectively forced the board to link the South African price to the world price (Vink, 1993, 2012). This is echoed in the price break analysis, which reflects an almost 50 per cent decline in the average price from 302 to 169 dollars

[66] One could argue that the MB did not have the final say in setting the price since the final decision rested with the Minister of Agriculture, but such a rebuttal was unlikely between 1948 and 1982 given the pro-farmer political regime at the time (Vink, 2012; Greyling, Vink & Van der Merwe, 2018).

per ton after 1988, an average level around which it remains thereafter. The *de jure* deregulation of agricultural marketing 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 coincided with the liberalisation of trade and increased consumer spending, especially through greater animal protein consumption (Ronquest-Ross, Vink & Sigge, 2015) that increased the demand for maize. The increased demand slowed the annual decline in the maize area planted to 1.3 per cent (from 1.7) after 2000 (Table 5.3, Figure 5.1panel b), with planted area stabilising since 2000.

While the spatial impact of removing these policies is yet to be quantified, Breitenbach & Fényes (2000) argued that farmers shifted their marginal maize hectares into planted pastures, and Vink (2004) postulated that the reversal of the spatial distortions resulted in a north-eastward shift in production. Vink et al. (2000) also suggested that it led to an increase in average yields and average farm size.

5.4 South African maize production: a spatial assessment

Location really matters for the productive performance of agriculture (Beddow et al., 2010; Beddow & Pardey, 2015), and a host of location-centric questions stand unanswered. For instance, did the geographical pattern of maize production in South Africa also return 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 it was areas with less favourable agroecological attributes that benefited from the supportive policy environment of the first half of the 20th century as Brand et al. (1992) claimed? Have these same areas lost ground as the policy supports to maize production were withdrawn in later years? Beddow and Pardey (2014) showed that the shifting location of U.S. maize production during the 20th century accounted for upwards of one-fifth of the growth in output of that crop in that country. Has the shifting location of South African production over the past 100 years been similarly beneficial to that country's maize crop?

To address these questions, I develop and deploy an entirely new, long-run, spatialized set of data on South African maize production for the period 1918 to 2007. The biological basis of maize production means that growing the crop is a spatially sensitive undertaking. Soil, climate, and pests and diseases vary from place to place, with potentially profound consequences for the production and productivity performance of a crop, and the abiotic (e.g., climate) and biotic (e.g., pests and weeds) risks faced by farmers in growing that crop. Thus, changes in crop location have direct food security implications—especially for a staple African food crop such as maize—and motivate the spatially explicit, historical assessment of South Africa maize production presented here.

5.4.1 The changing spatial concentration and pattern of production

Figure 5.3 gives a mapped comparison of the change in the spatial concentration of South African maize area planted and yields between the 1937, 1976 and 2007[67] censuses. These were selected because the area planted in 1937 was similar to that of 2007 and hence these can be compared to see if the area planted and yield relativities remained the same. The 1976 census was included because it is the mid-point between when the area planted peaked in 1968 and when it started to decline after 1981. The panel a) shows the area planted per district expressed as the percentage share of the national area planted during the year in question, while the panel b) shows the average yield per district expressed as an index of the national average of that year.

A side by side comparison of the area relativities (panel a) during the 1937, 1976 and 2007 Censuses reveal two main trends: One, the number of districts in the largest national area share category (in the 4.4–7.7 per cent) increased between 1937 and 2007; and moved toward the western corner of the maize triangle in 1976 but partially reverted back east by 2007. Two, the districts southwest of the maize triangle increased in importance by 2007 but still represent a small total area share (< 0.9 per cent). The area planted in these districts increased because of the development of Orange River irrigation system. In addition, area was also added in the far southwest as the areas around Cape Town.

With respect to relative yields (panel b), the figure shows that in 1937 and 1976 the districts with an above-average yield were concentrated in the eastern part of the maize triangle, as expected given the relatively higher rainfall (see Figure 5.5); this was also true for 2007. It also shows that in 2007 the districts with the highest yield of between 160 and 274 per cent above the national average were concentrated along the Orange Rver irrigation system.

Statistics on irrigated production are only available for 2002 and 2007. During these years 8 per cent of all maize was irrigated, yielding 18 per cent of national output. The development of irrigation (mostly pivot) infrastructure along the Orange River and its feeders followed the electrification of these areas from the late 1970s onward (Table 5.1). In 2007 the four largest

[67] Note that the maps 1937 shows the average of the 1930 and 1937, 1976 the average of 1971 and 1976, and 2007 the average of 2002 and 2007.

irrigated areas by volume were Herbert, Prieska, Hopetown and Hartswater, all situated within the Orange River system, with irrigated output constituting between 80 to 96 per cent of their total output.

The visual illustration of the concentration of maize production is quantified in Table 5.4. In 1918, 66 per cent of the country's maize production occurred in 25 districts, which represented just 10.9 per cent of all maize producing districts (229) in that year. At the time the 45 districts within the maize triangle collectively produced 71.6 per cent of national output on 72.7 per cent of the area. Collectively they represented 20 per cent of all maize producing districts. By 1965 the most important 25 districts produced 77.4 per cent of the national output on 71.6 per cent of the national area. The production and area share of 45 maize triangle districts increased to an all-time high of 86.8 and 81.0 per cent respectively. By 2007 the importance of the maize triangle districts had declined relative to 1965, encompassing 74.6 and 79.6 per cent of the national production and area share respectively. Before 1988 the maize triangle production shares consistently exceeded area shares, but this was reversed by the development of the higher yielding irrigation areas outside of the maize triangle as discussed. By 2007 the top 25 districts were responsible for 68.5 and 71.3 per cent of the national production and area planted respectively, and represented 13 per cent of all maize producing districts.

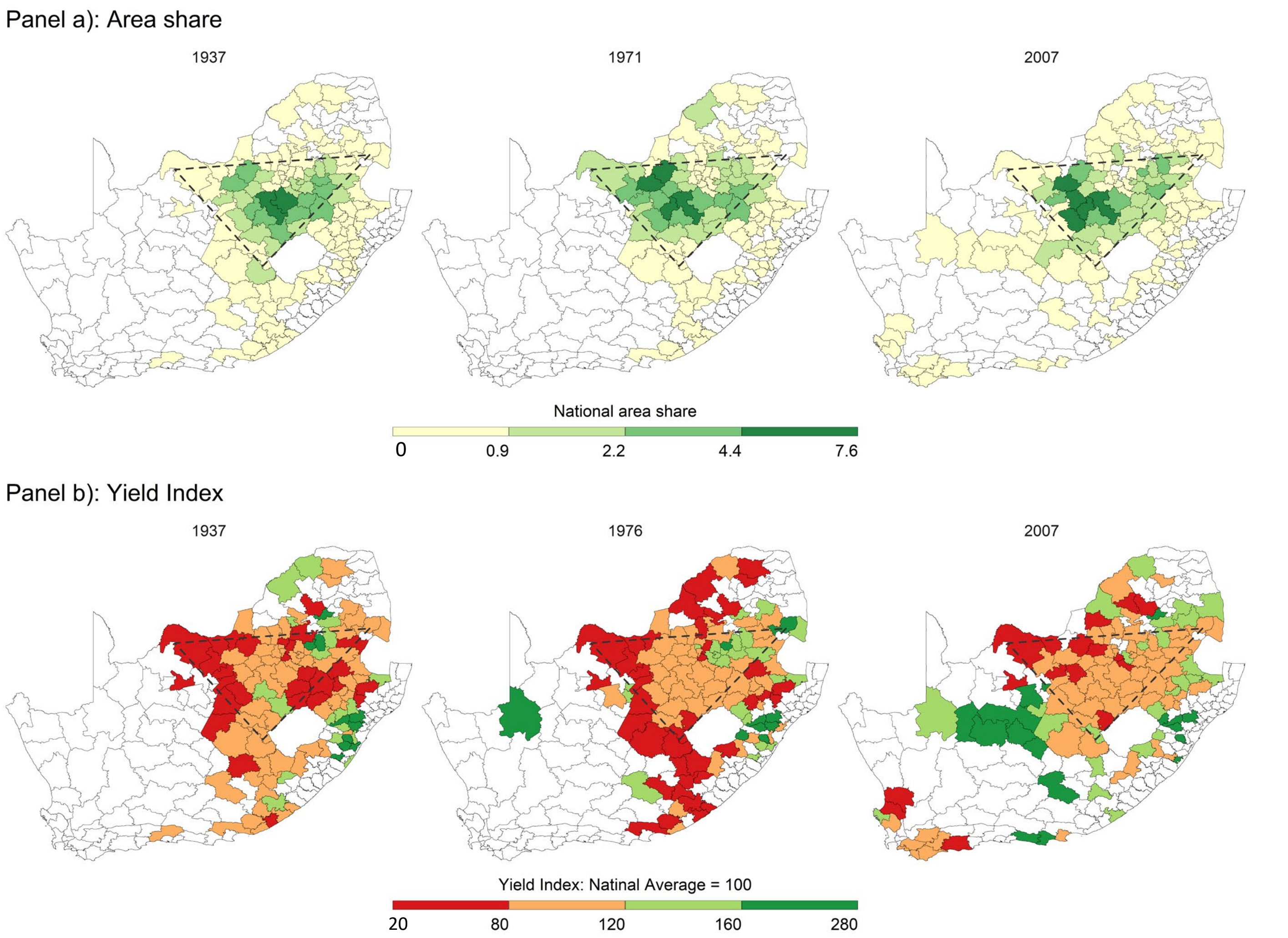

Figure 5.3: South African district maize area share and yield, 1937, 1981 and 2007

Source: *Authors construction, see text for sources.*

Notes: *Panel a) shows area planted per district as a percentage of the national total. The legend shows the area share range as 0 – 0.2 per cent, 0.2 to 1.5 etc. Panel b) shows the relative yield per district expressed as an index of the national total in that year. The legend shows the range of relative yields as 20 –80, 80 – 120 etc. Outlier yields because of districts with a small area planted and production were removed for simplification and clarity. The maize triangle is indicated in all maps as the dotted triangle.*

Table 5.4: Concentration of production in the 25 largest and maize triangle districts

Year	25 largest districts share in			Maize triangle's share in		
	all maize districts	total area	total production	all maize districts	total area	total production
1918	10.9	65.9	65.5	19.7	72.7	71.6
1922	10.9	70.1	67.5	19.7	75.8	69.8
1930	11.0	68.2	67.9	19.7	75.1	72.8
1937	11.0	67.5	69.7	19.8	75.3	76.6
1946	11.0	66.2	68.5	19.8	75.4	75.7
1950	11.0	69.6	73.4	19.7	77.0	81.0
1956	11.2	71.5	75.7	20.1	80.1	83.6
1960	11.1	71.3	76.5	20.0	79.8	85.4
1965	11.1	71.6	77.4	19.9	81.0	86.8
1971	11.4	70.3	74.3	20.5	80.3	83.2
1976	12.0	71.6	72.5	21.5	81.0	82.2
1981	12.8	72.4	72.9	23.0	81.3	82.6
1983	12.4	72.4	74.1	22.3	81.8	82.5
1988	13.7	75.0	70.8	24.7	84.1	80.9
1993	13.0	75.2	70.1	23.4	85.3	78.4
2002	13.8	75.1	70.9	24.9	83.7	78.3
2007	13.0	73.1	68.5	23.3	79.6	74.6

Source: Own calculation, see text for source

The coarse estimate of the spatial reallocation of production provided by Figure 5.3 and Table 5.4 can be quantified even more concisely by considering the changes in the national centroids of output and area. The centroid, or mean centre[68], of a spatial variable represents the point that minimises the sum of squared distances to all other points of that spatial variable. For example, the geographic centre of a symmetrical triangle formed by three points, would be an equal distance away from all three points. In this instance I calculate the geographic centre[69] of each district and assume that all the production and area planted takes place at this point. Therefore, the centre point of each district has both a location and a weight. The *centroid of production* for a specific year represents the point on the map that minimises the sum of squared distances between the *production weighted geographic centres* of all the maize producing districts.

[68] When a weighting is used, the centroid is sometimes referred to as the "mean center," while "centroid" is reserved for unweighted, purely spatial, calculations.

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

Table 5.5 shows the area and production mean centres calculated for each census included in this study. The movement is expressed in kilometres to the east (easting) and north (northing), with negative values indicating movements in the opposite direction either west or south. Two types of indicators are shown with respect to 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 results show that on the east-west plane, the area mean centre drifted westward toward regions with a relatively lower yield potential (see Figure 5.3 & 5.5); by 1965 it reached its furthest most western point of 101 kilometres west of its position in 1918. Hereafter it only showed a slight eastward movement. By 2007 it was still 96 kilometres west of its position in 1918. On the north-south plane the area mean centre showed a cumulative northward movement of 34 kilometres by 1965 and continued on this trajectory By 1988 it reached its furthermost northern point of 60 kilometres north of its position in 1918. It drifted south thereafter; by 2007 it reached a point only 20 kilometres north of its 1918 departure point.

The movement in the production output mean centres showed a similar trend. It reached its furthermost western point in 1960 at 73 kilometres west of its position in 1918, and in 1975 it reached its northernmost point of 75 kilometres north of its position in 1918. By 2007 it settled at a point 70 kilometres east and 29 kilometres north of its 1918 departure point.

Viewed together, the cumulative movement in the area and output mean centres show that by 2007 the westward area movement was far greater than the output movement (96 vs 70). This is the result of the relatively lower yield potential of the drier western production regions. On the north-south plane, the difference between the cumulative area and production movement by 2007 is far smaller (20 vs 29 kilometres cumulatively).

Figure 5.4 provides spatial context the discussion above by showing the cumulative movement in the area and production mean centres from the 1918 to 1976 and then 2007. Between 1918 and 1976 the area and production mean centres moved north-west toward the town of Klerksdorp. Their 1976 position brought them close to the geographic centre point of the maize triangle. Between 1976 and 2007 they moved south-westward toward the town of Bothaville, the so-called maize capital of South Africa.

Table 5.5: Movement in the maize area mean centre of selected years, 1918–2007

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

Source: Authors' calculation, see text for source.

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.

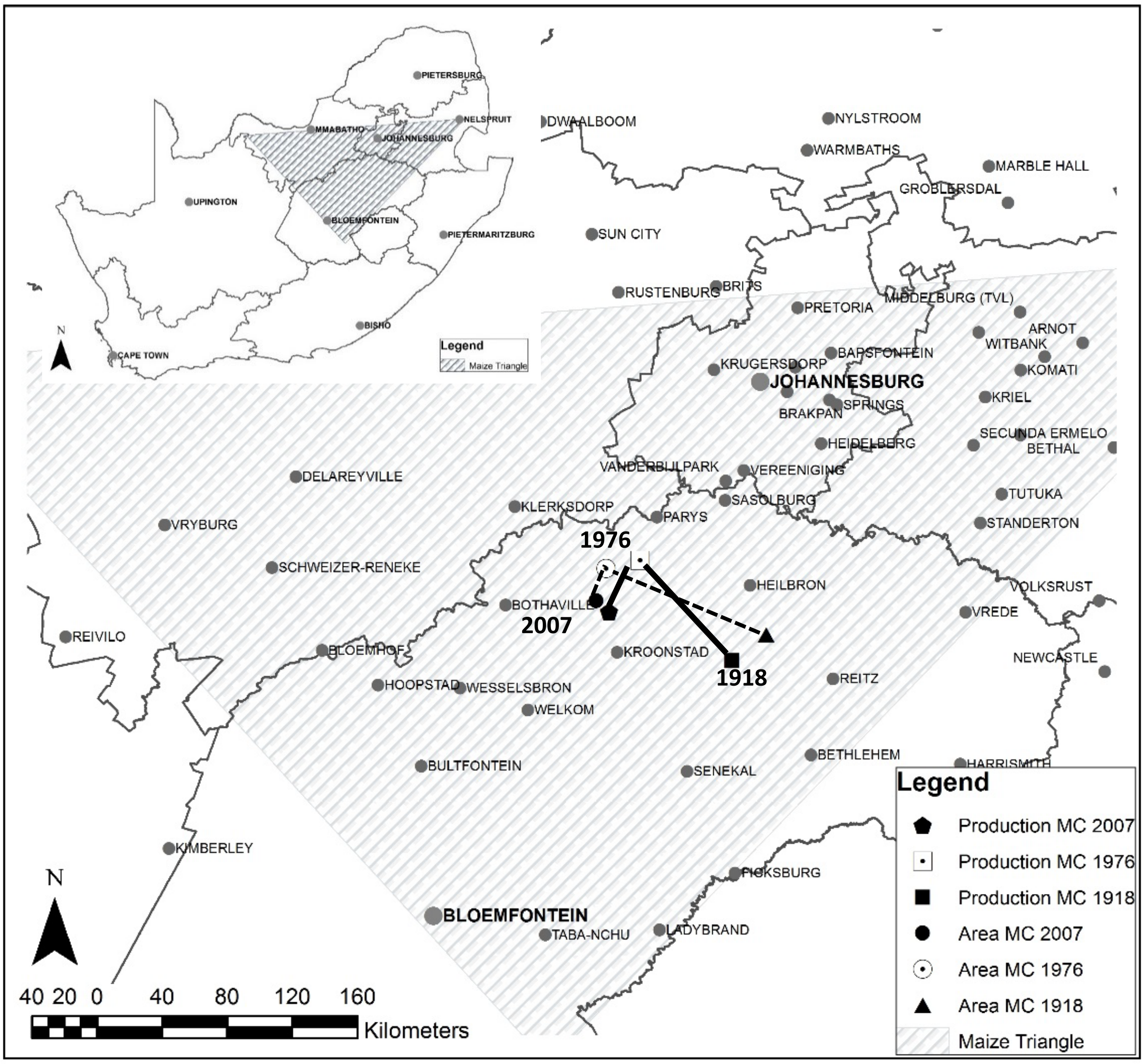

Figure 5.4: Area and production mean centre (MC) movement, 1918, 1976 and 2007

Source: Own calculations see text

Figure 5.5 shows the maize growing season (November-April) average rainfall per district as calculated from the Lynch (2004) rainfall database. It also includes the maize triangle and the movement in the area mean centre between 1918 and 2007. It shows that the average growing season rainfall decreases from west to east, declining from a high of between 689 to 860 mm per season measured around the north-western corner of the maize triangle to a low of between 27 and 190 mm per season in the western part of the country. With respect to the area mean centre, it shows that the western movement between 1918 and 2007 put in a region with a lower average growing season rainfall of between 337 to 468 mm, compared to an average of 468 to 582 mm observed at its location in 1918.

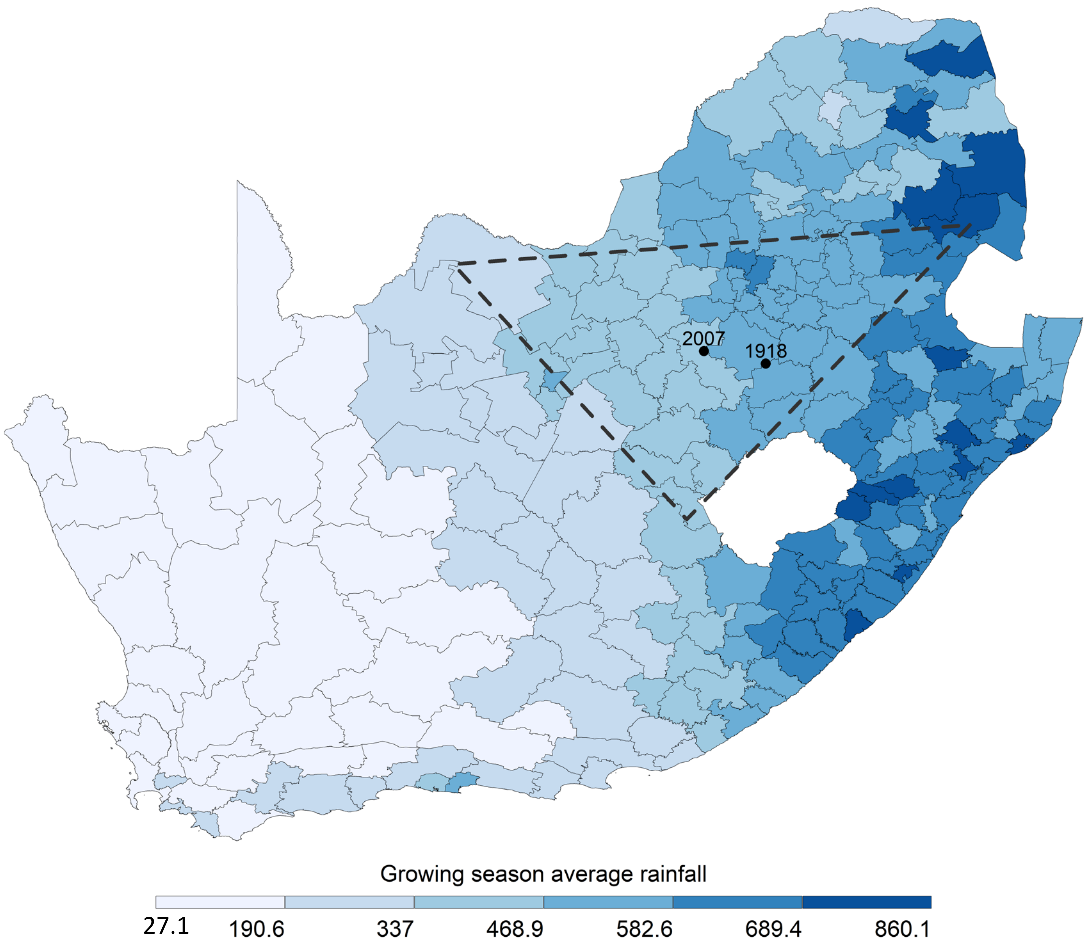

Figure 5.5: Growing season (November-April) average rainfall (1910-2000)

Source: Lynch (2004), own calculations

5.4.2 The spatial pattern of (relative) yields

Maize yields showed almost no change between the two World Wars (1920–1948), growing at a comparatively slow rate of 0.7 per cent per year but increased to 3.5 per cent per year from 1949 to 1981, primarily due to the adoption of hybrid maize. The first thirteen bags of hybrid maize were sold in 1949: while slow at first, adoption accelerated in subsequent years to the extent that it replaced open pollinated varieties in 1979 (Greyling & Pardey, 2018a). While hybrid maize played a major part during this period it also coincided with the adoption of fertiliser, chemical weed and pest control measures, (De Klerk, 1983; Liebenberg, 2012; Liebenberg & Pardey, 2012) and improved farming practices such as deep tillage and controlled traffic cultivation. The third period (1982–1998) saw maize yields continuing to grow but at a slower rate, averaging 2.1 per cent per year. Yield growth accelerated to a brisk rate of 3.1 per year after deregulation (1999–2015).

Figure 5.6 summarises the average yield per district of selected census years using smoothed density plots. The census average yield for the year in question is represented by the vertical line. Average yields only start their upward trend after the 1950s, but focussing on averages obscures inter-district yield differences and their changes over time. Figure 5.6 shows that yield densities are positively skewed in all years plotted and are widening over time.

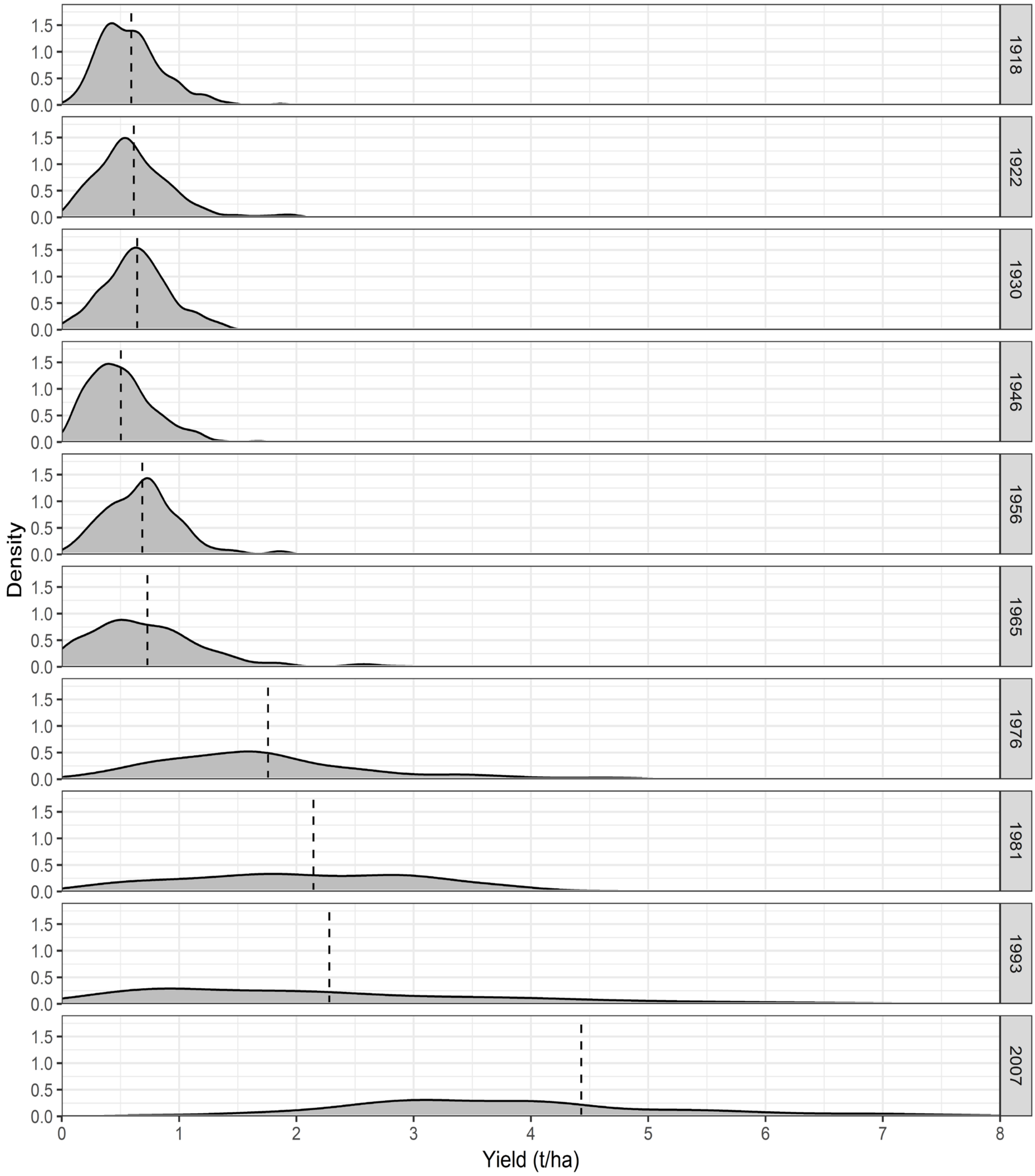

Figure 5.6: Spatial distribution of maize yields, 1918–2007

Source: Compiled from Union Statistics and Abstracts of Agricultural Statistics, 1960–2009. Values represent average per district per decade if multiple censuses were conducted. The average is indicated by the dotted line.

5.4.3 Consequences of changing location

To quantify the productivity changes in response to spatial changes, Beddow and Pardey (2013) developed three spatial output indices—area, reallocation and yield—using both a Paasche and Laspeyres specification for each index. The calculation of these spatially-specific indexes is enabled by the construction of the spatially standardized and balanced panel described in Section 5.2.2. The panel is structured such that a_t and y_t represent vectors of district-specific area planted[70] and yields for some year t. The length of each vector equals the total number of districts and is spatially aligned across the vectors, where the i-th element indicates the corresponding i-th municipal district. Therefore, the total production of district i in year t is represented by $y_t a_t$ and the total production nationally in year t is equal to the sum of $y_t{}'a_t$ as A_t.

Using Beddow and Pardey's (2014) nomenclature, a Laspeyres (I_Y^L) yield index (4) uses base period areas to weight both current and base period yields, while the Paasche (I_Y^L) yield index (5) uses current period areas to weigh both current and base period yields.

$$I_Y^L = \frac{y_t{}'a_b}{y_b{}'a_b} \tag{4}$$

$$I_Y^P = \frac{y_t{}'a_t}{y_b{}'a_t} \tag{5}$$

Intuitively the Laspeyres yield index shows the change in maize output attributable to yield changes if the area planted is held constant at base period levels. Similarly, the Paasche yield index shows the change in maize output attributable to yield changes but now with current area planted as reference. The converse is true with the Laspeyres (I_A^L) and Paasche (I_A^L) area indices as shown below, where yield now acts as weight and the area planted can vary. The area indices therefore show the changes in production attributable to changes in area if yields are held constant, with the Laspeyres (6) and Paasche (7) specifications using the base and current years as reference respectively.

$$I_A^L = \frac{a_t{}'y_b}{a_b{}'y_b} \tag{6}$$

$$I_A^P = \frac{a_t{}'y_t}{a_b{}'y_t} \tag{7}$$

[70] Area harvested could not be used since it was only sporadically reported. The discrepancy between area planted and harvested will be especially large in years with a high rate of crop failures. If average yields are calculated from total production and area planted, yields are depressed in general and especially so in below average years.

The area indexes cannot be taken at face value, however, since they confound the effect of changes in the national area with changes in the relative spatial allocation of production: an increase in the national area planted will result in an increase in the area index and *vice versa*. Alternatively, the total area planted could remain the same, but the area planted could be reallocated to districts with a higher yield. If the total area under production and the yield vector did not change, the reallocation would only be reflected in the area index even though the national average yield showed an increase. Since these joint effects can act against each other, Beddow and Pardey (2013) propose an alternative specification that separates the scaling effect of changes in the total area planted from the spatial reallocation effect, which I am interested in. This can be achieved by scaling the Laspeyres (I_A^L) and Paasche (I_A^L) area indexes by the ratio of the total area planted nationally during the base year as A_b and the national area planted in year t as shown in the respective reallocation indices below:

$$I_R^L = I_A^L \frac{A_t}{A_b} \tag{8}$$

$$I_R^P = I_A^P \frac{A_t}{A_b} \tag{9}$$

The relative spatial reallocation indexes answer slightly different questions from the area indexes: The Laspeyres index (I_R^L) (8) reflects the change in output due to the change in the relative spatial allocation of maize area, weighted by base-year yields. The Paasche index (I_R^L) (9) reflects the change in output due to the change in the relative spatial reallocation of maize area, weighted by current period (t) yields.

The constructed standardized panel does not include observations of area planted and production for all districts in all years. Neither maize area planted nor production data were reported in 8.4 per cent of the district-years in our panel, and so I took that to indicate maize production was absent from those district-years.[71] However, if any of these missing or null districts report a yield for the base year (in this instance, 1918) of the Laspeyres area index, then there is a potential bias introduced into the index since the district in question will be dropped from the calculation during all years.[72] To avoid this potential problem I estimate a counterfactual

[71] 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 to be unlikely in most of the cases, as only 2 per cent of the district years for which no data were reported also failed to report data in either of the adjacent years, or when they did report production, it was trivial, thus indicating they are likely to be marginal production district-years where the absence of data indicates the absence of production.

[72] As Beddow and Pardey (2014) 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.

yield in those district-years without yield observations, which represents the yield that would have occurred had the maize been grown in that district during that year. To do so I used an inverse-distance weighted mean function that imputes the missing yield based on the district's three nearest neighbours.

The spatial yield, area and reallocation indices calculated are shown in Figure 5.6, with the solid lines showing the Laspeyres and the dashed lines the Paasche specifications. I use 1918 as base year for the sake of simplicity. As expected the yield index starts to increase after 1946 and picks up momentum after 1965, given the adoption of hybrid maize. It reaches a local peak (411-415 per cent above the reference, see Appendix F) in 1981 following above-average yields, enabling a record harvest of 14.4 million tons. In 1981, the national average yield was 3.3 ton/ha versus an average of 2.1 ton/ha achieved during the preceding five years (1976–1980). The decline in the yield index thereafter is the result of consecutive droughts; aggregate production declined by 41 per cent (8.3 million tons) between 1981 and 1982 following a below-average yield of 1.9 ton/ha and a decline in the area planted of 1.4 per cent. The 1983 drought lowered the national average yield to a mere 1.0 ton per hectare, which in combination with a 5 per cent area decline, reduced national production by a further 52 per cent to 4 million tons. The drought continued in 1984, with production only recovering by 8 per cent to 4.3 million tons following a national average yield of 1.1 ton/ha and a 7 per cent decline in the area planted. By 2007 the yield index showed a cumulative increase of between 550 and 600 per cent depending on the specification.

The area index increased by 50 per cent between 1918 to the 1930, whereafter it levels off until the mid-1940s, only to resume its continued increase to peak in 1981 at almost a 150 per cent above the reference. The post-war increase in the area planted was enabled by the rapid increase in tractor use. South African farmers had access to just 6 000 tractors in 1937, increasing to 20 000 immediately after the war and continuing upward to peak at 174 000 units in 1976 (Liebenberg 2012). This replacement of animal draught with tractor power enabled farmers to both add new land to production and released for crop production the land previously dedicated to the production of animal feed (Brand 1969; Van Zyl, Vink & Fényes 1987). The 1981 peak of the index does not correspond with the peak in the area planted in 1968 or the 1970 turning point of the epochs discussed. One should keep in mind, though, that the area indices confound the effect of a change in the total area planted and the spatial reallocation of production between districts as discussed.

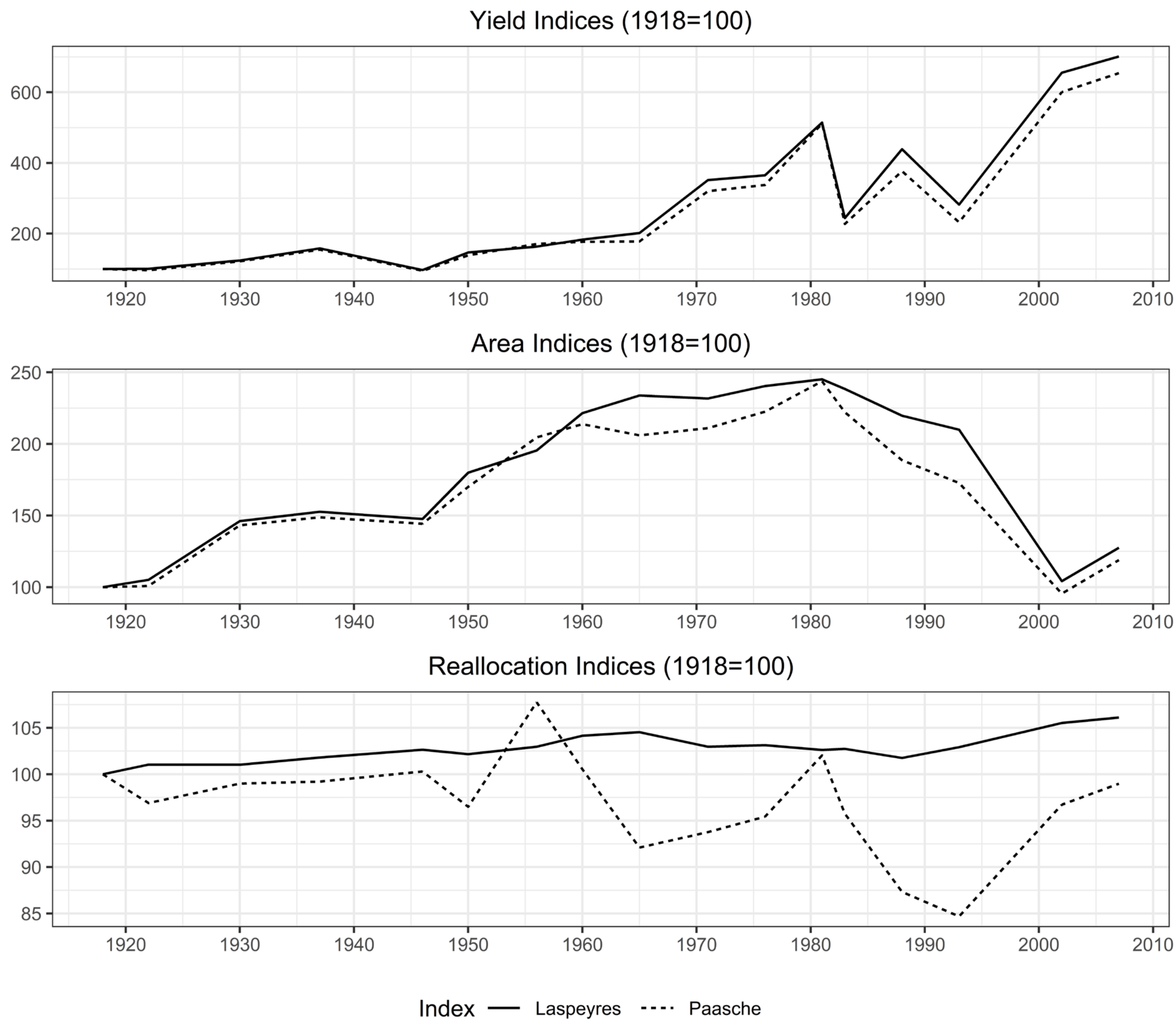

Figure 5.7: Area, reallocation and yield indices, 1918–2007

Source: *Authors construction.*
Notes: *Note the differing scales in the various panels since this causes the plotted versions of the yield indices to appear smoother than the other.*

By controlling for the change in the total area planted, the reallocation indices (third panel) show the output impact of the spatial reallocation of production. Unlike the yield and area indices, the specifications show substantial differences. This suggests that there are marked differences if the reallocated areas are weighted by either the base period yields – such is the case with the Laspeyres (I_R^L) specification – or current yields – such is the case with the Paasche (I_R^P) specification. The Laspeyres specification shows a relatively small but sustained increase (compared to the area and yield indexes), peaking for the first time at 4.5 per cent above the base year in 1965, and continued upward thereafter to a high of 6.1 per cent in 2007 (see Appendix F).

The same cannot be said for the Paasche specification of the index, which shows that the area reallocation had a negative impact on output, and by inference productivity, during most periods. This is especially true after 1946, apart from a brief jump to 7.8 per cent above the reference in 1956, the area reallocation during this period had a negative output impact of 7.9 per cent relative to the base year in 1965, which peaked at a low of 15.3 per cent below the reference by 1993. It recovered thereafter to within 1 per cent of the reference by 2007.

The intuition of these results can be summarised as follow: if the yield distributions did not shift over time as shown in Figure 5.6 but stayed symmetrical to that of 1918, then the reallocation of production would have made a positive contribution to output. However, given the changes in relative yields, the negative output impact of the reallocation of production areas into relatively lower yielding regions increased over time.

The reallocation index results obtained for the U.S. by Beddow & Pardey (2015) differ markedly from this study in two ways. First, they do not find a prolonged divergence between respective specifications. Second, they find that the relative spatial reallocation of production accounted for between 16 and 21 per cent of the output increase. Seeing that one can argue that both countries had access to similar technologies, for example hybrid seed (Chapter 4:), the distinguishing difference between the two countries was policy.

In the South African case the post-1946 decline in productivity because of the area reallocation shown by the Paasche specification corresponds with the price and area breaks identified in Section 5.3 and centroid movements discussed in Section 5.4.1. For example, the 1965 decline in spatial productivity of 7.9 per cent below the reference corresponds with the maximum area break identified in Section 5.3 and the furthermost cumulative westward movement of the area mean centre relative to 1918 as shown in Section 5.4.1. Hence the westward expansion into lower yielding areas was at its peak, and this is also reflected in the output/productivity penalty because of the spatial reallocation of production.

Also, the reallocation low point of 15.3 per cent below the base year shown by the Paasche index in 1993, straddles deregulation process of maize marketing which was started in 1988 and were completed in 1998. While both indices trended upward hereafter, the Paasche index showed the greatest gain between 1993 and 2007, since it increased from 15.3 per cent below the baseline to just 1.0 per cent below the baseline compared to the increase from 2.9 to 6.9 per cent above the baseline shown by the Laspeyres reallocation index. Hence unproductive areas were withdrawn from production, thereby increasing the importance of the remaining areas with relatively higher yields. This is also can be explained if viewed in conjunction with the cumulative movement in the area mean centres. While the cumulative westward movement into lower yielding areas peaked at 101 km in 1965, by 2007 it had only moved 5 km back east to a point 96 km west of the reference.

5.5 Conclusion

During most of the 20th century South African agriculture was subject to a potent package of distortionary farm policies that was only dismantled after the mid-1980s. I show that the changing orientation of these farm policies had a profound effect on the structure of production agriculture in South Africa.

I start by showing that changes in maize production patterns during the past century exhibit a close concordance with the changing nature of distortionary farm polices. Starting in the 1930s and tapering by the 1980s, the maize industry enjoyed a golden age of support, in response to which the area under production expanded markedly and yield growth took off. This was driven in part by the maize marketing interventions that raised the South African price above the reference as the price received by U.S. farmers. The gradual removal of support during the 1980s coincided with the removal of land from production, to the extent that by 2015 the area had returned to the level maintained almost 80 years earlier in 1935, a period before the implementation of the various support measures.

I then continue to estimate the productivity impact of this policy-induced distortion in the location of production using our newly compiled spatially disaggregated production data. I show that the distortionary policies induced a substantial expansion in the physical footprint of production in those areas that had previously supported little (if any) maize production. This undermined the environmentally-based spatial comparative advantages of production to reduce productivity by 15.3 per cent at its peak in 1993. Once the sectoral support policies were removed, not only did the total area contract markedly, but production also largely reverted back to the geographical areas with intrinsically higher production (yield) potential. As a result, the spatial productivity index to recovered to within 1 per cent of the reference by 2007. But I also find a degree of persistence since the spatial productivity of the 'new' areas still trailed that of the 'old' areas by 7.1 per cent. This can be explained by the cumulative movement in the area mean centres, which shows that by the end of the period, the area planted almost returned to the 1918 reference on north-south axis but remained close to the western most extreme on the east-west axis.

The persistence of the production in the drier and lower yielding regions can be attributed to various factors. One of the principal factors is the state-sponsored hybrid maize breeding program, increasingly private after 1965, that prioritized the breeding of drought tolerant hybrid varieties. This resulted in a 4.2 fold increase in the yield per unit of rainfall between 1950 and 1993 (Greyling & Pardey, 2018a). In addition, the persistence was also enabled by research on maximising rainfall utilization in dryland agriculture. This included the development of deep tillage (400 to 1 200mm) practices and the implementation controlled wheel traffic maize production systems with wide maize row widths (1 500 to 2 100mm)[73] during the late 1980s and early 1990s (Bennie & Botha, 1986; Bennie, Hoffman & Coetzee, 1995). Another contributing factor is the development of infrastructure such grain storage and handling systems; expanded road and rail networks; or irrigation systems such as those along the Vaal and Orange Rivers, and to a lesser extent the Western and Southern Cape. Government support to the instillation 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.

[73] For comparative purposes 86 per cent of US maize is planted at 762mm with the remainder being planted at between 381 to 1000mm (Jeschke, 2018)

Chapter 6: Conclusion

This dissertation reports the results of an investigation into policy-induced distortions in the location of agricultural production in South Africa. The complex interplay between changing agricultural policy regimes, agricultural production and productivity, and changes in the spatial footprint of production was explored from the perspective of maize, the principal South African field crop. A period of more than a century (1904–2015) was covered to encompass a series of important changes in the policy regimes affecting the structural transformation of South African agriculture. This enabled the estimation of a spatial baseline of maize production before the mid-1930s, when a series of distortionary farm policies were first implemented. This baseline was then used as a comparative point of reference for the subsequent distortionary policies, both during their implementation and after they were scrapped.

6.1 Summary

There is little (empirically grounded) consensus in the literature on the long-term path of planted maize area, output and composition in South Africa. Establishing this empirical benchmark was the prime objective of Chapter 2. A new compilation of maize production data revealed that South Africa increased its total maize production from 328,000 tons in 1904 to 1.68 million tons in 1935, and 12.22 million in 2015.[74] This 6.1-fold increase in overall maize production since 1935 occurred against a 35.7 per cent reduction in the area planted, made possible by an 8.6-fold increase in average maize yields. While commercial farmers now produce 94.6 per cent of the country's maize crop (on 87.5 per cent of the maize area), that was not always the case. In 1942, smallholder farmers–operating in the former homeland areas and outside those areas–accounted for 20.6 per cent of production on 40.6 per cent of the planted area. With respect to changes in the relative importance of white and yellow maize, the study found that although white maize constitutes a significant share of overall production (49.6 per cent in 2015), the importance of yellow maize is increasing since yellow maize has outpaced white maize in both area planted and yield.

Building on these new measures of the historical changes in maize production, Chapter 3 illustrated the complexity of the political tensions that emerged during the structural

[74] Five-year average tons centred on 2015.

transformation, from the perspective of the maize industry, from the gold discoveries of 1886 up to the start of apartheid in 1948 and beyond to the present. To this end it integrated the existing literature and supplemented it with newly compiled data. The qualitative institutional (1886-1948) analysis showed how the converging and diverging interests of groups within the mining and agricultural sectors were responsible for a transition process that began with the suppression of a large but marginalised group of smaller white and black farmers, to the suppression of mining interests and the support for white farmers while continuing to marginalise black farmers. This was in line with the emergence of apartheid and set the agricultural policy agenda for the half century to come.

Technological change is an intrinsic feature of the structural changes in the South African agricultural economy, as it is with agricultural sectors the world over. Chapter 4 reported the results of a study of a quantitative assessment of the adoption of hybrid maize by commercial farmers in South Africa. It was found that South Africa's 20-year lag behind hybrid adoption in the United States can be attributed in part to institutional impediments in the hybrid seed industry that curtailed private investments, thereby reducing overall R&D spending and slowing the rate of adoption. Adoption patterns in South Africa, like the United States, varied widely among regions in the timing and rate of hybrid seed adoption. However, in the case of South Africa, regional differences in the initial uptake of maize could not be attributed to differences in the availability of suitable hybrids—as Griliches (1957) found for the United States—although the early stages of adoption did appear to be associated with a period during which the yield advantage of hybrids was most pronounced relative to those found on farms, which were depressed because of drought. In this respect our findings confirm those that Sutch (2011) reported for the United States. I also devised a simple rainfall (partial) productivity index to test whether or not the breeding efforts directed at improving the drought tolerance of maize varieties planted in South Africa were successful. Juxtaposing maize production data from the South African agricultural censuses conducted between 1918 and 1993 against a recently developed long-term rainfall database, I estimate that on average the country's maize yield per unit of rainfall increased 4.2-fold between 1950 and 1993.

Chapter 5 integrated and supplemented the results of the preceding chapters to illustrate the complex interplay between policy, production and productivity. The shifting orientation of distortionary farm policies showed a close alignment with the increase in maize production and price. These distortionary production policies undermined environmental-based spatial comparative advantages by inducing a substantial expansion of the physical footprint of production into areas that had previously supported little (if any) maize production. It was estimated that this policy-induced shift in the location of production peaked between 1988 and 1993, when it reduced overall productivity by between 7.9 and 15.3 per cent. The dismantling of supportive maize policies during the 1980s and 1990s coincided with a reduction in the area planted to maize. By 2015 the overall area planted to maize had returned to the level it had reached almost 80 years earlier in 1935, before the supportive measures were implemented. But some of the spatial inefficiencies induced by the policies that were terminated in the 1980s persisted because some production continued in naturally drier, and hitherto lower-yielding, areas because of public investments in drought focussed research and development initiatives; and irrigation, grain storage and transport infrastructure. By 2015 the country's area mean centre—effectively the spatial centre of gravity of production—was still at a point to the west (the drier side) of the pre-distortion reference (dated 1918). This is also reflected in the spatial productivity indexes, specifically those relating to the "new" areas as the Paasche specification thereof. These recovered from their 1993 distortionary lows and almost returned to their "pre-distortionary" levels by 2007 since they recovered to within 1.0 per cent 1918 base year. The "old" areas, measured by the Laspeyres specification, showed an increase of 7.1 per cent above the 1918 base. This contrasts with the findings of Beddow and Pardey (2015), who showed that persistence in the spatial reallocation of U.S. maize production increased national output by between 16 and 21 per cent over the course of the 20th century.

6.2 General comments, contributions and recommendations

6.2.1 The structural transformation

One of the primary findings of this study is that the distortionary agricultural policies that were enacted in response to political tensions during South Africa's structural transformation prior to the 1950s also distorted the spatial footprint of maize production and lowered productivity, and, more importantly, that the spatial distortions and productivity impact thereof partially persisted after those policies were removed. This was because, among other things, location-specific investments in improving plant material, farming practices and irrigation infrastructure made it economically viable to continue producing maize in drier regions where previously little or no maize production had occurred. Among the factors that contributed to this spatial path dependence were a hybrid maize breeding programme that prioritized improved drought tolerance, and the development of improved production practices that increase overall rainfall utilisation, such as deep ripping and controlled wheel traffic production systems in wide row widths. This path dependence was also strengthened by investments in road, rail and grain storage infrastructure, some of which would not have been built in the absence of the distortionary policies, but have remained in use after the removal of the policies since they lowered production costs to the extent that production in marginal areas remained economically viable. The persistence was also likely aided by a learning-by-doing effect, whereby farmers gained the necessary experience to increase their productivity sufficiently to offset the reduction in support spending and sustain their economic viability in some of the more marginal areas. Stated another way, this study found that although South African maize production ended up in the wrong places given a suite of distortionary policies, in the end, region-specific investments in adapting crops and farming practices, together with investments in grain production and marketing infrastructure, made the wrong places more right.

Binswanger-Mkhize (2014) regarded the structural transformation that have occurred in the South African economy as exemplary of a failed case, not least since farm and non-farm incomes and productivities have failed to converge after the removal of the distortionary policies. He attributed this to the persistence of a dualistic agricultural production system consisting of small- and large-scale farmers and the inability of the mining and manufacturing sectors to absorb labour. This study provides an example of a physical impediment to the convergence of farm and non-farm productivities given the persistence of distortions in the location of production that have arisen from the distortionary policies of the past.

While it is problematic to consider the results obtained for a single crop, specifically maize, as being representative of developments pertaining to the entire agricultural (or at least cereal) sector, this may be justified in the case of the South African agricultural economy for two reasons. First, maize accounts for a significant share of the country's cereal sector, namely 82.5 per cent of the 3.67 million hectares sown to cereal crops in 2015, and 50.6 per cent of the country's cropped area when averaged over the period 1948–2007. Second, almost all the country's agricultural products were affected by the distortionary policies, and thus similar spatial production distortions and persistence are likely. The Marketing Act of 1937, together with its subsequent extensions, eventually controlled the marketing of 90 per cent of agricultural output.

If the findings for maize can be thus generalised, then the South African case serves as a cautionary example for other transforming countries. While a case may be made for policymakers acting to reduce the magnitude of any farm to non-farm income inequality arising from a widening productivity gap between the two sectors as the transformation process proceeds, it would be foolhardy to view the use of trade protection or direct price supports as a cost-free rite of passage in the development trajectories of all countries, since it carries both short- and long-term costs. It not only can result in spatial inefficiencies that persist and thus obstruct farm and non-farm productivity convergence, but may also divert public finances from alternatives that yield a higher long-term return, such as education (see for example Psacharopoulos & Patrinos, 2004), infrastructure (see for example Gramlich, 1994) and agricultural R&D (see for example Alston et al., 2010). It may also result in avoidable environmental costs associated with damage to natural habitats that would otherwise have not been cultivated. In the South African case, most of the additional maize area entailed cultivating grasslands (Palmer & Ainslie, 2005), with most of these being returned to planted pastures or grasslands after the removal of the various support measures (World Bank, 1994; Breitenbach & Fényes, 2000; Liebenberg et al., 2015). However, both international (Török et al., 2011) and domestic (Zaloumis, 2013) studies have shown that cultivated grasslands are unlikely to be fully restored to their former state. This is particularly relevant from an African perspective since half of the world's remaining uncultivated arable land is in sub-Saharan Africa, and of this 90 per cent is in just nine countries (Deininger & Byerlee, 2012).

The findings of this study are particularly relevant to sub-Saharan Africa since several of its countries have pursued or are still pursuing various forms of maize and other marketing interventions. At present Mozambique and Uganda are examples of countries whose maize market has been comprehensively deregulated and liberalised. They therefore represent possible case study sites for testing the findings of this study. Conversely, in Zambia, Malawi, Ethiopia, Tanzania and Kenya, the marketing of maize has only been partially liberalised. In those countries the private sector is typically encouraged to participate in the market, but the state is also actively involved therein, particularly through export bans, import and export tariffs, government directed imports and stock releases (Chapoto & Jayne, 2009). Studies have also shown that these mechanisms are exploited by the state for political gains. For example, there is evidence that the Zambian Food Reserve Agency, which is responsible for stabilising the maize market and maintaining a floor price, purchases 1.5 times more maize during election years (Mulungu & Chilundika, 2016). And these interventions are not just leftovers from the past, since some scholars are actively promoting their use. For example, Poulton et al. (2006) argue for the institution of an autonomous African agency which would be tasked with maintaining grain prices in major markets within a given band, both in and across seasons, thereby increasing price stability by levelling the price spikes and dips. Such interventions are doomed, however, since they face substantial political pressure to bias the band upward, as happened in South Africa before deregulation and is presently happening in Zambia. In addition, policymakers often get the setting of the band wrong since agricultural commodity markets are inherently volatile (FAO et al., 2011) and lack a long-term trend (Deaton, 1999).

In countries where distortionary price policies are in place, policymakers should try to ensure that spatial distortions are minimised over the short term and do not persist over the long term. Possible policy recommendations include strict control over the cultivation of new areasall and encouraging farmers to adopt land-saving technologies such as fertiliser, improved seeds and irrigation. Furthermore, large public or private investments in permanent grain storage infrastructure in marginal production areas should not be encouraged through tax concessions or public spending.

Output per worker need not be increased by temporarily distorting the price of agricultural commodities. An alternative strategy would be to increase the output per worker through sustained investments in agricultural research and extension in order to facilitate the adoption of improved seeds, fertiliser, irrigation and other technologies (Barrett, Christian & Shiferaw, 2017). The success of this process depends on increasing the integration of the agricultural sector into the rest of the economy by improving infrastructure and developing competitive markets (Barrett et al., 2017). Improved infrastructure would also give farmers access to foreign markets for the excess production and would lower the cost of inputs, especially inorganic fertiliser (Liverpool-Tasie et al., 2017).

Alternatively, the income per household could be increased by changing the commodity mix itself by switching from staples to higher-value, often export-oriented, crops. In fact studies have found that diversification is the single most important way to reduce poverty for small farmers (Dixon, Gulliver & Gibbon, 2001; Pingali, 2004). However, sub-Saharan African agricultural exports increasingly face substantial challenges since many countries have large populations living far from ocean ports and hence rely on domestic production. In fact, between 1980 and 2009 more than 80% of sub-Saharan African agricultural output was consumed in the country where it was produced, and in landlocked countries this was even greater at 90% (Barrett & Upton, 2013).

The output per worker can also be increased by pulling them out of agriculture through expanding employment in the manufacturing and services sectors. This would have the dual effect of stimulating the demand for agricultural produce and increasing the income of agricultural workers. However, in sub-Saharan Africa the manufacturing expansion would have to take place at an implausibly rapid rate for it to have an effect, given the incoming youth bulge (Barrett et al., 2017). This youth bulge offers both an opportunity and a challenge to the region. At present half of the population is under 25 years of age and it is projected that between 2015 and 2035 each year there will be half a million more 15-year-olds than there were the year before (Filmer & Fox, 2014).

6.2.2 Politics, power, location and persistence

Acemoglu and Robinson (2006, 2008) argue that while the development trajectory of many countries includes frequent changes in political institutions, constitutions or aspects of economic institutions, some economic institutions or outcomes can persist despite these changes. Examples of such economic institutions include those that govern the enforcement of property rights or labour repressive agricultural production systems such as those found in the southern US before and after the abolition of slavery. This can also be extended to South African agricultural labour relations during the twentieth century. Acemoglu and Robinson argue that such economic institutions persist because changes in *de jure* power following reforms in political institutions can be partially or completely counteracted by changes in the *de facto* power of elites. Keeping this in mind, the findings of this study can be viewed somewhat differently but in a meaningful way.

As shown in Chapter 3, South African farmers were successful in increasing their *de jure* political power during the first part of the twentieth century by lobbying the state for various supportive agricultural policies. At the same time the *de facto* power of farmers was also greatly increased after the victory of the pro-farmer National Party in 1948. As a result, farmers had sufficient political power from the 1950s to the 1980s to apply these policies to their benefit and were able to increase their influence in subsequent years. In the case of the maize industry, as shown in Chapter 5, this resulted in overproduction, a decline in productivity due to the reallocation of production and the distortion of the spatial footprint of production. South African commercial farmers lost their *de facto* political power after isolating themselves from the ruling National Party by siding with the Conservative Party in 1983 (Bernstein, 2004), and their *de jure* power declined following the removal of direct and indirect support measures, as discussed in Chapter 3 and 5, which began in 1988 and was completed in 1998.

This study has, however, shown that the economic impact of the reversal was smaller than expected, not because of the interaction between *de jure* and *de facto* power, but rather because of the persistence of spatial remnants of past power relations. Hence this study identifies a second factor that contributes to the persistence of past economic outcomes and explains why the effect of *de jure* reforms is smaller than expected.

6.2.3 Policy-induced innovation for increasing rainfall use efficiency

Hayami and Ruttan (1970, 1971) contrast US and Japanese agricultural development to argue that differences in relative prices, due to differences in factor endowments or changes therein, induced a process of directed technical change biased toward saving the limiting factors of production. While this hypothesis makes intuitive sense, numerous studies have endeavoured to either confirm, extend or criticise it (see Pardey, Alston & Ruttan, 2010 for a summary). Thirtle, Townsend and Van Zyl (1998) find that the hypothesis holds for South African agriculture but add that it provides an example of a policy-induced innovation, given the bias toward labour-saving technical change. They attribute this to agricultural R&D spending in general and the incentivisation of mechanisation through tax concessions for machinery purchases and subsidised credit. Seeing that they make no mention of the impact of the adoption of hybrid maize, it is possible that they overstate the importance of labour-saving mechanical technology and understate that of land-saving biological technologies. Olmstead and Rhode (1993), among others, also cite these over- and understatements as defects of the standard interpretation of the hypothesis in the US case.

The adoption of land-saving hybrid maize in the South African case would be justifiable since the production cost share of land increased throughout the period of hybrid adoption, from 6.6% in 1948 to a high of 15.5% by the mid-1970s, but declined to a low of 3.0% by 2007 (Liebenberg & Pardey, 2010). The increase resulted from the capitalisation of the various forms of direct and indirect support in land values (Binswanger, Deiniger & Feder, 1993). This would suggest that Hayami and Ruttan's induced innovation hypothesis should be retested for the South African case but with the advances in biological technologies considered explicitly.

The development of technologies that increase the productivity of rainfall, such as hybrid maize and special farming practices, such as deep tillage and controlled traffic cultivation, also raise an interesting question about the status of rainfall in the induced innovation hypothesis, and in the greater production and productivity literature. Can rainfall be regarded as an input? Rainfall as such does not receive any specific attention in the hypothesis, but Olmstead and Rhode (1993) mention the importance of biological investments in enabling 'dry-farming', citing the example of the development of hard red wheat cultivars that enabled the production of the crop in relatively dry states such as Kansas.

In the case of South Africa, I would argue that rainfall can be regarded as an input, given the country's deliberate investments in rainfall productivity-increasing technologies. The resulting technical change, biased towards increasing the amount of maize produced from a unit of rainfall, happened in response to an increase in the shadow price of rainfall because of the various distortionary policies.

6.2.4 Location, climate and adaptation

The South African hybrid maize breeding programme outlined in Chapter 4 provides a pertinent example of how drought-focused research efforts can deliver transformative results. When climate change is discussed in the context of crop production, it is typically assumed that the location of production is fixed and that the climate under which crops are produced changes over time. However, a change in the climate under which crops are produced can also result from a change in the location of production.

It can therefore be argued that a change in the location of production can serve as proxy for climate change. Thus, the expansion of maize production into marginal lower rainfall production areas, and the subsequent R&D investments to generate a sequence of innovations biased towards improving rainfall productivity in those regions, offers an example of a successful adaptation to a change in climate. Not only can these technologies be applied in regions that are becoming drier, they can also serve as an example of how drought-focused research efforts can deliver transformative results.

The finding in Chapter 4 that the relative advantage of hybrid maize is greatest during droughts, and that this advantage increases at an increasing rate as yields become more depressed, is especially important when devising climate adaptation strategies for smallholder farmers. This suggests that the use of hybrid maize should be promoted among smallholder farmers, not only to increase overall productivity but also to mitigate climate risk, thereby increasing their overall climate resilience and thus food security. This strategy is currently under-emphasised in the climate change literature. Some studies include it as one of several adaptation strategies (see for example Stringer et al., 2009); others disregard it completely (see for example

Morton, 2007; Cooper et al., 2008). An notable exception is Hellin et al. (2014), who recommend the adoption of heat and drought stress-tolerant improved maize varieties as a means whereby smallholders can adapt to climate change. They note that such a strategy is not without its difficulties: in Mexico adoption has been low since smallholders prefer their local landraces because of culinary, agronomic and cultural considerations. Hellin et al. thus recommend that public institutions should focus on both promoting improved maize varieties and improving the local landraces.

6.2.5 Data, measurement and methods

The techniques applied by this study for measuring the spatial movement and change in productivity are relatively simple, but because they are extremely data intensive, preparing the data requires a substantial investment in time and effort. For example, the preparation of the agricultural census boundaries required for the spatialisation of the data was a major undertaking. Not only had the boundaries to be digitised manually, they also had to be cross-checked against numerous historical maps to ensure the accuracy of the eventual product. In addition, the agricultural censuses were not always clear as to which boundaries were used for conducting and reporting the census, and hence I had to establish this on a trial and error basis. At the same time, the corresponding maize indicators reported in the censuses had to be digitised and organised, and numerous reporting inconsistencies had to be addressed. Thereafter the district names used in both the district maps and census datasets had to be standardised and codified so as to overcome the spelling and name changes that took place during the century. Only after the completion of these processes could I join the maize data to the boundaries, after which the spatial standardisation techniques were applied and eventually the data was analysed.

The whole process described above proved to be a good investment since it was relatively easy to use the boundaries to spatialise the hybrid maize data and allocate seasonal rainfall to districts. Not only will the resulting datasets permit further research, but the digitised census boundaries and accompanying index of standardised district names will enable researchers to spatialise other indicators as well.

6.3 Programme of future work

There are several ways in which the results of this study could be extended and improved. The most obvious is to seek other examples of spatial persistence because of distortionary policy, for other South African crops, for other countries, such as Uganda and Mozambique, and for Asia and South America. To do this study on a larger scale would require some technical innovation. As pointed out above, the techniques it applies are fairly simple but extremely data intensive, and the preparation takes considerable time and effort. However, recent advances in machine learning and other techniques could be used to automate the manual boundary digitisation that was done manually in this study. Such techniques could also be used to speed up the process of digitising and organising other historical datasets. Advanced text recognition would be helpful in dealing with name changes, identifying inconsistencies and errors, and so on. The technique used in this study to disaggregate and re-aggregate the census data according to contemporary boundaries, and even the spatial indexing itself, could also be automated. Progress has already been made in this respect, with the eventual goal of integrating it as a user-developed tool on the G.E.M.S™ platform.[75]

The spatial impact of distortionary policies on the use of other inputs such as labour, machinery and chemical inputs should also be tested. However, this would require the development of an alternative method for the disaggregation and re-aggregation of the census data, since the SPAM[76] database that I used only covers the major crops and not agricultural inputs. Developing and joining such spatially standardised indicators will make it possible to estimate multifactor and even total factor productivity indicators, which could further our understanding of the spatial impact of policy. It would also make it possible to estimate group- and meta-production frontiers in a stochastic framework, as proposed by Huang, Huang and Liu (2014). Standardising the labour and machinery data would also make it possible to improve the analysis of factor substitution in response to distortionary policy. The decline in South African agricultural employment after the mid-1960s was caused largely by policies that promoted mechanisation through subsidised credit and tax incentives (De Klerk, 1983; Liebenberg, 2012).

Further research should focus on improving our understanding of the mechanics of spatial persistence, to assist in the formulation of improved policies designed to counteract the spatial distortion of production. By highlighting the role of hybrid maize breeding in spatial movement and persistence, this study calls attention to the need for more research on drought-optimised farming practices and the role of infrastructure in encouraging spatial persistence. With the production data in hand, a fairly easy next step would be to test the way South African infrastructure developments have shaped the environment-based spatial comparative

[75] https://agroinformatics.org/
[76] Spatial Allocation Model, see http://mapspam.info/

advantages, especially since the state-sponsored programme of grain silo construction is well documented and the location of this infrastructure remains fixed.

Lastly, there is still more work to be done on the quantitative history of smallholder farming in South Africa. While this study has contributed a consistent long-term view of smallholder maize output, area planted and yields, little is known about other crops, especially sorghum, which was a major smallholder crop during the twentieth century. In addition, the smallholder maize production indicators are yet to be spatialised. Future studies should also endeavour to improve our understanding of the causes of the yield disparity between commercial farms and smallholder farms, especially between homeland and non-homeland smallholders. The smaller yield gap between large commercial farmers and non-homeland smallholders suggests that positive spill-over effects could have existed between these groups.

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Appendices

Appendix A: Maize output by type of farmer and type of maize

	All Farmers[77]		Commercial farmers			Smallholder farmers		
	Reported	Aggregated				All	Non-homeland	Homeland
Year	Maize	Maize	Maize	White	Yellow	Maize	Maize	Maize
	1	2	3	4	5	6	7	8
		3 + 6	4 + 5			7 + 8		
			(1000 metric tons)					
1904	328	328						
1911	783	783						
1912	827	827						
1913	873	873						
1914	922	922						
1915	1 019	1 019						
1916	983	983						
1917	1 086	1 086						
1918	1 147	1 147	881			266		266
1919	1 052	1 055	787			268		268
1920	1 116	1 124	850			274		274
1921	1 211	1 211	887			324		324
1922	1 146	1 234	894			340		340
1923	1 793	1 649	1 286			363		363
1924	1 020	930	666			264		264
1925	2 204	2 045	1 741			304		304
1926	991	918	697			220		220
1927	1 656	1 520	1 268			253		253
1928	1 741	1 601	1 368			233		233
1929	1 696	1 568	1 259			309		309
1930	2 024	2 031	1 566			465	139	326
1931	1 452	1 553	1 249			304	101	204
1932	1 727	1 845	1 508			337	118	219
1933	757	806	592			214	50	165
1934	2 188	2 188	1 683			505	171	335
1935	1 684	1 684	1 360			323	127	196
1936	1 359	1 359	1 125			234	122	112
1937	2 556	2 556	2 078			478	209	269
1938	1 746	1 746	1 348			398	161	237
1939	2 633	2 633	2 146			486	218	268
1940	1 878	1 878	1 533			345	158	188
1941	2 207	2 207	1 809			398	184	214
1942	1 482	1 482	1 129			353	115	238
1943	2 208	2 208	1 781			427	181	246

[77] See discussion in Section 2.2 (p. 14) on the reason for the differences.

1944	1 667	1 667	1 279			387	135	252
1945	1 668	1 668	1 349			319	135	184
1946	1 615	1 615	1 234			381	160	221
1947	2 227	2 227	1 717			511	221	290
1948	2 914	2 914	2 314			600	251	349
1949	1 906	1 906	1 534			372	186	186
1950	2 704	2 704	2 196			509	246	263
1951	2 729	2 729	2 306			423	242	181
1952	1 951	1 951	1 588			363	198	165
1953	3 063	3 063	2 512			551	292	259
1954	3 539	3 539	2 977			562	295	267
1955	3 397	3 397	2 872			525	264	261
1956	3 391	3 391	2 943			448	287	160
1957	3 926	3 926	3 308			618	298	320
1958	3 360	3 360	2 875			486	257	229
1959	3 765	3 765	3 189			576	286	290
1960	3 968	3 968	3 450	2 093	1 357	518	247	271
1961	4 703	4 694	4 094			600	277	323
1962	5 358	5 346	4 835			511	266	244
1963	5 467	5 454	4 933			520	242	279
1964	3 865	3 858	3 424			434	179	255
1965	4 011	4 010	3 661			349	160	190
1966	4 478	4 478	4 118			360	150	210
1967	9 762	9 566	9 080			486	147	339
1968	4 620	4 620	4 338			282	143	138
1969	4 529	4 529	4 208			321	123	198
1970	6 134	6 134	5 814			320		320
1971	7 199	7 030	6 533	3 692	2 841	497	169	328
1972	9 525	9 525	9 103			422		422
1973	4 202	4 490	4 248			242		242
1974	11 083	11 083	10 610			473		473
1975	9 139	9 139	8 689			450		450
1976	7 518	7 548	7 154	3 744	3 410	394		394
1977	9 793	9 793	9 285			508		508
1978	10 205	10 205	9 674			531		531
1979	8 475	8 800	8 340			460		460
1980	11 040	11 040	10 480			560		560
1981	14 872	14 872	14 423			449		449
1982	8 781	8 781	8 262			519		519
1983	4 399	4 399	4 004			395		395
1984	4 797	4 797	4 309			488		488
1985	8 444	8 444	7 909			535		535
1986	8 600	8 567	7 926	3 449	4 477	641		641
1987	7 890	7 874	7 071	3 574	3 497	803		803
1988	7 670	7 647	6 731	3 776	2 955	916		916
1989	12 481	12 445	11 552	6 366	5 186	893		893
1990	9 180	9 136	8 343	4 362	3 982	793		793
1991	8 614	8 573	7 825	3 829	3 996	748		748

1992	3 277	3 244	2 956	1 252	1 704	288	288
1993	9 997	9 963	9 077	4 416	4 661	886	886
1994	13 275	13 218	12 040	5 732	6 308	1 178	1 178
1995	4 866	4 836	4 406	2 120	2 286	430	430
1996	10 171	10 138	9 694	5 836	3 858	444	444
1997	10 136	10 106	9 582	5 209	4 373	524	524
1998	7 693	7 665	7 204	4 460	2 744	462	462
1999	7 946	7 916	7 461	4 601	2 860	455	455
2000	11 455	11 423	11 001	6 681	4 320	422	422
2001	7 772	7 745	7 487	4 260	3 227	258	258
2002	10 077	10 049	9 732	5 537	4 194	317	317
2003	9 705	9 678	9 391	6 366	3 026	286	286
2004	9 737	9 710	9 482	5 805	3 677	228	228
2005	11 749	11 716	11 450	6 541	4 909	266	266
2006	6 947	6 935	6 618	4 187	2 431	317	317
2007	7 339	7 339	7 125	4 315	2 810	214	214
2008	13 164	13 164	12 700	7 480	5 220	464	464
2009	12 567	12 567	12 050	6 775	5 275	517	517
2010	13 421	13 421	12 815	7 830	4 985	606	606
2011	10 924	10 924	10 360	6 052	4 308	564	564
2012	12 759	12 759	12 120	6 903	5 217	638	638
2013	12 486	12 485	11 810	5 607	6 204	675	675
2014	14 925	14 925	14 250	7 710	6 540	675	675
2015	10 629	10 629	9 956	4 736	5 220	674	674

Source: Compiled by authors based on sources listed in Appendices C and D.

Appendix B: Maize area planted by farmer and maize type

	All Farmers[78]		Commercial farmers			Smallholder farmers		
	Reported	Aggregated				All	Non-homeland	Homeland
Year	Maize	Maize	Maize	White	Yellow	Maize	Maize	Maize
	1	2	3	4	5	6	7	8
		3 + 6	4 + 5			7 + 8		
			(1000 hectare)					
1904								
1911								
1912								
1913								
1914								
1915								
1916								
1917								
1918			1 789					
1919			1 704					
1920			1 620					
1921			1 544					
1922			1 904					
1923			1 901					
1924			1 565					
1925			2 240					
1926			1 716					
1927			2 101					
1928			1 916					
1929			2 173					
1930			2 589					
1931			2 173					
1932			2 439					
1933			2 458					
1934			2 393					
1935	4 136	4 136	2 404			1 732	371	1 361
1936	3 295	3 295	2 090			1 205	378	827
1937	4 313	4 313	2 684			1 629	400	1 229
1938	4 422	4 422	2 461			1 962	437	1 525
1939	4 258	4 258	2 674			1 584	403	1 181
1940	4 091	4 091	2 581			1 511	395	1 116
1941	4 058	4 058	2 587			1 471	391	1 080
1942	4 477	4 477	2 360			2 118	357	1 761
1943	4 577	4 577	2 791			1 785	421	1 365
1944	5 117	5 117	2 761			2 356	433	1 923
1945	4 837	4 837	2 970			1 867	439	1 428
1946	4 698	4 698	2 574			2 124	497	1 627

[78] See discussion in Section 2.2 (p. 14) on the reason for the differences.

1947	5 259	5 259	2 941			2 318	562	1 756
1948	5 017	5 017	2 962			2 055	477	1 578
1949	4 503	4 503	2 801			1 702	505	1 197
1950	5 008	5 008	3 152			1 856	525	1 331
1951	4 318	4 318	3 014			1 304	470	834
1952	4 277	4 277	2 755			1 523	510	1 012
1953	4 818	4 818	3 136			1 682	542	1 140
1954	4 943	4 943	3 376			1 567	496	1 071
1955	5 068	5 068	3 476			1 592	474	1 118
1956	4 541	4 541	3 396			1 145	492	653
1957	5 117	5 117	3 468			1 649	464	1 186
1958	4 806	4 806	3 400			1 407	451	956
1959	5 294	5 294	3 640			1 654	484	1 170
1960	5 443	5 443	3 805	2 165	1 639	1 638	426	1 212
1961	5 281	5 281	3 672			1 609	435	1 174
1962	5 423	5 423	3 944			1 479	420	1 059
1963	5 493	5 493	3 931			1 562	395	1 168
1964	5 588	5 588	4 046			1 543	379	1 164
1965	5 450	5 450	4 003			1 446	287	1 160
1966	5 107	5 107	4 241			866		866
1967	5 274	5 274	4 589			685		685
1968	5 332	5 332	4 728			604		604
1969	4 995	4 995	4 205			790		790
1970	4 583	4 583	4 217			366		366
1971	4 626	4 626	4 027	2 260	1 767	599	224	375
1972	4 968	5 113	4 578			535		535
1973	3 975	4 125	3 611			514		514
1974	4 820	4 961	4 463			498		498
1975	4 792	4 910	4 488			422		422
1976	4 989	5 172	4 548	2 335	2 213	624		624
1977	4 706	5 011	4 406			605		605
1978	4 412	4 960	4 361			599		599
1979	4 566	4 896	4 305			591		591
1980	4 563	4 915	4 322			593		593
1981	4 488	4 934	4 338			596		596
1982	4 664	4 865	4 278			587		587
1983	4 680	4 623	4 065			558		558
1984	4 839	4 496	3 953			543		543
1985	4 502	4 421	3 887			534		534
1986	4 829	4 716	4 161	2 009	2 152	555		555
1987	5 063	4 697	4 130	2 318	1 812	567		567
1988	4 736	4 241	3 729	2 253	1 477	512		512
1989	4 394	4 327	3 805	2 160	1 645	522		522
1990	4 163	3 984	3 503	1 965	1 538	481		481
1991	3 816	3 647	3 207	1 717	1 490	440		440
1992	4 173	3 966	3 487	1 881	1 606	479		479
1993	4 377	4 165	3 662	1 984	1 678	503		503
1994	4 661	4 443	3 906	2 028	1 879	536		536

1995	3 526	3 357	2 952	1 401	1 551	405	405
1996	3 761	3 761	3 307	1 904	1 403	454	454
1997	4 023	4 023	3 361	1 794	1 567	662	662
1998	3 560	3 560	2 956	1 797	1 159	604	604
1999	3 567	3 567	2 905	1 830	1 075	663	663
2000	4 012	4 013	3 429	2 149	1 281	583	583
2001	3 189	3 189	2 674	1 562	1 112	515	515
2002	3 533	3 533	3 017	1 843	1 174	517	517
2003	3 651	3 651	3 185	2 232	953	466	466
2004	3 204	3 204	2 843	1 842	1 001	361	361
2005	3 223	3 223	2 810	1 700	1 110	413	413
2006	2 032	2 032	1 600	1 033	567	432	432
2007	2 897	2 897	2 552	1 625	927	345	345
2008	3 297	3 297	2 799	1 737	1 062	498	498
2009	2 896	2 896	2 428	1 489	939	469	469
2010	3 263	3 263	2 742	1 720	1 023	521	521
2011	2 859	2 859	2 372	1 418	954	487	487
2012	3 141	3 141	2 699	1 636	1 063	442	442
2013	3 238	3 238	2 781	1 617	1 164	457	457
2014	3 096	3 096	2 688	1 551	1 137	408	408
2015	3 048	3 048	2 653	1 448	1 205	395	395

Source: Compiled by authors based on sources listed in Appendices C and D.

Appendix C: Output data sources

#	Year	Source	Location
	Maize output - All farmers		
1	1904	Saunders (1930)	Table 4, p.28
2	1911-1949	Agricultural Censuses as reported in Farming South Africa by Vorster (1952)	Table 1, p.173
3	1950-1954 1950-1954	Census Summary report, Union of South Africa (1957), Agricultural Censuses compiled by authors and Liebenberg (2012)	Table C3, p.15
4	1955-1971	Agricultural Censuses as compiled by authors and Liebenberg (2012)	
5	1972-present	Abstract of Agricultural Statistics, SAGIS, FAO (1970-2006)*	
	Maize output - Commercial farmers		
6	1911-1949	Agricultural Censuses as reported in Farming South Africa by Vorster (1952)	Table 1, p.173
7	1950-1954	Census Summary report, Union of South Africa (1957)	Table C3, p.15
8	1955-1985	Agricultural Censuses as compiled by authors and Liebenberg (2012)	
9	1986-present	Sum of White and Yellow Maize according to SAGIS (2018)	
	Maize output – Commercial farmers: White and Yellow		
10	1960,1971,1976	Agricultural Censuses	
11	1986-1988	Breitenbach & Fényes (2000)	Table A2, 310-311
12	1989-present	SAGIS (2018)- Grain SA (2018b)	
	Maize output – Smallholders outside of homelands		
13	1918-1971	Agricultural Censuses as compiled by authors and Liebenberg (2012)	
	Maize output - Smallholders in homelands		
14	1918-85	Agricultural Censuses as compiled by authors and Liebenberg (2012)	
15	1986-present	SAGIS (2018) - Grain SA (2018b)	

Source: *Compiled by authors.*
Notes: **FAO (2017) excluded smallholder production from their reported totals beginning in 2007.*

Appendix D: Area planted data sources

#	Year	Source	Location
Maize area planted - All			
1.1	1911-1949	Vorster (1952)	Table 1, p.173
1	1911-1971	Agricultural Censuses as compiled by authors and Liebenberg (2012)	
2	1972-present	Abstract of Agricultural Statistics, SAGIS (2018), FAO (1970-2006)*	
Maize area planted - Commercial Farmers			
3	1911-1936	Agricultural Censuses as compiled and processed by authors and Liebenberg (2012)	
4.1	1911-1949	Vorster (1952)	Table 1, p.173
4.2	1920-1936	SAGIS (2018)	
5	1937-1985	Agricultural Censuses as compiled and processed by authors and Liebenberg (2012)	
6	1986-present	Sum of White and Yellow Maize according to SAGIS (2018), Grain SA (2018b)	
Maize area planted - Commercial - White and Yellow			
7	1986-1988	Breitenbach & Fényes (2000)	Table A2, 310-311
8	1989-present	SAGIS (2018), Grain SA (2018b)	
Maize area planted - Smallholders on White Farms			
9	1935-1971	Agricultural Censuses as compiled by authors and Liebenberg (2012)	
Maize area planted - Smallholders in Reserves			
10	1935-65	Agricultural Censuses as compiled by authors and Liebenberg (2012)	
11	1966-present	SAGIS (2018), Grain SA (2018b)	

Source: *Compiled by authors.*
Notes: **FAO (2017) excluded smallholder production from their reported totals beginning in 2007.*

Appendix E: Regional rate of adoption, additional estimates

Region		(4) Unweighted Logit b_4	(5) Unweighted Generalised linear (GLM) b_5	(6) OLS log linear b_6
Central and Southern Free State[+]	(C&SFS)	0.02 (0.05)	0.04 (0.05)	0.02 (0.03)
Cape, Natal and Eastern Griqualand	(Cape)	0.10 (0.06)*	0.10 (0.04)**	0.06 (0.04)
Eastern Transvaal Highveld	(ETHv)	0.06 (0.1)	0.15 (0.08)*	0.01 (0.03)
Northern and Eastern Transvaal	(N&ET)	0.17 (0.07)*	0.14 (0.05)**	0.07 (0.04)*
North Eastern Free State	(NeFS)	0.08 (0.03)**	0.09 (0.03)***	0.05 (0.02)**
North Western Free State	(NwFS)	0.04 (0.06)	0.09 (0.06)	0.02 (0.02)
Rand	(Rand)	0.21 (0.06)**	0.25 (0.09)**	0.04 (0.01)***
Western Transvaal	(WT)	0.09 (0.11)	0.26 (0.09)**	0.01 (0.02)

*Notes: Signifiance codes: 0.001 '***' 0.01 '**' 0.05 '*'*
+ Included the Western Free State

Appendix F: Index values

Year	Laspeyres			Paasche		
	yield	area	reallocation	yield	area	reallocation
	I_Y^L	I_A^L	I_R^L	I_Y^P	I_A^P	I_R^P
			(index value, 1918 = 100)			
1922	100.7	105.1	101.0	96.5	100.8	96.9
1930	124.1	146.2	101.0	121.6	143.2	99.0
1937	158.5	152.7	101.8	154.5	148.8	99.2
1946	97.1	147.6	102.6	94.9	144.2	100.3
1950	146.7	180.0	102.2	138.5	170.0	96.5
1956	163.3	195.5	103.0	171.0	204.6	107.8
1960	183.2	221.5	104.1	176.9	213.8	100.5
1965	201.7	233.8	104.5	177.7	206.0	92.1
1971	351.5	231.7	103.0	320.0	211.0	93.8
1976	365.0	240.4	103.1	337.8	222.5	95.4
1981	514.4	245.1	102.6	511.5	243.7	102.0
1983	244.1	238.3	102.7	227.5	222.1	95.8
1988	438.9	219.7	101.8	376.7	188.6	87.3
1993	282.2	209.9	102.9	232.2	172.7	84.7
2002	655.6	104.2	105.5	600.9	95.5	96.7
2007	701.2	127.5	106.1	654.1	118.9	99.0

Source: Calculated using the data described in the text.