
Property rights, market access and crop cultivation in Southern Rhodesia: evidence from historical satellite data

TAWANDA CHINGOZHA
DIETER VON FINTEL

Stellenbosch Economic Working Papers: WP03/2019

www.ekon.sun.ac.za/wpapers/2019/wp032019

March 2019

KEYWORDS: land titling, access to markets, machine learning, remote
sensing

JEL: C81, N37, Q13, Q15

Laboratory for the Economics of Africa's Past (LEAP)
<http://leap Stellenbosch.org.za>
ReSEP (Research on Socio-Economic Policy)
<http://resep.sun.ac.za>

DEPARTMENT OF ECONOMICS
UNIVERSITY OF STELLENBOSCH
SOUTH AFRICA



UNIVERSITEIT
STELLENBOSCH
UNIVERSITY



A WORKING PAPER OF THE DEPARTMENT OF ECONOMICS AND THE
BUREAU FOR ECONOMIC RESEARCH AT THE UNIVERSITY OF STELLENBOSCH

www.ekon.sun.ac.za/wpapers

PROPERTY RIGHTS, MARKET ACCESS AND CROP CULTIVATION IN SOUTHERN RHODESIA: EVIDENCE FROM HISTORICAL SATELLITE DATA¹

Tawanda Chingozha², Dieter von Fintel³

ABSTRACT

Agriculture plays a central role in the efforts to fight poverty and achieve economic growth. This is especially relevant in sub-Saharan Africa (SSA) where the majority of the population lives in rural areas. A key issue that is generally believed to unlock agriculture potential is the recognition of property rights through land titling, yet there is no overwhelming empirical evidence to support this in the case of SSA (Udry, 2011). This paper investigates access to markets as an important pre-condition for land titles to result in agricultural growth. Using the case of Southern Rhodesia, we investigate whether land titles incentivised African large-scale holders in the Native Purchase Areas (NPAs) to put more of their available land under cultivation than their counterparts in the overcrowded Tribal Trust Areas (TTAs). We create a novel dataset by applying a Support Vector Machine (SVM) learning algorithm on Landsat imagery for the period 1972 to 1984 - the period during which the debate on the nexus between land rights and agricultural production intensified. Our results indicate that land titles are only beneficial when farmers are located closer to main cities, main roads and rail stations or sidings.



¹ Von Fintel gratefully acknowledges funding from the National Research Foundation (Grant number IFR170208222264) and the Elite Fund of the Faculty of Economic and Management Sciences. Errors remain those of the authors, and opinions expressed do not necessarily reflect those of the funders.

² PhD student, Stellenbosch University, Department of Economics, Private Bag X1, 7602 Matieland, South Africa, Email: tchingozha@gmail.com

³ Associate Professor, Laboratory for the Economics of Africa's Past (LEAP) and Research on Socioeconomic Policy (ReSEP), Stellenbosch University, Department of Economics, Private Bag X1, 7602, Matieland, South Africa; Research Affiliate, Institute of Labor Economics (IZA), Bonn. E-mail: dieter2@sun.ac.za

1 INTRODUCTION

From the mid-1970s, there was a general belief that land titling would lead to agricultural growth in developing countries. However, researchers found very little evidence to support this view (Udry, 2011). There have been various modern-day attempts to transition from traditional communal tenure systems to land titling in sub-Saharan Africa (SSA). The goal has been to promote access to land, but also to increase bankability of cultivated land that is not individually owned. Despite a lack of consensus, a section of the literature continues to argue that individual property rights can improve household agricultural production in some circumstances (Deininger & Jin, 2006; Goldstein & Udry, 2008; Newman et al. 2015). Several proposed mechanisms include incentives to invest, less time spent in conflicts over land with multiple claims of ownership, better access to credit, reduction in land transfer transaction costs through proper registration, as well as incentives to innovate (Muchomba, 2017; Fenske 2011). Some empirical studies support these arguments, showing that titling enhances farm yields (Abdulai et al., 2011; Newman et al., 2015) and leads to more intensive cultivation of available land (Do and Iyer, 2008) in certain circumstances. In addition, secure property rights have reduced conflict over land, as well as transactions costs⁴ in the land market (Aryeetey & Udry, 2010; Deininger, Ali, Holden, & Zevenbergen, 2008; Deininger, Jin, Xia, & Huang, 2014).

However, the lack of consensus on the role of property rights in agricultural growth prompts further investigation. Is the transition only successful when other complementary conditions are also in place? For instance, the effect of property rights on agricultural production is stronger in areas with better infrastructure and market access (Markussen, 2008). A separate literature documents the role of infrastructure and market access in the growth of rural economies, without taking land tenure into account. For instance, historical investments in railways positively influence economic activity (including agricultural production) and settlement patterns (Herranz-Loncán & Fourie, 2017; Jedwab & Moradi, 2016). In Ghana, colonial railway construction encouraged the cultivation of cocoa due to reductions in transportation costs (Jedwab & Moradi, 2016). Jedwab, Kerby, and Moradi (2017) illustrate the path dependence and persistence of city location in Kenya, even after the decline of colonial

⁴ With land titles, it is much easier for land ownership to change from one person to another.

railroads. Historical infrastructure investments therefore determine the spatial distribution of current economic activity directly (by providing means to transport goods to market) and indirectly (by creating markets which agglomerated and remain in transport nodes, even in the cases where infrastructure became outdated). Contemporary studies find that enhancing roads and transportation infrastructure is key in improving market access, especially for smallholder farmers (Jordaan *et al.*, 2014; Masuku *et al.*, 2001; Ahmed *et al.*, 2016; Senyolo *et al.* 2009; Boughton *et al.*, 2007; and Poulton *et al.*, 2006). If better infrastructure reduces transactions costs, farmers tend to sell their produce in more profitable, distant markets than at the farm gate (Abu, Issahaku & Nkegbe, 2016). Hence, distance to market proxies for transport costs, and ultimately the decision of small farmers to embark on profitable transactions in central markets.

This paper draws these two strands of literature together in a historical context. Using data from Southern Rhodesia, we argue that land titling is only effective if property owners are integrated into markets in which they can sell their goods. Reforming land rights unconditionally may therefore have little impact on small producers' livelihoods. Multiple property rights regimes existed simultaneously in Southern Rhodesia: our analysis compares groups that were farming in the same period and broader political context, rather than studying a transition from traditional rights across time; we therefore study the outcome of colonial policies once their implementation had been in place for a number of decades. Southern Rhodesia's Land Apportionment Act of 1930 (LAA 1930) formalised racial land segregation in favour of European farmers. Under LAA 1930, the majority of Africans were forced to live in overcrowded Tribal Trust Areas (TTAs) under a traditional communal tenure system. However, the LAA also allowed some Africans to farm in small parts of the country demarcated as Native Purchase Areas (NPAs), where formal individual land rights were granted to the native population; this exception was designed to ease potential tensions between Africans and Europeans. Inhabitants in designated European Areas (EAs) and NPAs were the only groups that were granted land titles. While farmers in TTAs had relatively weak property rights, those in NPAs also did not enjoy the advantages of market proximity and high quality land that was found in EAs. Because of geographic and racial distinctions in property rights, the

LAA 1930 is a central colonial policy that subsequently determined agricultural fortune in Southern Rhodesia.

The majority of papers that have investigated the effects of land titles have relied on household survey datasets and therefore consider modern transitions to more secure property rights (Abdulai et al., 2011; Fenske, 2011; Goldstein & Udry, 2008; Markussen, 2008; Ravallion & Van De Walle, 2006). These data are largely unavailable for many countries, and in particular in early periods. We therefore create a novel dataset by classifying Landsat satellite imagery into areas that were cultivated and those that were not, using a Support Vector Machine (SVM) algorithm for the period 1972 – 1984. This period corresponds to the time that substantial emphasis on a nexus between land titles and productivity emerged (Udry, 2011). It also represents a time long after colonial policies were enforced: we therefore do not rely on measuring short-run effects of changes in property rights, but analyse long-established differences resulting from discriminatory land allocation. This data is used to test how differential land rights affected farmers' cultivation decisions in the various regions. We compare the TTAs, NPAs and EAs to assess whether land rights in and of themselves provided incentive for production, or whether NPAs faced other obstacles that EAs did not. We explore whether NPA farmers' property rights enabled similar cultivation intensity as for Europeans, taking into account their relatively poor access to markets. Alternatively, we assess whether isolation from markets meant that NPA farmers faced similar production incentives as those in TTAs.

The rest of the paper is structured as follows: Section 2 presents an overview of Southern Rhodesia, from colonialization and how that culminated in the segregated apportionment of land. A discussion of African agriculture production (in general and in the 1970s) is also presented in this section. Section 3 discusses the data, analysis procedure and results. Lastly, Section 4 presents the conclusions.

2 SOUTHERN RHODESIA OVERVIEW

2.1 The role of land in Southern Rhodesia

After the Berlin Conference (which serves as a historical marker for the so-called “Scramble for Africa”), the British Empire lacked the finances to seek more territory in Africa. However, Cecil Rhodes’ (the prime minister of the Cape Colony) British South African Company (BSAC) had the necessary private financial and military resources to further British interests. The company expanded into current-day Zimbabwe in 1890, prompted by prospects of large gold deposits (Andersson & Green, 2016; Green, 2016; Palmer, 1971; Rifkind, 1969). However, settlers soon realised that estimates of potential mineral resources were inflated. Over-optimistic views regarding the prospects for mining persisted for one and a half decades. In the meantime the BSAC invested in other infrastructure (such as railways) and the land itself to recover the costs of moving into the region (Arrighi, 1967). The company encouraged the development of a white agricultural class, in order to increase the value of land, railways, mines and other assets that they had established in the region. The pioneers therefore shifted their attention away from mining to agricultural land (Andersson & Green, 2016; Duggan, 1980; Frankema, Green, & Hillbom, 2016; Moyana, 1975; Pollak, 1975; Weinrich, 1979; Arrighi, 1967).

The BSAC was granted the Royal Charter to administer the colony until 1915, although this would later be extended by another ten years (Rifkind, 1969). All land became the property of the Crown, and the BSAC acquired large tracts of land to sell to European immigrants (Floyd, 1962; Pollak, 1975). Pollak (1975) claims that the Company acquired land by “treaty, occupation and conquest”. After the so-called “war of dispossession”, the British Government gave an Order-in-Council that appointed a Land Commission to deal with disputed territory in Matebeleland (Floyd, 1962; Moyana, 1975; Stocking, 1978). This Commission recommended the creation of Gwai and Shangani for resettlement of the defeated Ndebele (Floyd, 1962; Moyana, 1975; Palmer, 1971). These two reserves were only a quarter of the size of the previous Ndebele kingdom, and the soil was barren and dry as observed by the British Deputy Commissioner in 1897 (Moyana, 1975).

Despite the land imbalances that arose after the BSAC conquest, Africans were able to purchase land in the colony. An Order-in-Council of 1898 ruled that a native could purchase, hold and sell land under the same conditions as those of the non-native (Jennings & Huggins, 1935; Pollak, 1975). However, few Africans could afford to buy land at the time (Floyd, 1962; Jennings & Huggins, 1935). By 1921, European settlers had acquired 31 million acres of land versus the 40 000–47 000 bought by African farmers (Arrighi, 1967; Moyana, 1975; Pollak, 1975).

Motivated by the need to deter competition, the colonial administration did little to promote commercial African agriculture (Machingaidze, 1991). Continued displacement from their land aggrieved the native population (Duggan, 1980; Herbst, 1991; Moyana, 1975; Pollak, 1975). In 1925, the Morris Carter Commission was formed to bring the issue of the land to finality, and to consolidate the advantage that Europeans held over the native population.

The commission recommended that racial tension in the colony was a product of the contact between the European and African races. Therefore, the proposed solution was complete separation (Floyd, 1962; Jennings & Huggins, 1935; Pollak, 1975). The recommendations of the Morris Carter Commission were promulgated as the Land Apportionment Act (LAA) in 1930 (Floyd, 1962; Pollak, 1975). The LAA is one of several pieces of legislation that the colonial government had enacted to protect their interests and to formalise racial segregation (Ncube, 2000; Ranga, 2004; Jennings & Huggins, 1935). By 1963 the native African population (of more than 2.5 million) was concentrated within 50 000 square miles of land, while about a fifth of a million settlers owned the other 75 000 square miles.

At the same time, Southern Rhodesia pursued limited equality to align politically with the United Kingdom (UK). A compromise was achieved in setting up the so-called Native Purchase Areas (NPAs), where Africans could continue to buy land (Andersson & Green, 2016). The colonial administration believed that very few Africans would have the financial resources to acquire land, and therefore limited the geographic extent of the NPAs. Africans' rights to the land were thus effectively suspended, except in the 81 NPAs (Floyd, 1962; Jennings & Huggins, 1935). Other Africans who could not afford to buy land in the NPAs were forcibly moved to Tribal Trust Areas (TTA) (where communal land tenure existed. At inception of the LAA,

around half of the land area was designated for whites, while only 30% had been set aside for Africans (Herbst, 1991). Figure 1 presents the land distribution that was formalised by the Land Apportionment Act.

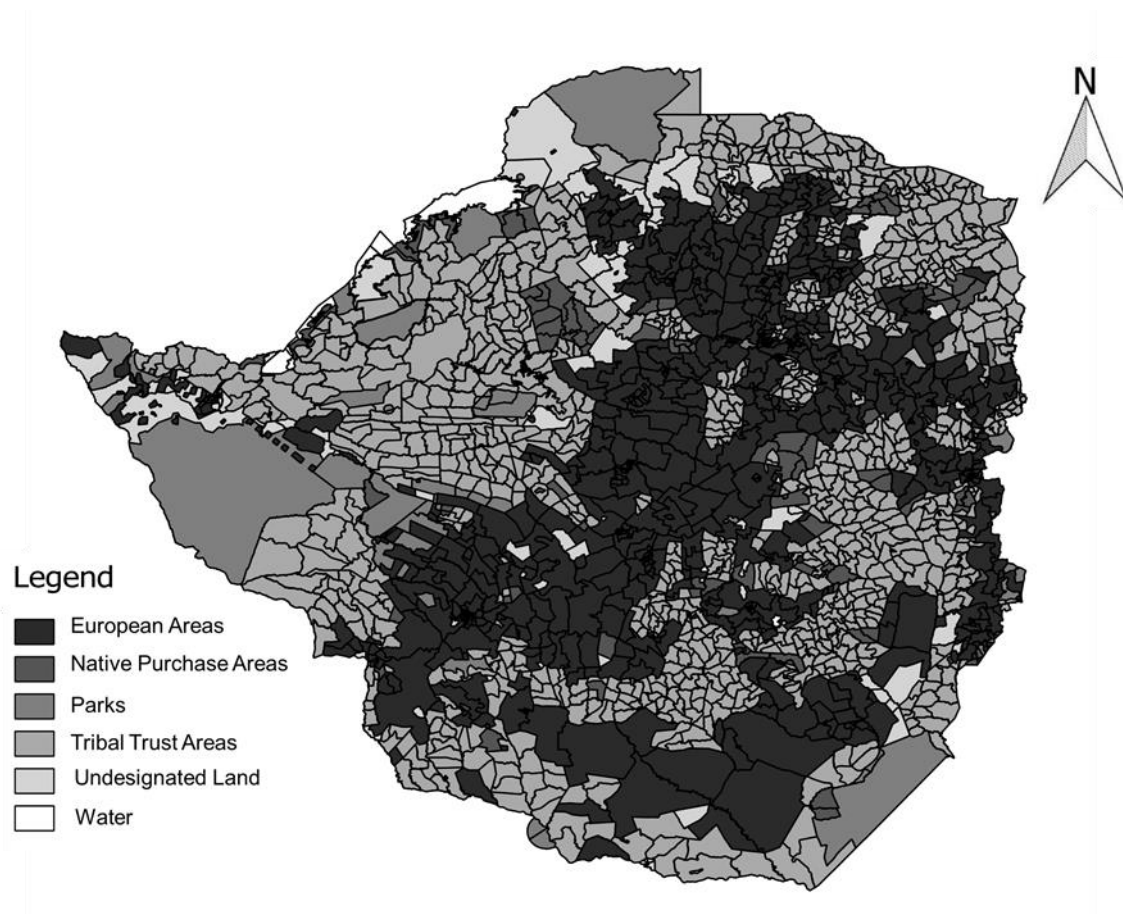


Figure 1: The Land Apportionment Act Land Distribution

Source: Ward level image showing the different land use classes. It is based on Federal Department of Trigonometrical and Topographical Surveys (1963). Available online at: <http://www.digitalcollections.lib.uct.ac.za/special-collections-maps>

2.2 Agriculture and the Economy in Southern Rhodesia

Southern Rhodesia became an agricultural and economic leader in Africa. In the 1950s, the country was the main producer of tobacco in Africa (Haviland, 1953), and it was the most prosperous state in British Africa (Andersson & Green, 2016). Good (1976) argues that Rhodesia had enormous advantages because of its relatively rich endowment of natural resources such as iron, steel, asbestos and various crops. By 1979 – 1980 the territory became

a net agricultural exporter; this was a rare achievement for an African country (Munslow, 1985).

State intervention by the colonial administrations of South Africa and Southern Rhodesia was focussed on improving the conditions of white farmers. They were primarily aimed at achieving maize price stabilisation in relation to international prices (Jayne & Jones, 1997). On the other hand, Machingaidze's (1991) view is that "it was not state policy to encourage Africans to produce for market"⁵. Transport infrastructure was also planned to achieve these ends. Roads and rail lines were constructed to connect European farming areas to markets and urban centres (Austin, 1975). The main railway route traversed the European agricultural highveld, although this was supposedly "sheer coincidence" (Punt, 1979). TTAs and NPAs did not receive the same investments, which exacerbated the effects of the weaker property rights that applied in those regions.

Altering tribal land tenure rules had long-run negative consequences for African farmers (Hughes, 1971). In the TTAs, the Act enforced permanent land for grazing and farming. Farmers had to switch to continuous agriculture, resulting in soil erosion and reducing the fertility of their land (Arrighi, 1967; Duggan, 1980; Machingaidze, 1991). Moyana (1975) asserts that the distribution of land limited the extent to which Africans could actively participate in the economic development of the country. Many natives and their families therefore settled on European farms, primarily in exchange for labour supply (Arrighi, 1967; Moyana, 1975; Youé, 2002).

Almost three quarters of the land allocated to Africans was drought prone, dry and more suitable for only extensive livestock and crop production. In contrast, European Areas (EAs) enjoyed good rainfall that allowed intensive crop and animal production (Floyd, 1962; Herbst, 1991; Palmer, 1990; Pollak, 1975). Moyana (1975) observes that African areas were located in the dry lowveld whose soils did not have much potential; while Floyd (1962) emphasises broken terrain, dryness, lack of water and tsetse fly infestation in these areas. This is despite the fact

⁵ Jayne & Jones (1997) state that state intervention sought to "prevent African farmers from eroding the viability of the less efficient European producers." It is acknowledged that Africans had traditionally been successful agriculturalists Phimister (1974). For example, Phimister (1988) [in Andersson & Green (2016)] observe that the native commissioner of Chilimanzi (now Chirumanzi) wrote that by 1904 the Africans produced 90% of the country's crop production available for market.

that the majority of Africans⁶ relied directly on agriculture, in stark contrast to only 30% of Europeans. Settlers held almost all areas that were suitable for dairy farming (Machingaidze, 1991) and more than three-quarters of land that was suitable for intensive farming (Clarke, 1975). Phimister (1974) notes that African agricultural returns were too small to re-invest; they could not undersell the European farmers because in many cases the latter sold produce on behalf of the former.

Farmers in NPAs faced similar disadvantages to those in TTAs; they too were isolated from transport and communication infrastructure, lacked water, and the soils were largely infertile (Pollak, 1975). Only 25% of African farmers were located within 25 miles of a rail line, while this was the case for 75% of their European counterparts (Ndlela & Robinson, 2007). African market access was deliberately constrained (Abu et al., 2016; Ahmed et al., 2016). Usually [for example between 1860 and 1912 in Europe as discussed by Bogart (2009)] the development of rail systems followed high demand in densely populated areas. Infrastructure development in Southern Rhodesia therefore limited market access of African farmers, despite the large market potential in the areas where they were located.

However, Andersson & Green (2016) posit that development paths pursued by Africa's former colonial governments had unintended consequences. Although the policies that were implemented by settler governments were meant to promote European farming, some sections of African society experienced positive spill over effects (Andersson & Green, 2016). For instance, NPA farmers had more secure property rights and cultivated more land compared to those in the TTAs. Farmers in these areas therefore constituted an African "middle class". This study adds empirical support to these claims.

Nevertheless, the hypothesised success of agriculture in the NPAs relative to the TTAs may remain disputed based on a number of obstacles that property rights would not have been able to resolve. The NPAs did not only lack good soils, market access and infrastructure, they also did not have the effective organization of the Rhodesian National Farmers Union (RNFU). This organisation was established in 1949 by European farmers (Herbst, 1991). The RNFU had substantial influence on the colonial government, since the latter relied on the former's

⁶ Clarke (1975) puts 60 – 70% as the figure for Africans living and depending on rural land.

increased crop production to meet the requirements resulting from WWII (Herbst, 1991). Haviland (1953) offers that after WWII, African evictions from European designated areas cleared land for allocation to ex-service men. The RNFU was able to pressure the administration to pass the Farmers Licensing Act, which compelled farmers to purchase licences from the union, effectively shutting out African farmers from state sponsored research and other benefits of union lobbying (Herbst, 1991). Furthermore, farmers in the NPAs were excluded from access to finance. For example, the Land and Agriculture Bank that had been formed in 1924 served “persons of white descent only” (Machingaidze, 1991).

2.3 African Agriculture in the 1970s and Early 1980s

The proportion of land under cultivation fluctuated significantly over time in the NPAs, TTAs and EAs (see Figure 2). Land policies were a major reason for the decline in yields of African agriculture (Arrighi, 1970; Binswanger, Deininger & Feder, 1995), but the fluctuations in the intervening periods for both African and European areas may be explained by production disturbances owing to the nationalist war of independence. The nationalists were a group of independence activists and later political leaders who organized and led the bush war against white minority rule. Weinrich (1979) points out that after 1976, a large number of white men exited the economy to join the war. On the back of that, government expenditure focused mostly on military and defence spending, while emigration rates increased to 1 000 per month (Weinrich, 1979). The colonial administration forced thousands of Africans into ‘protected villages’ in order to cut off their contact with the nationalist fighters (Duggan, 1980). By 1977, more than 1 million natives had been resettled, disturbing existing production (Weinrich, 1979).

These factors potentially explain agricultural production fluctuations. Apart from that, Sithole (1972) and Whillow (1980) argue that dense settlement in the TTAs impeded agricultural growth. African landholders were customarily obliged to accommodate many of their kinsmen (such as a deceased brother’s wife or divorced sister and their children) on their plots (Chavunduka, 1975). This custom intensified existing overcrowding. Riddell (1978) argues that the TTAs exceeded their carrying capacity by one fifth. However, conditions in NPA areas appeared to have been less severe. By 1982, African farmers who held title contributed 4% to

the country’s agricultural output (Munslow, 1985). For the 1975 – 1979 period, Zinyama (1986) puts this contribution at between 2 and 3 percent.

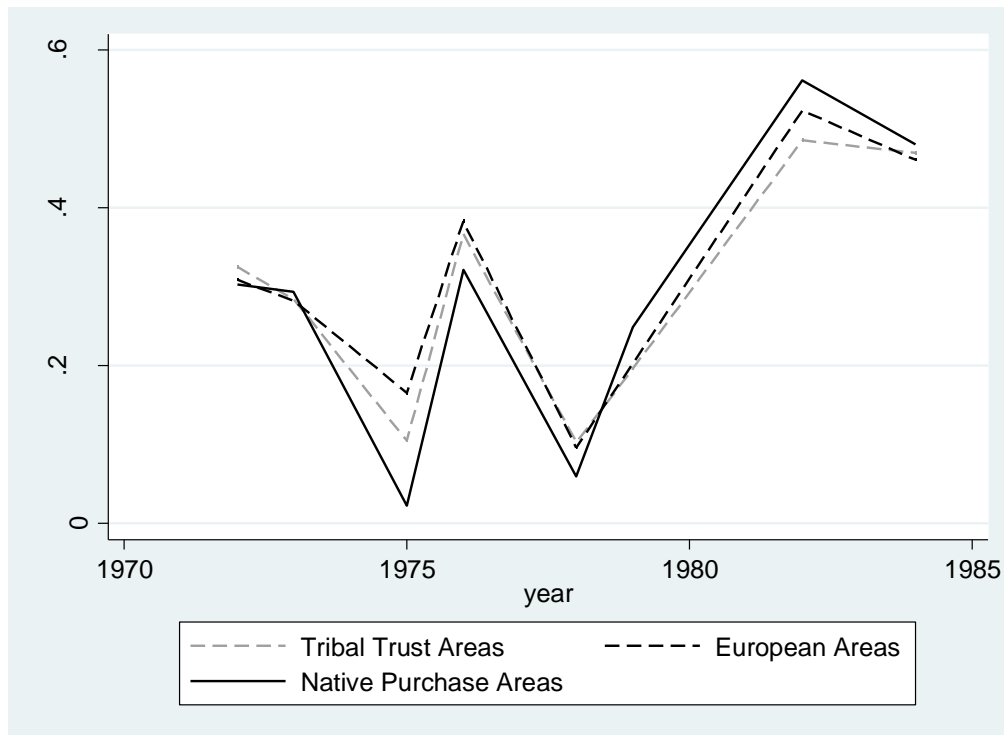


Figure 2: Ratio of cropland to total ward area (1972 – 1984)

Source: Own Illustration-using data generated from Landsat imagery through machine learning

3 DATA, ANALYSIS APPROACH AND FINDINGS

3.1 Classification of Images Using Machine Learning

Very little quantitative data is available to represent the various geographic regions defined by the 1930 LAA. Extricating the agricultural contribution of NPAs from that of the TTAs and the other regions has therefore traditionally been difficult. We therefore leverage historical satellite data to monitor land cover in colonial Rhodesia. The closest classification of land in the early colonial period is the work by Robbins (1934) in neighbouring Northern Rhodesia. Robbins (1934) used aerial photographs taken at the altitude of 10 000 feet by the Aircraft Operating Co. of South Africa. The main objective of the exercise was to assist in quicker area mapping; this study takes forward that work and classifies cropland in the NPAs, TTAs and EAs using machine learning and images captured in the colonial era by the Landsat MSS sensor (see Appendix 2 for details on the data source). We first analyse data from 1972 to

1979, which excludes the confounding influence of the transition from minority rule in 1980. However, our analysis is then extended up to 1984 to assess whether the relationships we estimate change beyond that time.

When electromagnetic energy from the sun hits an object on the surface of the earth, some of that energy is reflected back to satellites. Red (R), Blue (B) and Green (G) bands are the most common, and are visible to the human eye. Of particular importance is the invisible near infrared band: crops are most likely to reflect this band back to satellites than any other objects on the earth's surface. Crop classification takes advantage of this property, together with the fact that objects on the earth's surface have different spectral signatures of electromagnetic energy reflection (Chamunorwa, 2010; Eastman, 2003).

We employ the Support Vector Machine (SVM) algorithm [developed by Cortes & Vapnik (1995)] to classify images from the Landsat 1–5 Multispectral Scanner (MSS) (see appendix 2). In a supervised classification, we train the samples used to distinguish between cropland and other forms of land cover (mainly consisting of natural forest) in Quantum GIS (QGIS)'s SCP plugin. Final image classification in R produces a raster image with pixels 1 and 0 denoting cropland and all other types of land cover respectively. Our unit of analysis is current-day Zimbabwean wards (classified into NPAs, TTAs and EAs). The predicted binary images are aggregated to these geographic demarcations; our dependent variable is therefore the proportion of the ward area covered by crops. While this indicator does not measure the output obtained from land, it does give an indication of the extent of land under production. In Appendix 2, the data created through machine learning are compared with aggregated productivity time series data from Jayne & Jones (1997) and Thirtle et al. (1993). The agricultural data created in this study correlates highly⁷ over time with data from the other sources. We are therefore confident in the quality and reliability of the data. In addition, Appendix 2 discusses statistical metrics that establish that the classification was reliably conducted. For the first time, we have disaggregated indicators of crop production for small geographic areas in Southern Rhodesia's history. Furthermore, while greater areas of crop

⁷ The crop coverage for TTAs, NPAs and EAs are the preferred variables used in the analysis. The highest correlation is between TTA crop hectorage and communal area output at 0.9994.

production do not necessarily entail superior yields, the strong correlations between these quantities over time do suggest that studying only the former does provide valuable insights into variations in agricultural success of various regions. While we therefore cannot conclude whether property rights raise incomes from yields, we can rely on the extent of land covered by crops as an indicator of welfare.

3.2 Approach

In investigating how holding land titles in Southern Rhodesia affected agricultural production, we compare the area under cultivation of farmers in the TTAs to those in the NPAs. The main channel that we consider is differential access to markets [assuming that farmers in NPA areas unintentionally benefitted from better access to markets, as suggested by Andersson & Green (2016)], although we include many other control variables in our models to account for potential selection effects. Apart from plot sizes, most other variables such as soil quality, lack of access to credit and research are similar across these region types. More pertinently, we introduce an unconventional dataset to test how property rights and differential market access (as measured by distance to rail, road and urban centres) affected agricultural production.

3.3 Model Specification

The endogenous variable is the proportion of land under cultivation in a given region. Our main specifications are estimated using Ordinary Least Squares (OLS) that account for spatial dependence in the error terms (Conley, 1999). However, following Papke & Wooldridge (1996), we also adopt a fractional probit model because the dependent variable ranges between 0 and 1, and the linearity assumption of Ordinary Least Squares may not be suitable (Schwiebert, 2016; Gallani & Krishnan, 2017)⁸. Our model is expressed as:

$$Crop\ Share_{wft} = \alpha_0 + \alpha_1 Land\ Type_{wt} + \alpha_2 X_{wt} + C_f + \lambda_t + \mu_{wft}$$

where w and t index geographic wards and time respectively; $LandType$ represents a set of dummy variables to distinguish NPAs from TTAs and European Areas; X_{wt} is a vector of explanatory variables (namely regional population, precipitation, temperature, distance to

⁸ For the sake of robustness, we also estimate the models with a Tobit specification, acknowledging that the dependent variable is censored from the bottom at 0 and from the top at 1.

main road, distance to secondary road, distance to rail station or siding, distance to any road and a crop suitability index). C_f captures agro-ecological and frame⁹ fixed effects, while λ_t incorporates year¹⁰ and season¹¹ fixed effects. Five agro-ecological zone fixed effects, premised on FAO (2016), account for the fact that various parts of the country are suitable for specific crops and farming systems, which may naturally lead to higher crop cover. Frame fixed effects account for the fact that data is downloaded in 22 path/row frames from the US Geological Survey (USGS), each with its own measurement anomalies (see Appendix 3). Landsat 1-5 represent some of the first generation satellites deployed by the US National Aeronautics and Space Administration (NASA); later versions introduced improvements that enabled more reliable data analysis. Earlier satellites only recorded a handful of images per year over the chosen area, many of which are unusable due to cloud cover. Thus, year on year it is impossible to download imagery for the same month within the same season. Month and year fixed effects attempt to filter out any confounding effects of seasonality¹².

3.4 Explanatory Variables

We digitise the Land Apportionment map in Figure 1 to allocate current-day Zimbabwean wards to the various land classifications. We furthermore use historical shape files to calculate distances to main roads, secondary roads, any roads, rail stations and sidings and main cities, as shown in Figure 3. These variables proxy for market access in each ward.

⁹ As shown in Appendix 3, Landsat images are available as frames or tiles. To obtain an image mosaic for the whole country, 22 tiles (that represent areas with different geographies and potentially differential data quality) are pieced together. Frame Fixed Effects (FEs) are introduced into the specification to absorb any systematic characteristics related to these images.

¹⁰ The period 1972 – 1979 is rather eventful and the war of independence pitting the African nationalist fighters and the Rhodesian army is the major highlight. We introduce year FEs in an attempt to account for these fluctuations.

¹¹ Southern Rhodesia (Zimbabwe)’s rain fed agricultural season starts around late October and ends around April. Ideally, the machine-learning algorithm should be applied on images for this period. However, the MSS 1-5 represents first generation sensors and the image time frequency is low. For some frames and years, images are selected even if they fall outside the agricultural season in order to ensure full geographic coverage of the country. Even where images are available for the same month (within the farming season), some are unusable due to cloud cover and the only option is to select another image from another month, preferably within the farming season. The season, month and frame FEs attempt to correct these differences in image acquisition dates.

¹² It is also for this reason that our inference does not account for serial autocorrelation in addition to spatial dependence.

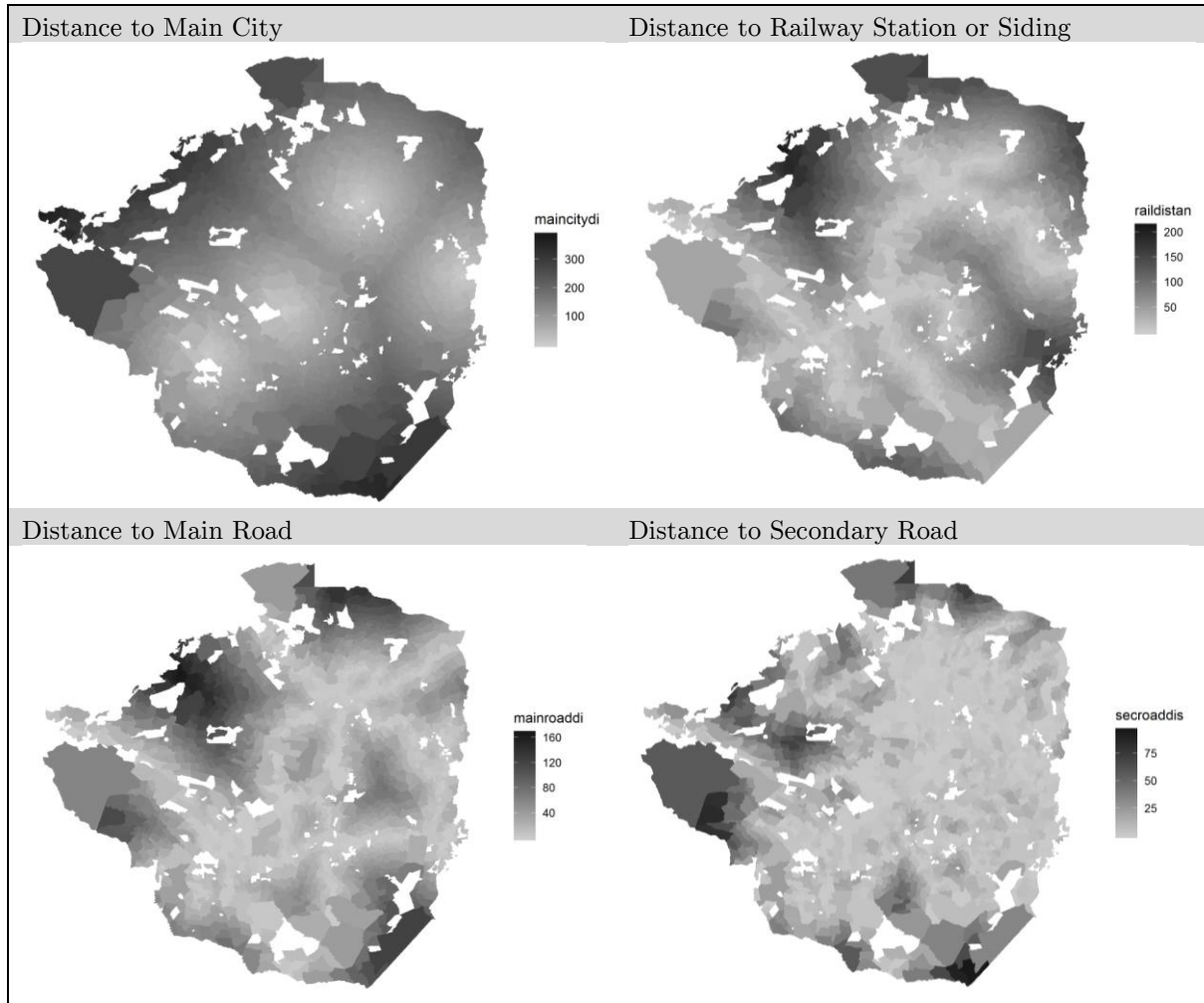


Figure 3: Distance Variables

Note: *maincitydi*, *raildistan*, *mainroaddi* and *secroaddi* are distance to main city, distance to rail station, distance to main road and distance to secondary road respectively. White values mean no data.

Source: Own illustrations

Control variables are introduced to account for selection of populations into various regions with varying conditions suitable to agriculture. Local population numbers are based on the Federal Department of Trigonometrical and Topographical Surveys, Rhodesia and Nyasaland (1962) map shown in Appendix 1. Each blue dot represents 1 000 native heads of household. Hence, we are able to compute a rough estimate of the working population in each ward in 1962. While the levels would have changed since that time and our period of analysis, we must assume (for lack of other data) that spatial variation has remained constant – in other words, we assume that migration resulting from conflict did not significantly change the relative geographic concentrations of populations between 1962 and our period of analysis. This assumption may not be realistic. However, we take this approach because we do not have

disaggregated population figures closer to our period of analysis. For the sake of robustness, we employ data aggregated by land class for 1970 and 1982 by Zinyama & Whitlow (1986). For 1970 and 1982, the data allocation to wards is based on the 1962 figures – the intermediary years are computed by relying on a geometric progression (see Table A1.1 in Appendix 1). The central findings of our models remain robust to using both imperfect approaches.

Even after controlling for population, a number of favourable characteristics may have driven selection into regions. We therefore construct further variables to account – as far as possible – for any bias in our models. Historical rainfall and temperature data are obtained from Willmott & Matsuura (2001), while a soil suitability index is sourced from Galor, Özak & Sarid (2016), Galor & Özak (2014) and Galor et al. (2016). Precipitation, temperature and soil suitability raster grids were processed in QGIS to match current-day Zimbabwean wards.

3.5 Results and Discussion

Before we present regression estimates, we descriptively assess whether farmers with titles in the NPAs cultivated more of their land than those without individual property rights in TTAs. We indirectly test the assertions of Anderson & Green (2016), who describe NPA farmers as a middle class relative to those in the TTAs; however, we cannot directly test whether more intensive production also improved yields and incomes, even if these are strongly correlated in aggregate over time. Figure 4 shows a choropleth map depicting the proportion of each ward area that was cultivated, for the pooled period 1972 – 1984. The central highlands of Zimbabwe, which were allocated to Europeans (EAs), had higher agricultural activity per land area than the TTAs and NPAs. It is more difficult to see differences in crop production across the latter two region types on the map. Our regression analysis will distinguish whether these effects are the result of land classifications only, or whether other contributing factors (such as suitable agricultural conditions) result in the distinction.

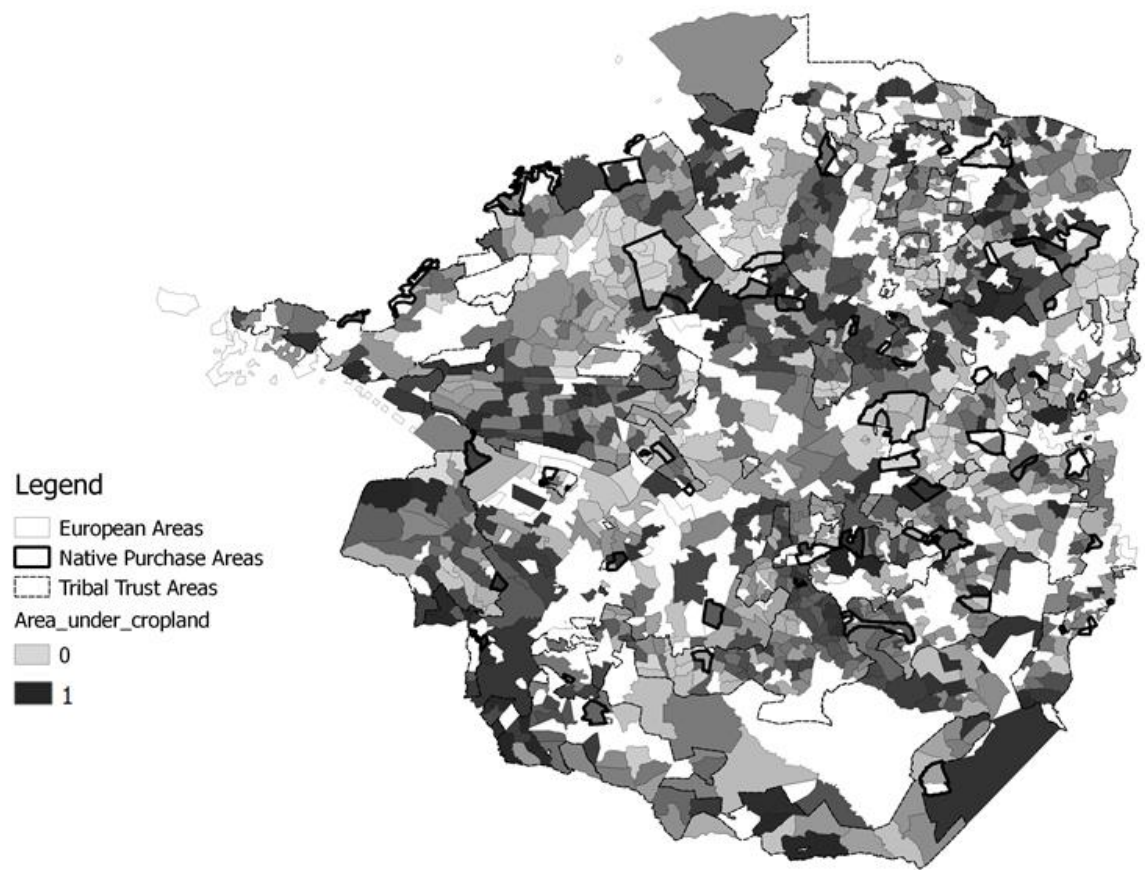


Figure 4: Proportion of land under crop cultivation (1972 – 1984)
Source: Own compilation

Table 1: Class Effects of Colonial Land Policy (OLS Estimates with S.Es adjusted for Spatial Dependence)

	(1)	(2)	City (3)	Road (4)	Rail (5)	(6)	(7)	City (8)	Road (9)	Rail (10)
	<i>Period: 1972-1979</i>					<i>Period: 1980-1984</i>				
European Areas	0.026 (0.013)** [0.004]***	0.028 (0.013)** [0.004]***	-0.047 (0.092) [0.030]	0.026 (0.031) [0.007]***	0.068 (0.046) [0.025]***	0.052 (0.023)** [0.007]***	0.056 (0.023)** [0.006]***	0.065 (0.169) [0.052]	-0.044 (0.060) [0.017]***	0.032 (0.087) [0.041]
NPA	-0.019 (0.024) [0.005]***	-0.020 (0.023) [0.005]***	0.603 (0.291)** [0.109]***	0.389 (0.110)** [0.020]***	0.568 (0.125)** [0.059]***	0.040 (0.047) [0.013]***	0.038 (0.047) [0.012]***	0.766 (0.487) [0.413]***	0.280 (0.209) [0.055]***	0.651 (0.285)** [0.078]***
ln(dist city)			0.000 (0.015) [0.006]	0.005 (0.013) [0.004]	0.005 (0.013) [0.005]			0.019 (0.029) [0.020]***	0.011 (0.025) [0.007]*	0.016 (0.025) [0.007]**
ln(dist main road)			0.007 (0.006) [0.002]***	0.008 (0.007) [0.002]***	0.007 (0.006) [0.002]***			-0.018 (0.010)* [0.002]***	-0.028 (0.012)** [0.003]***	-0.017 (0.010) [0.002]***
ln(dist rail)			-0.002 (0.008) [0.004]	-0.001 (0.008) [0.004]	0.007 (0.010) [0.007]			0.025 (0.015)* [0.003]***	0.025 (0.015)* [0.003]***	0.025 (0.017) [0.007]***
EAs x Distance			0.018 (0.020) [0.007]**	0.003 (0.010) [0.003]	-0.009 (0.013) [0.007]			-0.001 (0.036) [0.011]	0.036 (0.019)* [0.005]***	0.009 (0.025) [0.011]
NPA x Distance			-0.130 (0.060)** [0.022]***	-0.122 (0.032)** [0.006]***	-0.154 (0.032)** [0.016]***			-0.152 (0.102) [0.028]***	-0.068 (0.060) [0.014]***	-0.162 (0.075)** [0.019]***
Constant	0.346 (0.076)*** [0.021]***	0.400 (0.104)*** [0.025]***	0.395 (0.122)*** [0.030]***	0.360 (0.115)*** [0.027]***	0.338 (0.115)*** [0.031]***	0.164 (0.116) [0.031]***	0.420 (0.193)** [0.039]***	0.231 (0.232) [0.071]***	0.295 (0.219) [0.047]***	0.240 (0.221) [0.062]***
FEs	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Ward Controls	N	Y	Y	Y	Y	N	Y	Y	Y	Y
N	2108	2108	2108	2108	2108	696	696	696	696	696

NOTES: Individual ward controls are population, rainfall, and temperature and soil suitability index. FEs denote region, frame, month and year fixed effects. White robust standard errors are reported in parentheses while Conley (1999) spatial dependence adjusted standard errors are shown in square brackets. Conley SEs are computed using distance cut-off of 100 km. Results remain robust at 16km and 50 km. Base category = Tribal Trust Areas (TTAs). Columns 3 and 8; 4 and 9; 5 and 10 presents results from the regression that interacts land class with distance to main city, distance to main road and distance to rail station or siding respectively. * p < 0.10, ** p < 0.05, *** p < 0.01

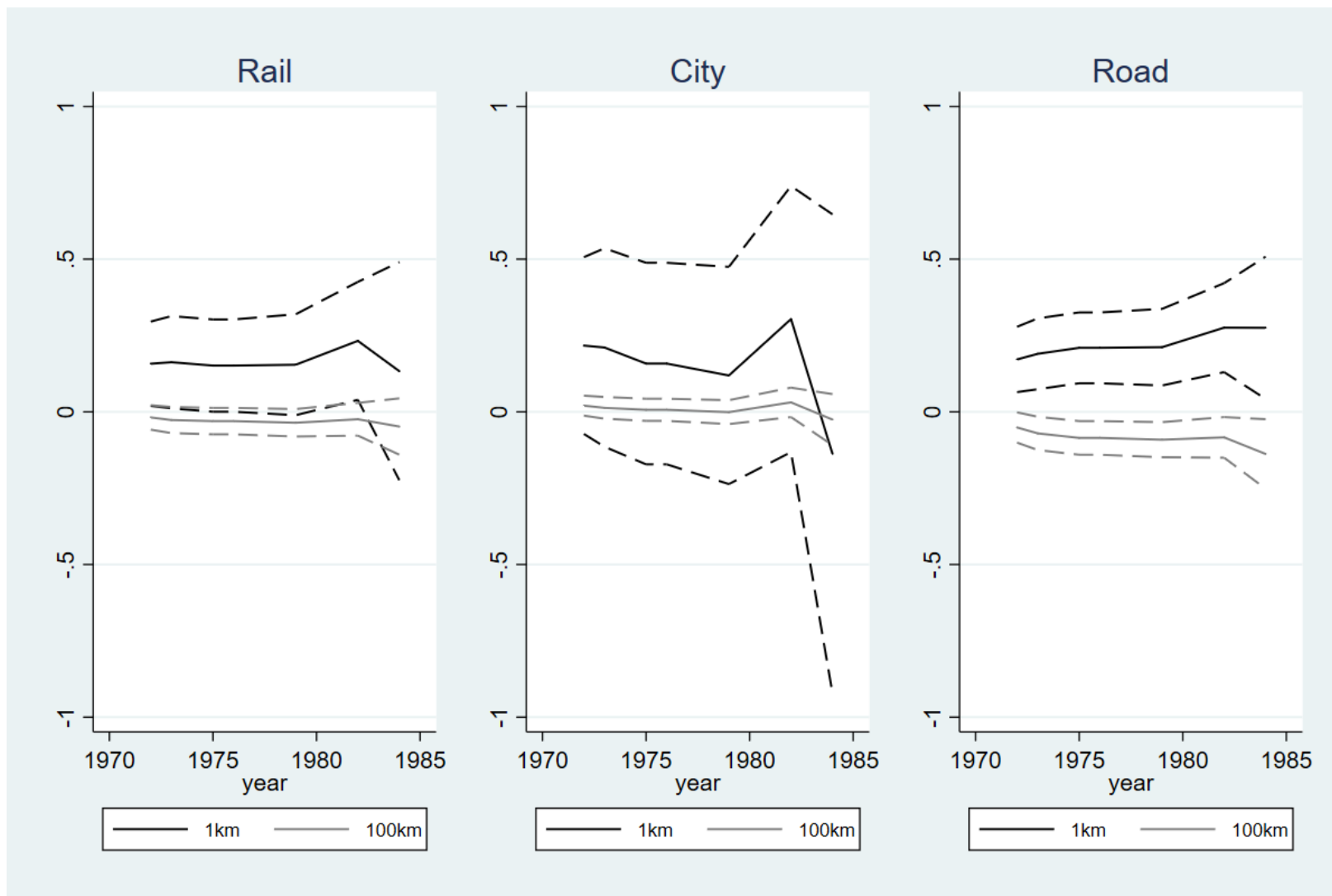


Figure 5: Advantages of NPAs over TTAs in various periods and locations: results from rolling regressions (1972 – 1984)

Source: Own compilation. Results represent the NPA advantage in crop coverage over TTAs at various distances from the relevant infrastructure. The 1972 regression only includes that year. Estimates for later years include all prior years. Dashed lines are 90% confidence intervals

We estimate regressions to establish whether NPA farmers in Southern Rhodesia had more land under cultivation as compared to their counterparts in the TTAs. The regressions also explore whether advantages in crop production were contingent on access to markets and infrastructure in the form of major cities, main roads and railways lines. Core results are presented in Table 1 using Ordinary Least Squares (OLS) models that adjust for spatial dependence following the procedure by Conley (1999) and implemented by Nunn and Wantchekon (2011). Tables A4.1 and A4.2 repeat these results using fractional probit and tobit specifications. Estimated marginal effects from the fractional probits (which are not shown) are very close to those from OLS estimates. Tobit models also yield similar results. We therefore limit our discussion to Table 1, which allows us to interpret coefficient magnitudes with ease, and also allows us to assess the role of spatial dependence in inference. Conley standard errors never reduce the statistical significance of our coefficient estimates, regardless of the distance threshold chosen. Our results are therefore robust to our mode of statistical inference. Specifications capture three different channels that affected agricultural production in Southern Rhodesia, namely distance to main cities, distance to main roads and distance to rail station or siding.

We start with estimates that only include the period before 1980. Column (1) provides a base specification, which includes only relevant fixed effects to account for seasonal and frame-specific measurement errors¹³. Crop coverage was 2.6 percentage points higher in European Areas compared to TTAs. We measure no significant differences in production between NPAs and TTAs using White robust standard errors, but with Conley adjustments the effect is significant. On average (before taking into account access to markets) NPAs had significantly less land under cultivation in comparison to TTAs. Controlling for population, climatic variables and soil suitability in column (2) only marginally influences these results. Area under cultivation was therefore much greater in the less densely populated European regions. Our finding is therefore consistent with literature that suggests that African areas were overcrowded and experienced high competition for resources. Many Africans had few options but to find employment either in cities or European farming areas. However, differentials in

¹³ Without fixed effects, we detect no differences in crop coverage between the various land classes. This, however, results because usable images were non-randomly distributed across various seasons in the three areas.

property rights, farming conditions and settlement patterns do not fully explain this gap: we estimate a disadvantage for NPA farmers whose property rights were less well-defined than those in TTAs.

If climatic and soil advantages do not explain the greater extent of cultivation in European areas, then one important omitted factor is proximity to markets and infrastructure. We control for distance to a main road, to railways and to a main city. However, we posit that these market access variables may have heterogeneous effects across the various land classifications. Columns (3) to (5) explore this possibility with interaction terms. The main effects reveal that NPA farmers that (hypothetically) lived next to¹⁴ main cities, main roads and railways cultivated 60.3, 38.9 and 56.8 percentage points more of their total available land respectively, compared to similar farmers in TTAs. Significant negative coefficients on interactions reveal that the advantages of individual property rights decay the further farmers were located from these key infrastructures. These results suggest that access to transport infrastructure and main cities (markets) was crucial for cultivation decisions of farmers in NPAs. Those who were located close to roads and rails were more likely to cultivate greater expanses of land, while those further away more closely resembled their counterparts in TTAs. Lack of property rights stymied cultivation in TTAs; however, even land rights in NPAs did not guarantee production that is more expansive. Crucially, areas where Africans enjoyed individual land rights only achieved more expansive cultivation if they were better connected to external markets. Hence, the notion that NPA farmers performed better than TTAs was conditionally true: land rights assisted them if they could also easily transport their goods for sale beyond local markets. Our results suggest that land tenure reform can only be successful if other market failures (which also arose from exclusionary, isolationist policies) are simultaneously addressed.

3.6 Robustness checks

A number of potential confounders may drive our results. Firstly, local political power of European farming unions is difficult to control for. However, as discussed above, estimated

¹⁴ Main effects represent households that live 1km from the various infrastructures, since $\ln(\text{distance})=\ln(1)=0$ and this eliminates the interaction term.

European advantage becomes statistically insignificant if we consider models that are heterogeneous in access to infrastructure. As a result, we do not consider union power to be a remaining confounder; in fact, the ability to lobby for the infrastructure that we control for represents this political influence. National political power of the Rhodesian Front (RF) may also be influential in determining our results. To test this assertion, we re-run all our regressions for a sample that includes only the period after 1980 (see columns (6) to (10)). Our core coefficients are stable; we conclude that regime change did not deteriorate the higher cultivation areas in NPA regions that were adequately closely located to relevant transport infrastructure.

To test this further, we conduct rolling regressions across time. In each year we run a regression that includes data from the prior and subsequent period, so that we have a three year rolling window in each sub-sample¹⁵. Model predictions at selected distances from railways, main roads and cities are represented over time in figure 5. Results focus on the premium which NPA farmers exhibit vis-à-vis TTA farmers. In all cases, farmers in NPAs have a premium in crop production over TTAs if they are located within 1km of the respective infrastructures. The relationship is robust over time, except towards the very end of the period. The magnitude of the NPA advantage diminishes as farmers are located further from cities, railways and roads. Again, this result is stable over time, except towards the end of the period. Our results also include 90% confidence intervals: in the case of distance to railways and cities, we do not have sufficient statistical power to distinguish year-specific estimates from zero. Close proximity to roads is, however, advantageous (from an economic and statistical perspective) for the extent of NPA cultivation in all periods; the reduction of the effect with remoteness is also statistically significant and robust to the period of analysis. Overall, the magnitudes of our estimates suggest that the results found in pooled analysis are also stable over time; where we have statistical power, we can also show that they are significant. The most convincing estimates emphasise proximity to roads as a pre-condition for property rights to change farmer decisions. We conclude that in all periods property rights only incentivised land production if

¹⁵ The first and last year naturally only comprise a 2 year window. We pool regressions to smoothe over idiosyncratic fluctuations in specific years, and to gain statistical power, as the year-specific analyses contain few NPA observations relative to TTAs.

located close to infrastructure; in contrast, NPA property rights made no difference (vis-à-vis TTAs) to the extent of production if access to markets and infrastructure was absent. Our estimates are not spuriously driven by specific events, such as transition to majority rule in 1980.

4 CONCLUSION

The majority of people in SSA live in rural areas and rely on agriculture for their sustenance. Land titling can serve as a possible mechanism to promote access to land and improve agricultural growth. However, previous research has not provided unequivocal evidence for these links (Udry, 2011). This paper contributes to this debate. We turn to a historical setting, where we are able to compare three groups of interest: African farmers in TTAs operated in a context of communal ownership, while Africans in NPAs were granted individual title; EAs were also governed by individual property rights. Moreover, the two regions allocated to Africans were located in inferior agricultural areas, and were isolated from markets and key infrastructures (Machingaidze, 1991). In contrast, European farmers were advantaged by the 1930 LAA by being granted land that was agriculturally suitable and also proximate to markets. From historical accounts, we anticipated a production hierarchy that emphasised the advantages of both location and property rights.

Our study investigated the importance of access to markets over and above putting in place individual property rights, using newly constructed crop production data obtained from historical satellite imagery. The paper finds evidence that the farmers in the NPAs had more land under cultivation, as long as they were located close to main cities, main roads and railway stations or sidings. Access to land rights was not sufficient to create the incentives for more expansive cultivation. Instead, access to infrastructure that linked to other markets was important for farming decisions. Our results highlight that proximity to transport infrastructure was important for NPA farmers. The results show that as distance increases from key infrastructure, NPA farmers tended to perform worse than those in TTAs. TTAs were overcrowded with high population density, while the opposite was true in NPAs. Access to profitable, external markets was therefore more important for NPA farmers than those in TTAs, and combined with private property rights to incentivise production. In principle, land

titles may increase the area of land under crops. Yet, access to markets complements individual property rights in contributing to greater areas of land under cultivation.

While our empirical analysis cannot conclude on agricultural yields and incomes of the various farmer groups, time series evidence shows that proportion of area under cultivation is strongly correlated with the former over time (Appendix 2, Tables A2.1 and A2.2). We therefore tentatively infer that this analysis extends to other (unmeasurable) indicators of agricultural success. Our results, however, have other contributions to make. They are the first to use reconstructed regional micro data for analysis in Southern Rhodesia; the benefit is that we could control for a host of observables that may have driven the selection of superior land for advantaged groups. Time series aggregates – which are more readily available – are not sufficient to account for such biases. The historical context within which this study is located provides an ideal setting to weigh up the roles of market access and land titles in agricultural production; this is because these characteristics were purposefully allocated to the various groupings through legislation, and could be clearly identified. Our study, however, also adds quantitative estimates to understand an existing historiography on Southern Rhodesia. Our models are able to uncover heterogeneity in the impact: in particular, we emphasise the necessary role that market access plays in the process of reforming land rights in sub-Saharan Africa.

5 REFERENCES

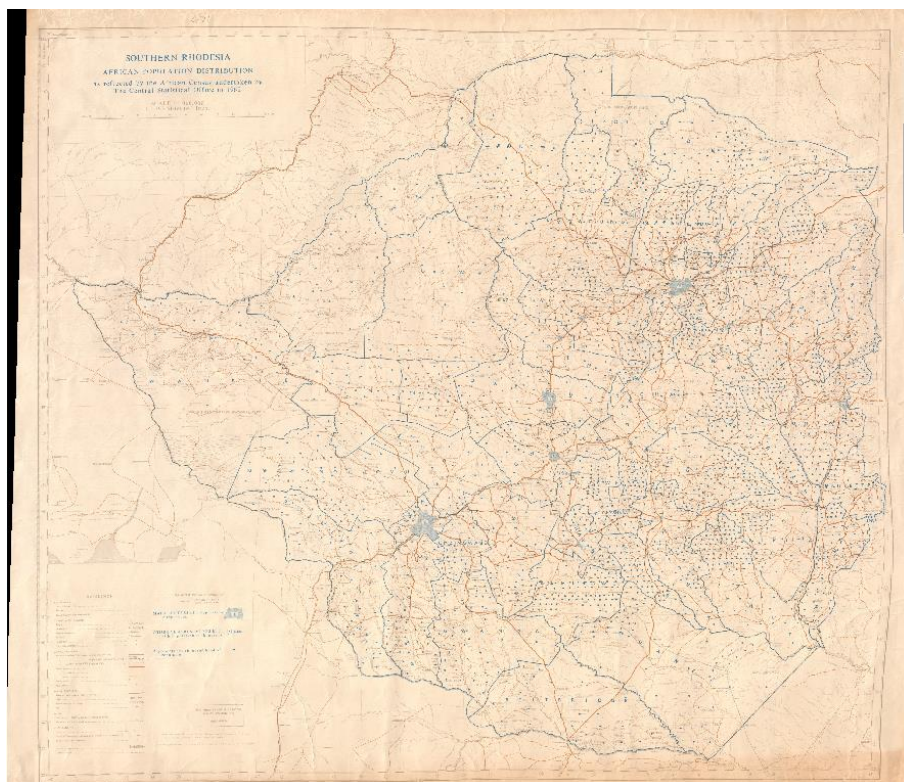
- Abdulai, A., Owusu, V., & Goetz, R. (2011). Land tenure differences and investment in land improvement measures: Theoretical and empirical analyses. *Journal of development Economics*, 96(1), 66-78.
- Abu, B. M., Issahaku, H., & Nkegbe, P. K. (2016). Farmgate versus market centre sales: a multi-crop approach. *Agricultural and Food Economics*, 4(1), 21.
- Ahmed, U., Ying, L., Bashir, M., Abid, M., Elahi, E., & Iqbal, M. (2016). Access to output market by small farmers: The case of Punjab, Pakistan. *Journal of Animal and Plant Sciences*, 26(3), 2016.
- Andersson, M., & Green, E. (2016). Development Under the Surface: The Rise of Indigenous Agriculture as an Unintended Consequence of Settler Institutions in Southern Rhodesia, 1896–1962. *Journal of International Development*, 28(1), 127-146.
- Arrighi, G. (1967). *The political economy of Rhodesia* (Vol. 16): Mouton The Hague.
- Arrighi, G. (1970). Labour supplies in historical perspective: a study of the proletarianization of the African peasantry in Rhodesia. *The Journal of Development Studies*, 6(3), 197-234.
- Aryeetey, E., & Udry, C. (2010). Creating property rights: Land banks in Ghana. *American Economic Review*, 100(2), 130-134.
- Austin, R. (1975). *Racism and apartheid in southern Africa: Rhodesia: a book of data*: Unesco Press.
- Binswanger, H. P., Deininger, K., & Feder, G. (1995). Power, distortions, revolt and reform in agricultural land relations. *Handbook of development economics*, 3, 2659-2772.
- Bogart, D. (2009). Nationalizations and the development of transport systems: Cross-Country evidence from railroad networks, 1860–1912. *The Journal of Economic History*, 69(1), 202-237.
- Boughton, D., Mather, D., Barrett, C. B., Benfica, R., Abdula, D., Tschirley, D., & Cunguara, B. (2007). Market participation by rural households in a low-income country: An asset-based approach applied to Mozambique. *Faith and economics*, 50(1), 64-101.
- Chamunorwa, A. (2010). Comparative Analysis of Agricultural Productivity between Newly Resettled Farmers and Communal Farmers in Mashonaland East Province.
- Chavunduka, G. (1975). Rural and urban life. *Zambezia*, 4(II).
- Clarke, D. (1975). Land inequality and income distribution in Rhodesia. *African Studies Review*, 18(1), 1-7.
- Conley, T. G. (1999). GMM estimation with cross sectional dependence. *Journal of econometrics*, 92(1), 1-45.
- Cortes, C., & Vapnik, V. (1995). Support-vector networks. *Machine learning*, 20(3), 273-297.
- Deininger, K., Ali, D. A., Holden, S., & Zevenbergen, J. (2008). Rural land certification in Ethiopia: Process, initial impact, and implications for other African countries. *World Development*, 36(10), 1786-1812.
- Deininger, K., & Castagnini, R. (2006). Incidence and impact of land conflict in Uganda. *Journal of Economic Behavior & Organization*, 60(3), 321-345.
- Deininger, K., & Jin, S. (2006). Tenure security and land-related investment: Evidence from Ethiopia. *European Economic Review*, 50(5), 1245-1277.

- Deininger, K., Jin, S., Xia, F., & Huang, J. (2014). Moving off the farm: land institutions to facilitate structural transformation and agricultural productivity growth in China. *World Development*, 59, 505-520.
- Do, Q.-T., & Iyer, L. (2008). Land titling and rural transition in Vietnam. *Economic Development and Cultural Change*, 56(3), 531-579.
- Duggan, W. R. (1980). The Native Land Husbandry Act of 1951 and the rural African middle class of southern Rhodesia. *African Affairs*, 79(315), 227-239.
- Eastman, J. R. (2003). *IDRISI Kilimanjaro: guide to GIS and image processing*: Clark Labs, Clark University Worcester, MA.
- FAO. (2016). Chapter 2: Zimbabwe's natural regions and farming systems. *FAO Corporate Document Repository*.
- Floyd, B. N. (1962). Land apportionment in southern Rhodesia. *Geographical Review*, 52(4), 566-582.
- Frankema, E., Green, E., & Hillbom, E. (2016). Endogenous processes of colonial settlement. the success and failure of european settler farming in sub-saharan africa. *Revista de Historia Económica/Journal of Iberian and Latin American Economic History (New Series)*, 34(02), 237-265.
- Gallani, S., & Krishnan, R. (2017). Applying the fractional response model to survey research in accounting. *School HB*.
- Galor, O., & Özak, Ö. (2014). The agricultural origins of time preference: National Bureau of Economic Research.
- Galor, O., Özak, Ö., & Sarid, A. (2016). Geographical Origins and Economic Consequences of Language Structures. *Brown University Working Paper*, 2016.
- Goldstein, M., & Udry, C. (2008). The profits of power: Land rights and agricultural investment in Ghana. *Journal of political economy*, 116(6), 981-1022.
- Good, K. (1976). Settler colonialism: economic development and class formation. *The journal of modern African studies*, 14(4), 597-620.
- Green, E. (2016). The development of settler agriculture in British Africa revisited: Estimating the role of tenant labour in Southern Rhodesia, C 1900-1960: African Economic History Network.
- Haviland, W. (1953). Tobacco farm organization, costs and land-use in Southern Rhodesia. *South African Journal of Economics*, 21(4), 367-380.
- Herbst, J. (1991). The dilemmas of land policy in Zimbabwe. *Africa Insight*, 21(4), 269-276.
- Herranz-Loncán, A., & Fourie, J. (2017). "For the public benefit"? Railways in the British Cape Colony. *European Review of Economic History*, 22(1), 73-100.
- Hughes, A. J. B. (1971). Tribal land tenure-an obstacle to progress?: special reference to the Tribal Trust Land of Rhodesia. *Africa Insight*, 1(1), 56-73.
- Jayne, T. S., & Jones, S. (1997). Food marketing and pricing policy in Eastern and Southern Africa: A survey. *World Development*, 25(9), 1505-1527.
- Jedwab, R., Kerby, E., & Moradi, A. (2017). History, path dependence and development: Evidence from colonial railways, settlers and cities in Kenya. *The Economic Journal*, 127(603), 1467-1494.
- Jedwab, R., & Moradi, A. (2016). The permanent effects of transportation revolutions in poor countries: evidence from Africa. *Review of Economics and Statistics*, 98(2), 268-284.

- Jennings, A., & Huggins, G. (1935). Land Apportionment in Southern Rhodesia. *Journal of the Royal African Society*, 34(136), 296-312.
- Jordaan, H., Grové, B., & Backeberg, G. R. (2014). Conceptual framework for value chain analysis for poverty alleviation among smallholder farmers. *Agrekon*, 53(1), 1-25.
- Machingaidze, V. E. (1991). Agrarian Change from Above: The Southern Rhodesia Native Land Husbandry Act and African Response. *International Journal of African Historical Studies*, 557-588.
- Markussen, T. (2008). Property Rights, Productivity, and Common Property Resources: Insights from Rural Cambodia¹. *World Development*, 36(11), 2277-2296.
- Masuku, M., Makhura, M., & Rwelarmira, J. (2001). Factors affecting marketing decisions in the maize supply chain among smallholder farmers in Swaziland. *Agrekon*, 40(4), 698-707.
- Moyana, H. V. (1975). Land and race in Rhodesia. *African Review*, 5(1), 17-41.
- Muchomba, F. M. (2017). Women's Land Tenure Security and Household Human Capital: Evidence from Ethiopia's Land Certification. *World Development*, 98, 310-324.
- Munslow, B. (1985). Prospects for the socialist transition of agriculture in Zimbabwe. *World Development*, 13(1), 41-58.
- Ncube, M. (2000). Employment, unemployment and the evolution of labour policy in Zimbabwe. *Zambezia*, 27(2), 161-194.
- Ndlela, D., & Robinson, P. (2007). Distortions to Agricultural Incentives in Zimbabwe. *Agricultural Distortions Paper*, 39.
- Newman, C., Tarp, F., & Van Den Broeck, K. (2015). Property rights and productivity: The case of joint land titling in Vietnam. *Land Economics*, 91(1), 91-105.
- Nunn, N., & Wantchekon, L. (2011). The slave trade and the origins of mistrust in Africa. *American Economic Review*, 101(7), 3221-3252.
- Palmer, R. (1971). War and land in Rhodesia. *Transafrican Journal of History*, 1(2), 43-62.
- Palmer, R. (1990). Land reform in Zimbabwe, 1980-1990. *African Affairs*, 89(355), 163-181.
- Papke, L. E., & Wooldridge, J. M. (1996). Econometric methods for fractional response variables with an application to 401 (k) plan participation rates. *Journal of applied econometrics*, 11(6), 619-632.
- Phimister, I. R. (1974). Peasant production and underdevelopment in Southern Rhodesia, 1890-1914. *African Affairs*, 73(291), 217-228.
- Phimister, I. R. (1988). *An economic and social history of Zimbabwe, 1890-1948: Capital accumulation and class struggle*: Longman London.
- Pollak, O. B. (1975). Black farmers and white politics in Rhodesia. *African Affairs*, 74(296), 263-277.
- Poulton, C., Kydd, J., & Dorward, A. (2006). Overcoming market constraints on pro-poor agricultural growth in Sub-Saharan Africa. *Development policy review*, 24(3), 243-277.
- Punt, E. (1979). The development of African agriculture in Southern Rhodesia with particular reference to the interwar years.
- Ranga, D. (2004). The migration effects of the economic structural adjustment programme on a rural community in Zimbabwe.
- Ravallion, M., & Van De Walle, D. (2006). Land reallocation in an agrarian transition. *The Economic Journal*, 116(514), 924-942.

- Riddell, R. C. (1978). The land problem in Rhodesia; alternatives for the future.
- Rifkind, M. (1969). *The politics of Land in Rhodesia*: University of Edinburgh.
- Robbins, C. R. (1934). Northern Rhodesia; an experiment in the classification of land with the use of aerial photographs. *Journal of Ecology*, 22(1), 88-105.
- Schwiebert, J. (2016). A Sample Selection Model for Fractional Response Variables.
- Senyolo, G., Chaminuka, P., Makhura, M., & Belete, A. (2009). Patterns of access and utilization of output markets by emerging farmers in South Africa: Factor analysis approach. *African Journal of Agricultural Research*, 4(3), 208-214.
- Sithole, P. (1972). Two Trade Union Viewpoints. *The Rhodesian Journal of Economics*, 6(4).
- Stocking, M. A. (1978). Relationship of agricultural history and settlement to severe soil erosion in Rhodesia. *Zambezia*, 6(2), 129-145.
- Thirtle, C., Atkins, J., Bottomley, P., Gonesse, N., Govereh, J., & Khatri, Y. (1993). Agricultural productivity in Zimbabwe, 1970-90. *The Economic Journal*, 103(417), 474-480.
- Udry, C. (2011). Land tenure. *The Oxford Companion to the Economics of Africa*, 1.
- Weinrich, A. K. H. (1979). *Women and racial discrimination in Rhodesia*: United Nations Educational.
- Whillow, J. (1980). Land use, population pressure and rock outcrops in the tribal areas of Zimbabwe-Rhodesia. *Zimbabwe Rhodesia Agricultural Journal*, 77(1), 3-11.
- Willmott, C., & Matsuura, K. (2001). Terrestrial Air Temperature and Precipitation: Monthly and Annual Time Series (1950 - 1999).
http://climate.geog.udel.edu/~climate/html_pages/README.ghcn_ts2.html .
- Youé, C. (2002). Black squatters on white farms: segregation and agrarian change in Kenya, South Africa, and Rhodesia, 1902–1963. *The International History Review*, 24(3), 558-602.
- Zinyama, L. (1986). Agricultural development policies in the African farming areas of Zimbabwe. *Geography*, 105-115.
- Zinyama, L., & Whitlow, R. (1986). Changing patterns of population distribution in Zimbabwe. *GeoJournal*, 13(4), 365-384.

APPENDIX 1: 1962 POPULATION



Source: Federal Department of Trigonometrical and Topographical Surveys, R. a. N. (1963). Southern Rhodesia: Land Apportionment. from <http://www.digitalcollections.lib.uct.ac.za/special-collections-maps>

Table A1.1: European Commercial Agriculture

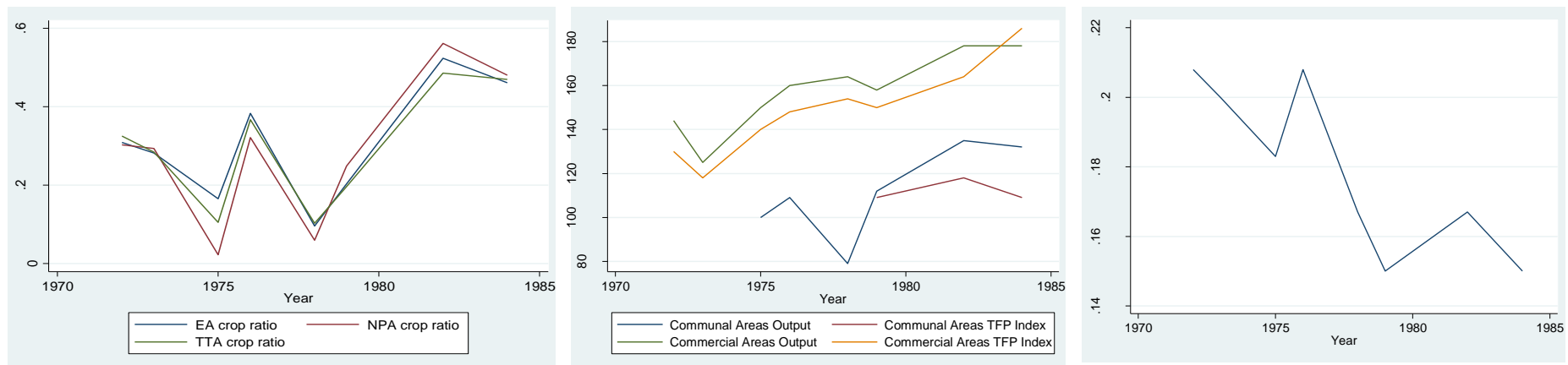
Land class	Population Count
Tribal Trust Areas (TTAs)	4 163 000
European Areas (EAs)	2 220 000
Native Purchase Areas (NPAs)	297 000
Unassigned Class	226 000

Table A1.1 shows the rural population data by land class based on the 1962 Southern Rhodesia census. Native Purchase Areas (NPAs) population as a percentage of total was 6.66%. We then split the data on the African population for 1970 and 1982 as provided by Zinyama and Whitlow (1986) (Table 1) into NPAs and TTAs using that ratio. We then allocate the 1970 and 1982 population figures to wards based on the 1962 population count, and impute figures for the intermediate years using a geometric mean. Using these figures, we repeat our analysis and the results remain robust.

APPENDIX 2: SVM CLASSIFICATION ACCURACY

Classification performance for each Landsat path/row frame or footprint are available here: <https://tinyurl.com/yau2pk9n>. Figure A2.1 shows a comparison of the agriculture data generated by the study to aggregate data in Thirtle et al., (1993) and Jayne and Jones (1997). The scales are different, making this an uneasy task, yet the very high correlations shown in Table A2.1 inspire confidence in the data.

Figure A2.1: Comparison of machine-learning generated data to other sources



a. Ratio of crop to ward area (endogenous variables) created with machine learning from Landsat images. It is shown here for European Areas (EA), Native Purchase Areas (NPAs) and Tribal Trust Areas (TTAs)

b. African communal areas and European commercial areas agriculture aggregate output and Total Factor Productivity (TFP) indices in Thirtle et al., (1993).
* Graph reconstructed using approximate figures from the original.

c. Per capita grain production in the African communal lands from Jayne and Jones (1997).
* Graph reconstructed using approximate figures from the original.

APPENDIX 2: SVM CLASSIFICATION ACCURACY (continued...)

Table A2.1: Time Series Correlations of European Commercial Agriculture with Aggregates from Classified Images

	EAs crop ratio	EA crop hectorage	Commercial Agriculture Output	Commercial Agriculture TFP Index
EAs crop ratio	1			
EAs crop hectorage	0.9645	1		
Commercial Agriculture Output	0.4495	0.4413	1	
Commercial Agriculture TFP Index	0.4527	0.399	0.9448	1

Table A2.2: Correlations of Time Series of African Agriculture with Aggregates from Classified Images

	Per Capita Grain Production in Communal Areas	Communal Areas Output	Communal Areas TFP Index	NPA crop ratio	NPA crop hectorage	TTA crop ratio	TTA crop hectorage
Per Capita Grain Production in Communal Areas	1						
Communal Areas Output	0.6003	1					
Communal Areas TFP Index	1	0.6003	1				
NPA crop ratio	0.7004	0.9913	0.7004	1			
NPA crop hectorage	0.0733	0.8417	0.0733	0.7632	1		
TTA crop ratio	0.5419	0.9975	0.5419	0.9794	0.8779	1	
TTA crop hectorage	0.627	0.9994	0.627	0.9952	0.8229	0.9945	1

APPENDIX 2: SVM CLASSIFICATION ACCURACY (continued...)

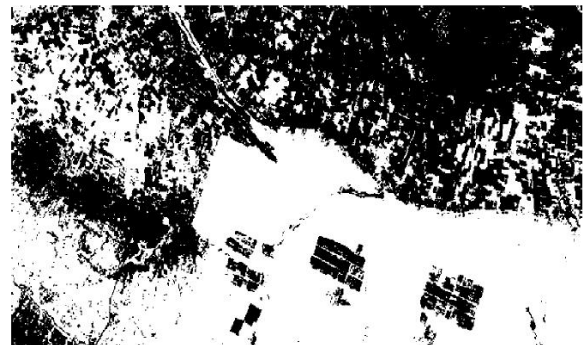
As already discussed, the individual graphs in Figure A2.1 are not superimposed on each other for easier comparison due to the different scales. Rather, correlation coefficients are calculated between the data classified from Landsat imagery through machine and aggregate indicators in Jayne and Jones (1997) and Thirtle et al. (1993). Table A2.1 and A2.2 show the correlation results for European commercial and African agriculture respectively. In Table A2.1 and A2.2, EAs crop ratio, EAs crop hectorage, NPA crop ratio, NPA crop hectorage, TTA crop ratio and TTA crop hectorage represent the data created through machine learning from Landsat imagery, whereas the rest represents data from the other sources. The correlations are quite high (as high as 0. 9994), which means that the data are reliable.

Figure A2.3: Comparing Near Infrared composite and predicted raster

NIR Composite



SVM Predicted Algorithm



Source: Near Infrared Composite (NIR) created in QGIS using Landsat multispectral bands. After identifying the training points, the SVM algorithm is implemented in R to obtain the predicted image in black and white on the right.

APPENDIX 3: LANDSAT FRAMES AND IMAGE DATES



Frame	Dates				
168072	08-Sep-72	25-Mar-73	24-Jun-84		
168073	08-Sep-72	25-Mar-73	26-Apr-79		
168074	03-Aug-72	13-Jan-73	25-Jul-79		
168075	07-Dec-72	30-Jan-73	25-Jul-79		
169072	04-Sep-73	09-Sep-79	02-Aug-84		
169073	08-Dec-72	17-Aug-73	10-Aug-76	18-Aug-84	
169074	17-Aug-73	10-Aug-76			
169075	08-Dec-72	10-Aug-76	16-Jun-78		
170071	10-Sep-72	22-Jun-84	27-Jul-79		
170072	11-Nov-72	09-Mar-73	31-Dec-84		
170073	03-Nov-72	14-Jan-73	11-Aug-76	26-Sep-84	
170074	10-Sep-72	05-Sep-73	08-Jan-76		
170075	03-Nov-72	19-Feb-73	22-Sep-75		
171071	22-Nov-72	06-Sep-73	12-Aug-76		
171072	06-Sep-73				
171073	06-Sep-73	12-Aug-76	29-Jun-84	22-Nov-72	
171074	11-Sep-72	28-Mar-73	13-Jul-75	12-Aug-76	29-Jun-84
172072	23-Nov-72	20-Jun-84			
172073	29-Dec-72	07-Sep-73	06-Sep-75	13-Aug-76	16-Aug-79
172074	29-Dec-72	13-Oct-73	13-Aug-76		
173072	02-Oct-72	05-Feb-73	14-Aug-76	02-Oct-79	
173073	14-Aug-76	18-Nov-84			

APPENDIX 4: RESULTS USING NON-LINEAR ESTIMATORS

Table A4.1: Class Effects of Colonial Land Policy (Fractional Probit Estimates)

	(1)	(2)	City (3)	Road (4)	Rail (5)	(6)	(7)	City (8)	Road (9)	Rail (10)
	<i>Period: 1972-1979</i>					<i>Period: 1980-1984</i>				
European Areas	0.080** (0.037)	0.086** (0.037)	-0.13 (0.266)	0.076 (0.092)	0.20 (0.132)	0.13** (0.057)	0.14** (0.058)	0.17 (0.412)	-0.11 (0.149)	0.079 (0.213)
NPA	-0.052 (0.070)	-0.059 (0.070)	1.79** (0.765)	1.16*** (0.304)	1.62*** (0.260)	0.10 (0.112)	0.097 (0.113)	1.97* (1.029)	0.73* (0.430)	1.74*** (0.464)
ln(dist city)			0.0043 (0.046)	0.017 (0.038)	0.016 (0.038)			0.051 (0.077)	0.032 (0.063)	0.043 (0.063)
ln(dist main road)			0.018 (0.018)	0.024 (0.022)	0.020 (0.018)			-0.045* (0.027)	-0.072** (0.033)	-0.043 (0.027)
ln(dist rail)			-0.0048 (0.024)	-0.0017 (0.024)	0.021 (0.031)			0.064* (0.038)	0.063* (0.038)	0.063 (0.047)
EAs x Distance			0.050 (0.058)	0.0079 (0.029)	-0.027 (0.036)			-0.0029 (0.089)	0.092* (0.048)	0.023 (0.059)
NPAs x Distance			-0.38** (0.157)	-0.37*** (0.091)	-0.44*** (0.071)			-0.39* (0.218)	-0.18 (0.131)	-0.43*** (0.129)
Constant	-0.45* (0.260)	-0.29 (0.337)	-0.33 (0.382)	-0.43 (0.364)	-0.49 (0.368)	-0.87*** (0.174)	-0.034 (0.431)	-0.55 (0.563)	-0.38 (0.524)	-0.54 (0.530)
FEs	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Ward Controls	N	Y	Y	Y	Y	N	Y	Y	Y	Y
N	2108	2108	2108	2108	2108	696	696	696	696	696

NOTES: Individual ward controls are population, rainfall, and temperature and soil suitability index. FEs denote region, frame, month and year fixed effects. White heteroscedasticity robust standard errors are reported in parentheses; Base category = Tribal Trust Areas (TTAs). Columns 3 and 8; 4 and 9; 5 and 10 present results from regressions that interacts land class with distance to main city, distance to main road and distance to rail station or siding respectively. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A4.2: Class Effects of Colonial Land Policy (Tobit Estimates)

	(1)	(2)	City (3)	Road (4)	Rail (5)	(6)	(7)	City (8)	Road (9)	Rail (10)
	<i>Period: 1972-1979</i>					<i>Period: 1980-1984</i>				
European Areas	0.027** (0.012)	0.030** (0.012)	-0.049 (0.090)	0.028 (0.031)	0.073* (0.044)	0.052** (0.023)	0.057** (0.023)	0.069 (0.160)	-0.042 (0.058)	0.042 (0.085)
NPA	-0.017 (0.023)	-0.019 (0.023)	0.61** (0.262)	0.39*** (0.107)	0.57*** (0.095)	0.042 (0.048)	0.039 (0.045)	0.78** (0.393)	0.28* (0.161)	0.66*** (0.161)
ln(dist city)			0.0071 (0.006)	0.0088 (0.008)	0.0077 (0.006)			-0.018* (0.011)	-0.029** (0.013)	-0.017 (0.011)
ln(dist main road)			-0.0017 (0.008)	-0.00058 (0.008)	0.0076 (0.011)			0.027* (0.016)	0.027* (0.015)	0.028 (0.020)
ln(dist rail)			-0.00071 (0.015)	0.0043 (0.013)	0.0040 (0.013)			0.018 (0.031)	0.010 (0.025)	0.015 (0.025)
EAs x Distance			0.019 (0.020)	0.0023 (0.010)	-0.010 (0.012)			-0.0016 (0.035)	0.036* (0.019)	0.0057 (0.024)
NPA x Distance			-0.13** (0.054)	-0.12*** (0.031)	-0.15*** (0.025)			-0.15* (0.083)	-0.067 (0.050)	-0.16*** (0.045)
Constant	0.34*** (0.102)	0.38*** (0.124)	0.38*** (0.139)	0.34** (0.133)	0.32** (0.134)	0.17 (0.106)	0.42** (0.167)	0.22 (0.220)	0.30 (0.203)	0.23 (0.206)
FEs	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Ward Controls	N	Y	Y	Y	Y	N	Y	Y	Y	Y
N	2108	2108	2108	2108	2108	696	696	696	696	696

NOTES: Tobit results account for censoring from below at 0 and from above at 1. Individual ward controls are population, rainfall, and temperature and soil suitability index. FEs denote region, frame, month and year fixed effects. White heteroscedasticity robust standard errors are reported in parentheses; Base category = Tribal Trust Areas (TTAs). Columns 3 and 8; 4 and 9; 5 and 10 present results from regressions that interacts land class with distance to main city, distance to main road and distance to rail station or siding respectively.

* p < 0.10, ** p < 0.05, *** p < 0.01