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Wheat productivity in the Cape Colony in 1825: evidence from newly transcribed tax censuses

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ABSTRACT
We calculate, for the first time, farm-level wheat productivity for Cape Colony settler farmers in 1825. We can do so because we now have access to a fully transcribed tax census for that year. Although there is some variation in wheat productivity across the Colony, probably a result of the varying environmental factors, we find much larger variation within districts. We perform various tests to explain this large variation. We find, surprisingly, that slave labour has no explanatory power. Khoe labour, however, helps to differentiate farmers according to their productivity.

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1. Introduction

Travelling through the Cape Colony in 1824, the merchant George Thompson remarked that the Colony's wheat farmers had little incentive to produce a large surplus, owing to the harsh limitations on grain exports. Such poor incentives, he argued, often gave rise to conditions that approached outright famine. One year later, however, an abundant harvest allowed the governor, Lord Charles Somerset, to grant export licences for almost half of all wheat brought to market in Cape Town. Cape wheat farmers, it seems, had prospered.

This paper investigates which of these pictures best reflects the economic conditions at the Cape in 1825. Were the Colony's wheat farmers producing just above subsistence levels, inhibited by the overbearing government regulations that characterised this pre-industrial, colonial society? Or were they benefiting from the more liberal British rule in contrast to the monopsonistic Dutch East India Company rule of only two decades earlier? Were wheat farmers barely grubbing a living from the soil, or were they a wealthy, productive farming class, part of the elite of Cape society? To decide this question, we estimate the productivity of Cape wheat farmers in 1825 using a newly transcribed series of household tax censuses, the Cape of Good Hope Panel (Fourie and Green 2018).

We find a large variation in the productivity of Cape wheat farmers. Some of the variation is between districts, with wheat farmers in Stellenbosch and the Cape district being more productive than those in the east, perhaps because of environmental differences, but most of it is within districts. Because we use farm-level output, we are the first to prove this empirically. We next identify the determinants of more productive farmers. We find, surprisingly, that slave labour, one of the most important sources of labour in the Colony, does not explain productivity differences. Khoe labour, however, has large explanatory power.

Our results contribute to at least three debates in the literature. First, we show that only a small portion of Cape wheat farmers were living just above subsistence level. Some were producing large surpluses that could only have been for sale on the market. This finding contrasts with the view of an

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earlier generation of historians (Feinstein 2005; Trapido 1990) who emphasised the poverty of the Colony and its settlers. Trapido refers to it as an 'economic and social backwater' that 'advanced with almost extreme slowness'. Our results support a more recent historiography that emphasises the dynamic nature of the Cape economy and its farmers' prosperity (Fourie 2013a, 2014; Fourie and Garmon 2022).[1]

Second, our results add the Cape Colony to the literature on the productivity of eighteenth – and nineteenth-century wheat farmers globally, a literature that is now at least five decades old (Ball and Walton 1976; Clark 1987; Olmstead and Rhode 2002; Overton 1984; Parker 1967; Turner 1982). More recently, a large literature has returned to measuring agricultural productivity as a way to identify the pre-industrial origins of economic growth (Kelly and Grada 2013). Differences in labour intensity of wheat versus rice cultivation may, for example, explain Western Europe's earlier industrialisation (Vollrath 2011).

We use frontier analysis as our method. This allows for interactions between the factors of production, pinpointing the inputs contributing to productivity. As our results show no role for slave labour as a productivity advantage, our third contribution is to debates about the importance of slave labour in facilitating elite formation. Dooling (2005a), for example, identifies property in land and people as the fundamental cause of elite formation. The small and insignificant coefficient we find on slave labour suggests that slave ownership may have been a consequence and not a cause of wealth creation at the Cape; the most productive farmers were not those who owned the most slaves. Why was slave labour still so popular, then, if it had no productivity advantage? As others have argued, slaves at the Cape (and elsewhere) were used not only for labour but also as a form of capital (Fourie 2013b). In fact, slaves were the primary source of capital liquidity at the Cape and were widely used as collateral within the dense informal network of settler debt and credit transactions.

2. Wheat farming at the Cape

Wheat farming arrived with settler colonisation at the southern tip of Africa in the mid-seventeenth century. The intention of the Dutch East India Company was to establish a refreshment station providing fresh food for the ships sailing between Europe and the East Indies. Soon after settlement, though, Company officials realised that trading with the indigenous Khoesan would not provide a sufficient supply for both the settlement and the passing ships. In 1657, nine Company servants were released to become 'free farmers', producing wheat and meat for supply to the fort.

Success was slow in coming. Many former Company workmen struggled to farm successfully on the wind-swept Cape Peninsula. But over the next few decades, as war and smallpox pushed the pastoral Khoesan deeper into the interior, more land became available for freed servants and, by the 1680s, Huguenots fleeing persecution in France. By the beginning of the eighteenth century, several hundred settler households were farming in the fertile region west of the first mountain ranges.

The Company offered some subsidies on inputs, and land was granted free of charge. Cheap loans allowed farmers to buy seed and basic equipment, and the Company facilitated slave imports from across the Indian Ocean territories as a source of labour. Slaves outnumbered settlers for most of the eighteenth century. Although the Company did not allow the enslavement of Khoesan, many worked on settler farms under conditions very similar to slavery. This was especially true in the drier interior, where pastoral farming was the main type of production.

There were three reasons why slavery was the preferred source of labour (and not, for example, European wage labourers). First, supporting the Nieboer-Domar hypothesis, as long as the frontier remained open and land was freely available, coercion was necessary to maintain a steady workforce (Green 2014). It was only towards the end of the eighteenth century, when migrating settlers met the more densely settled amaXhosa around the Fish river, that land became increasingly limited. Second, following the Antebellum literature, slave labour may have also been more productive (Fogel and

Engerman 1977; Olmstead and Rhode 2011). The third reason was the dual use of slaves for labour and capital.

For much of the eighteenth century, wheat was mostly (but not exclusively) produced by farmers in the Cape, Stellenbosch and Drakenstein districts. As the frontier expanded and earlier frontier regions became more settled, crop cultivation expanded too. Part of the reason for this geographic concentration was environmental: the fertile Cape district soil and abundant winter rainfall offered the right conditions for its production. But a second important reason was institutional: all produce had to be sold to the Company at fixed prices. Prices often remained constant over several years or even decades. No private trade (either with the indigenous Khoesan or with passing Dutch ships or those of other nationalities) was allowed. All wheat that was not for own consumption, therefore, had to travel to Cape Town, an expensive journey through rugged terrain. One potential consequence of this monopsonistic rule is that risk averse farmers may have been disincentivised to produce large surpluses, inhibiting farmers' ability to benefit from economies of scale. But lower output may have concentrated production on the most suitable land, raising productivity. It is unclear which of these two effects dominate.

There was an important reason the Company imposed fixed prices: wheat exports were profitable. According to Ross and van Duin (1987, 19), wheat exports from the Cape made good profits in the Netherlands, 'since the *Heren XVII* had made a careful cost calculation of the possibilities for Cape wheat in the Amsterdam market, compared to its Polish and Zeeland competitors, and had come to the conclusion that, even including shipping costs, grain export from the Cape was a worthwhile undertaking'. It is therefore no surprise that, despite the monopsonistic prices, 'grains and pulses' (of which wheat was the most important) was the Colony's largest export category until the 1780s, when production fell substantially, probably as a result of the Fourth Anglo-Dutch war.

The Cape became a British colony in 1795, returned to Batavian rule between 1803 and 1806, and then became a British colony again in 1806, remaining so until 1910. There were few immediate consequences of British rule. The Abolition of the Slave Trade Act in 1807 limited the supply of new slaves but did not cause a major shift in production techniques. What did happen, in 1809, perhaps as a consequence of the limited supply of slaves, was the introduction of the 'Caledon Code', a law aimed at limiting the movement of Khoesan in the Colony and increasing farmers' ability to coerce them (Dooling 2005b). It was not until 1828, with Ordinance 50, that the Khoesan obtained more legal rights. The slaves gained their freedom only in 1838, four years after serving as apprentices on settler farms.

Just as labour coercion remained entrenched in Cape society after the British takeover, so, too, did monopsonistic practices. George Thompson (1827, 394), in his *Travels and Adventures in Southern Africa*, explained the wheat farmers' lack of incentives thus:

> [T]he trade in corn [wheat] has hitherto been in a situation which must, so long as it continues, not only preclude [the Colony] from becoming an exporting country, but occasionally subject it to those seasons of scarcity, sometimes approaching to famine, under one of which it is at the present moment smarting. The Burgher Senate annually procures a return of the quantity of corn on hand in the Colony; and having ascertained from the population returns the number of mouths to consume it, a proclamation is issued by the Government, stating what quantity (if any) may be exported before the next harvest. In consequence, no one grows more than he is likely to find vent for in the home market; for what merchant would be at the pains of procuring a regular foreign market for an article, which, after all, he finds himself precluded from sending, except now and then in dribblets, by these paltry regulations?

In his seminal thesis, DJ Van Zyl (1967) questions this assertion. He explains that it was indeed the internal market, rather than foreign markets, that explained the growth in Cape grain production in the first decade after the British takeover in 1806. But after 1815, owing to the personal intervention of Lord Charles Somerset, the governor appointed in 1814, Cape grain was increasingly in demand abroad. It was in demand in England, in South America (in Argentina and Brazil) and on the island of St. Helena, where Napoleon's presence between 1816 and 1821 caused a sudden increase in demand for Cape produce. In times of poor harvest, the Cape could import from markets as distant as America and Chile (Van Zyl 1967, p. 136). Cape officials applied for lower tariffs on wheat exports to Britain, but without success.

Despite the more liberal approach after 1815, Thompson is indeed correct to say that the hand of government regulation still weighed heavily on farmers. When local prices were high, exports would be curtailed or, at worst, barred, ostensibly to stabilise domestic prices (Van Zyl 1967, 139). These monopsonistic regulations explain why historians have viewed the Cape as an 'economic and social backwater' that 'advanced with extreme slowness'. Many considered Cape farmers indolent and poverty-stricken, notably those on the frontier, unaffected by market conditions. They say those who were producing for a market represented a small elite, often with close ties to the government of the time. But more recent work, relying less on traveller accounts and letters from disgruntled farmers and more on new datasets and statistical tools, have questioned these assertions. Using probate inventories, Fourie (2013a) showed that the average Cape farmer's wealth was equal to or higher than that of settlers in eighteenth-century North America or inhabitants of England and the Netherlands. Du Plessis and Du Plessis (2012) found surprisingly high real wages at the Cape. In more recent work, Fourie and Garmon (2022), using the same tax censuses we use here, found that Cape settler farmers produced greater quantities of crops and higher valued crops than their counterparts in three American states, Maine, Massachusetts and Virginia, at the beginning of the nineteenth century. When wine and brandy production was added, the differences were much larger.[2]

What is not clear is why Cape farmers were so remarkably productive, even in the face of legislation that would seem to inhibit development. Could the reason simply be the low cost of land and labour? If that were indeed the case, then there would be little variation between farmers. But as we show below, we found some variation by district and considerable variation within districts. Other household-level factors must explain these differences in productivity. We might ask whether there is a role for technology and human capital (education), as stated in standard growth theory. Fourie and Von Fintel (2014), using an early version of the tax censuses, showed that Huguenots from wine-producing regions in France were more productive than other viticulturists at the Cape. As they found no effect of the farmers' origin regions on wheat output, they argued that producing wine requires specialised knowledge of the terroir and the manufacturing process, while wheat cultivation requires little specialised expertise. And indeed, what we know of the process of wheat cultivation suggests that there was little change during the eighteenth and early nineteenth centuries. Biological innovations in wheat varieties and, later, the introduction of tractors and combine harvesters that would boost productivity, came only during the second half of the nineteenth-century (Olmstead and Rhode 2002).

In this paper we use an innovative technique, stochastic frontier analysis, to explain the variation in wheat farmers' productivity in 1825. We can do this because we have household-level farm output data. It is the detail in these records that enables us to investigate the interactions between different farm inputs and identify the determinants of the high productivity we observe of some of these farmers.

3. A census of agricultural production

The harvest of 1825 was exceptional. During that year, 4 316 933 kg (52 962 mud[3]) of wheat was brought to Cape Town and the governor consequently granted licences for exporting 2 037 750 kg (25 000 mud) (Van Zyl 1967, 140).

Van Zyl and others relied on aggregated statistics to document the fluctuating fortunes of Cape farmers. These statistics reveal a changing preference for certain grains at the Cape, notably after 1820. As Figure 1 shows, wheat production peaked in 1815 before declining by about 10% by 1824. By contrast, the output of barley, oats and rye increased steadily after the arrival of the British. One reason for this was perhaps the steady eastward shift of the Colony's borders, where these other types of grain would be easier to grow in the harsher environment.

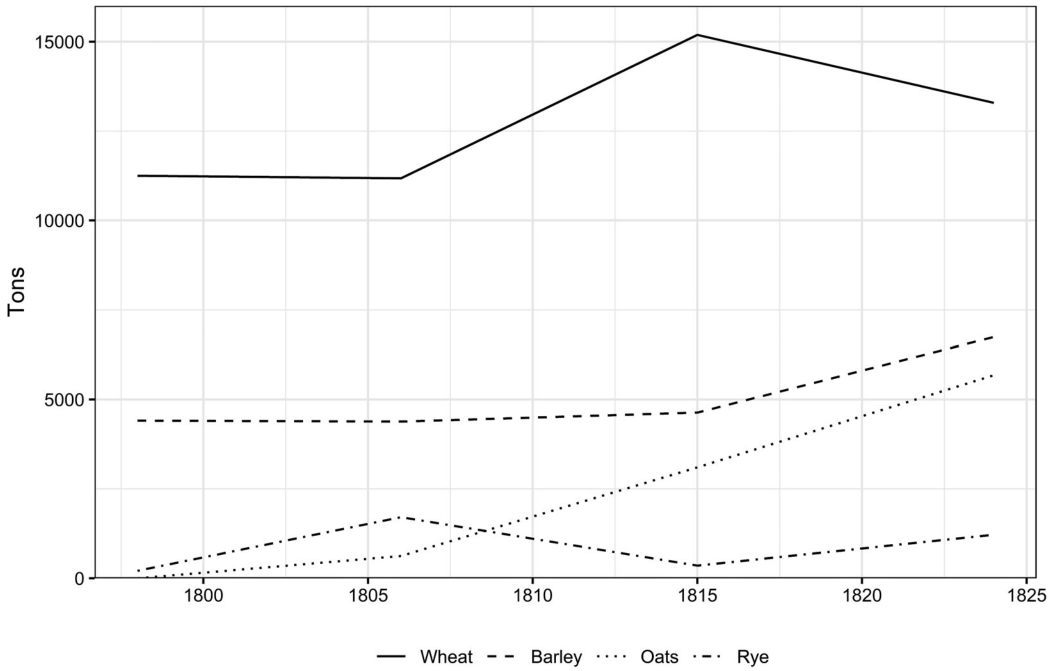

Figure 1. Grain production in the Cape Colony. *Source:* Van Zyl (1967).

What aggregated production cannot, however, reveal is farm-level productivity. For that reason, we make use of the household-level, annual tax censuses, or *opgaafrolle,* that began to be recorded in the early years of Dutch East India Company rule and remained in place after the British takeover. They included every settler household, listing the names of the male and female household head and the numbers of male and female children, male and female servants, male and female slaves, Khoe workers, and various agricultural inputs, outputs and assets.

In a large new project, these censuses are now being transcribed. Because the names of the husband and wife are included allowing us to make more accurate matches across years, once complete, it would allow for the construction of an annual panel – the Cape of Good Hope Panel – across more than 140 years (Fourie and Green 2018; Rijpma, Cilliers, and Fourie 2020). We do not use the panel in this paper; instead, we are interested in the productivity of wheat farmers for a single year: 1825. Others have investigated wealth accumulation or labour utilisation for the same year, but only for certain districts (Cilliers, Green, and Ross 2022; Links, Fourie, and Green 2020). We choose 1825 because it is the only year in the nineteenth century where the *opgaafrolle* for all districts in the Cape Colony have now been fully transcribed. So instead of working with aggregated production figures, or perhaps district totals, we can, for the first time, calculate farm-level productivity estimates for the entire Colony.

We did not choose 1825 only because of data availability. As Van Zyl notes, 1825 saw a bumper harvest. This suggests that environmental factors – adverse weather in part of the Colony, for example – are unlikely to bias our productivity estimates. It was also after the arrival of several thousand British settlers on the eastern frontier in 1820. Although their arrival came with much hope of boosting wheat supplies, harsh conditions meant frequent crop failures in the first three years. Many left the farms for the fledgling villages that began to dot the landscape. Those who remained ultimately switched to sheep farming. But as this did not happen until after 1825, we are not likely to see appreciable declines in wheat production in the 1825 records due to production displacement. Finally, by 1828, new labour policies, in the form of Ordinance 50, allowed greater freedom of movement to the Khoe workforce and six years later the slaves were emancipated. Our choice of the year 1825 allows us to analyse wheat production before these changes occurred.

3.1 Summary statistics

A total of 13 273 households across eleven districts are included in the 1825 tax census. Figure 2 shows the districts in 1825, with Worcester being the largest (12.1 million hectares) and Albany the smallest (0.52 million hectares). Together the districts covered a total area of 34.12 million hectares, which is 2.6 times the size of the Western Cape province today (12.94 million ha).

Since all households in the Colony are included in the tax records, only 55.6% (7386) of them produced at least one agricultural product. The tax census includes 14 of these. Animals included are breeding horses, breeding cattle, wethered rams, breeding sheep, wool sheep, donkeys, goats and pigs. Crops included are wheat, barley, oats and rye, and crop products are wine and brandy. Wheat is one of the most widely produced crops, with 3112 farmers[4] reporting that they cultivated it. All subsequent discussions and analyses are limited to this subset of wheat-growing households.

In total, the Colony produced 13 381 527 kg of wheat in 1825, with output being dominated (65%) by three districts. Table 2 shows that the Cape district, Stellenbosch and Swellendam contributed 28, 21 and 16%, respectively. There were large differences in output at farm level, with the largest farm producing 130 416 kg and the smallest 41 kg. The distribution of wheat output per farm is right-skewed given an average and median production per farm of 4300 kg and 1956 kg, respectively (Table 1, Panel a). For comparative purposes, in 1811, the average and median production in the ten US states sampled[5] by Garmon (2019) was 220 and 217 kg per farm, respectively. The biggest farmer in these states produced 1901 kg. However, maize was a more popular crop at the time in the US, with average, median and maximum production per farmer in these states being 905, 508 and 12 700 kg, respectively. Thus, regardless of the crop, Cape Colony farmers were substantially larger producers than their American counterparts.

Figure 2. The Cape Colony, 1825. *Source:* Van Zyl (1967).

Note: Today's provincial borders are indicated in light grey.

Table 1. Summary statistics by variable.

	Min	1st quartile	Median	Mean	3rd quartile	Max	CV	Total
Panel a) Cape Colony by variable								
Wheat vol (kg)	41	897	1 956	4 300	4 076	130 416	198	13 381 527
Wheat seed (kg)	4	82	163	406	408	10 596	175	1 235 556
Draught animals	0	10	15	21	25	764	111	64 808
Slave men	0	0	1	3	4	56	177	8 790
Khoe men	0	0	1	3	4	29	133	7 879
Wagons	1	1	1	2	2	11	65	4 546
Diversification	1	5	6	6	8	14	40	
Panel b) Wheat production by district								
Albany	82	326	652	796	1 080	2 445	76	35 009
Beaufort	326	897	1 630	2 188	2 812	10 189	93	170 641
Cape	245	2 445	6 276	13 992	17 790	130 416	132	3 735 950
Clanwilliam	122	978	2 201	3 169	3 912	20 296	107	662 228
Cradock	163	978	1 712	2 232	3 097	11 493	78	633 924
George	82	815	1 467	2 098	2 731	16 302	96	736 484
Graaff-Reinet	82	978	1 630	2 796	3 668	14 672	97	623 480
Stellenbosch	122	1 569	3 749	8 814	9 496	122 265	165	2 873 268
Swellendam	61	815	1 630	2 783	3 260	35 864	130	2 181 493
Uitenhage	61	571	1 141	1 697	2 282	10 107	99	475 163
Worcester	41	1 223	2 812	4 714	6 949	28 936	104	1 253 889

Although wheat was produced in all the districts, there were large inter – and intra-district output differences (1, Panel b). For example, the Cape district's median wheat output per farm was almost double that of Stellenbosch, their closest rival, and 12.5 times that of Albany, the district with the smallest median output. Worcester and Clanwilliam had the third and fourth highest medians. Swellendam, the third biggest wheat-producing region, ranks only sixth, together with Graaff-Reinet and Beaufort. The relevance of this difference will become evident in Section 5. It is also worth mentioning that Swellendam had more than twice as many wheat farmers as George, the district with the second largest number of wheat farmers (Table 2).

Figure 3 shows the distribution of wheat output per farm and the median output per district. Besides the differences in median production per district, the steep distribution and lower coefficient of variation also makes it clear that the differences between farms were smaller in the districts with smaller farms.

Households reported the amount of wheat seed used during the season, but this cannot be translated into a seeding rate per hectare, given that neither farm size nor the area sown is reported (see Section 3.2). However, the larger wheat-producing districts (Cape district, Stellenbosch and Swellendam) tended to use less wheat seed per unit of production, thus being more efficient converters of seed to output.

Work horses and draught oxen were the main means of traction on Cape Colony farms. Since farmers used one or the other, or both, we converted draught oxen to horse equivalents. It is

Table 2. District totals.

District	Wheat farms	Wheat vol (kg)	Wheat share	Wheat seed (kg)	Draught animals	Slave men	Khoe men	Wagons
Albany	44	35 009	0%	4 606	501	25	55	48
Beaufort	78	170 641	1%	14 488	1 431	123	394	126
Cape	267	3 735 950	28%	316 177	9 191	1 341	538	507
Clanwilliam	209	662 228	5%	57 556	3 431	415	797	278
Cradock	284	633 924	5%	36 516	4 322	388	1 251	410
George	351	736 484	6%	55 580	7 062	733	780	445
Graaff-Reinet	223	623 480	5%	43 781	4 925	540	1 227	385
Stellenbosch	326	2 873 268	21%	305 975	9 662	2 204	449	700
Swellendam	784	2 181 493	16%	196 215	10 485	1 364	1 046	802
Uitenhage	280	475 163	4%	37 372	6 271	353	550	320
Worcester	266	1 253 889	9%	167 289	7 529	1 304	792	525
Total	3 112	13 381 529	100%	1 235 555	64 810	8 790	7 879	4 546

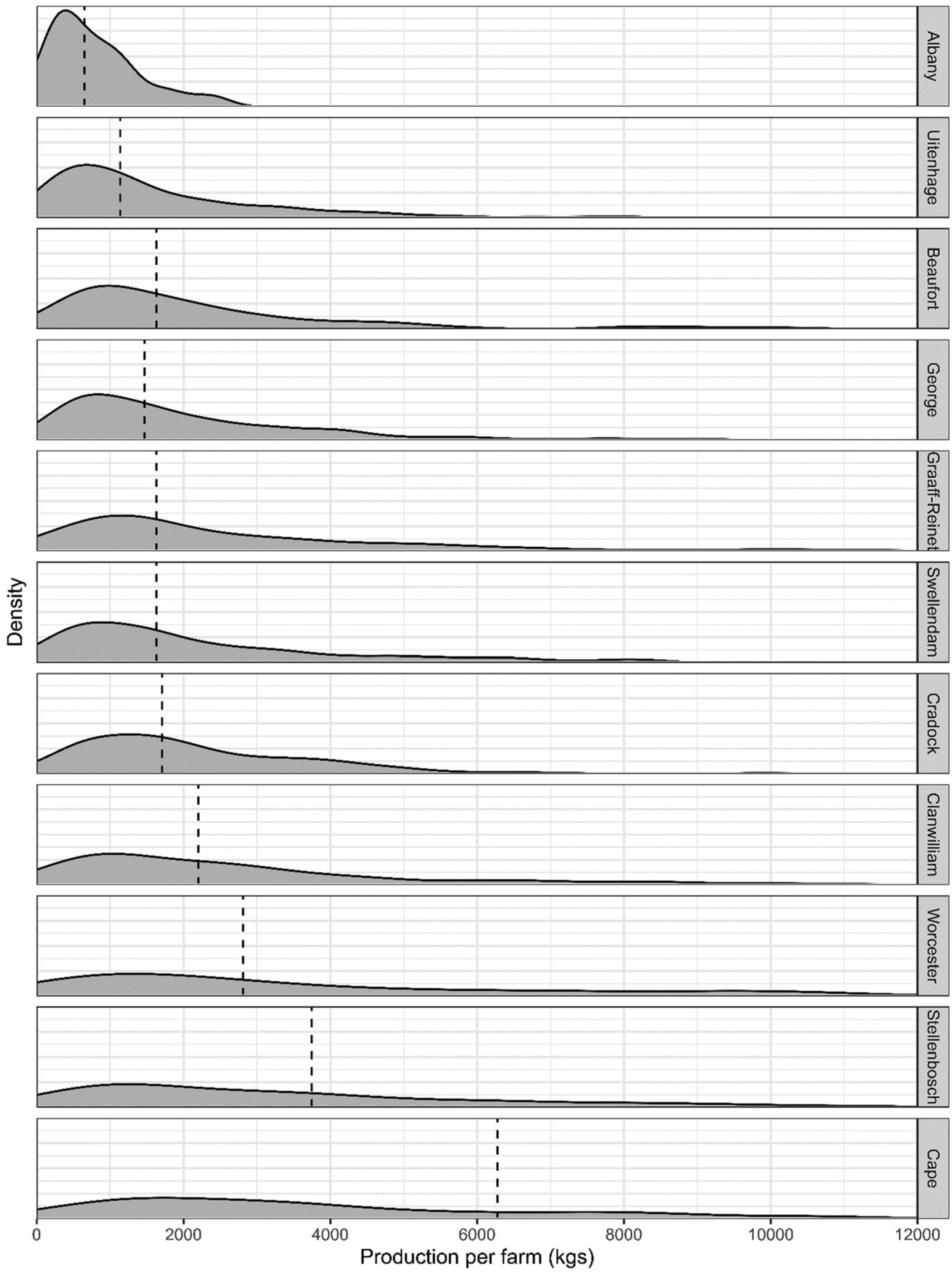

Figure 3. Wheat production distribution by district.

Note: The dotted vertical lines indicate the median production by district.

estimated that a well-fed horse can do between 25 and 30% more fieldwork than an ox per day (Smil 2004).The variable *Draught animals* represents the sum of work horses and horse equivalents as the number of draught oxen less 25%. Farms had between 0 and 764 draught animals, with 21 on average, as shown in Table 1 Panel a. The table shows that the largest wheat-growing areas also had the largest number of draught animals.

The number of male *Slaves* and *Khoe*, as the main workforce on the farms, includes both adults and children under sixteen. Wheat-growing farms in the Colony had access to the labour of 8790 slaves and 7879 Khoe men, with the average per farm being three of each. However, the ratio between these two worker types differed substantially between districts. Stellenbosch, for example, had 4.9 slaves for every Khoe worker, while the Cape district and Swellendam had only 2.5 and 1.3, respectively (Table 2).

Wagons were one of the main farm assets, with the median farm owning one and the largest farm 11. The *Diversification* variable reflects the total number of agricultural products produced by wheat farmers. On average, farms produced seven types of product, with half of them producing between five and eight, as shown in Table 1.

3.2 Limitations

A major limitation of the Cape tax censuses is that farm sizes are either omitted or reported inconsistently across districts. The inconsistency is because several tenure arrangements existed in the Colony at the time, such as freehold, fixed-term and perpetual loan places, and fixed-term and perpetual quitrent contracts (Swanepoel and Fourie 2018). No data is reported on the size of the area dedicated to crop or livestock production. This is because taxes at the time was not land-based but linked to output rather than inputs and often to the amount sent to Cape Town to be sold to the Company. Given that the total farm size was mostly unavailable and would serve as an imprecise proxy for the production area, it was excluded from the analysis. We address this in a number of ways. First, because tenure arrangements varied by region, we add region fixed-effects. Also, farm sizes within regions would have varied substantially less than between regions, where environmental differences were much larger (the more fertile, wetter coastal region versus the drier interior, for example). We also test our results separately by region (not shown) and find consistent estimates. Despite these attempts, we acknowledge that the lack of controls for land size may result in omitted-variable bias that affects the coefficients of the translog production function.

Another econometric limitation is endogeneity of the regressors. Farmers choose the number of wagons, draught animals that they use based on their perception of the quality of the land available to them. We, unfortunately, have no sensible instrumental variable that would allow us to circumvent endogeneity concerns. We hope that future attempts at matching households to farm locations may be able to address this serious limitation.

A limitation of using a tax census for data is the temptation to underreport output to reduce the amount of tax due. However, this study considers the relative and not absolute productivity differences between farmers in the Colony. Hence if we assume that the level of underreporting is consistent across districts, it does not affect our results. To date, no evidence has been found for inconsistent misreporting across districts.

Although we focus our analysis on 1825, for three districts, notably Clanwilliam (1824), Worcester (1824) and Cradock (1823), we had to use records from earlier years. For those three districts, the tax censuses of 1825 are either ineligible or unavailable. The extent to which this would bias our results is unclear. Since tax censuses were collected annually until the 1840s, it would be possible to construct an annual panel, to calculate dynamic productivity estimates. However, as the transcription of all districts was incomplete at the time of writing we chose for the time being to focus on 1825.

A final limitation is our explicit focus on *settler* production. Although wheat was a crop brought to the Cape by European settlers, by 1825 some Khoe farmers were also producing wheat in scattered settlements created during the preceding century of dislocation from their traditional economy. Links (2023) uses tax censuses of these settlements to calculate a wheat yield for the Swellendam district of almost 815.1 kg (10 mud) per household and double that for barley. These yields are much lower than those of settler farms, the consequence of limited capital inputs and the need to produce only for local consumption. Wheat was also produced at mission stations, although this, too, was mostly for local consumption (Fourie, Ross, and Viljoen 2014b). Further east, Xhosa farmers may also have acquired wheat seeds from the settlers, but we could find no evidence of Xhosa wheat cultivation at this early stage.

4. Methods

This study derives farm-level productivity estimates using Battese and Coelli's (1995) technical efficiency effects stochastic frontier production function model. A truncated normal distribution of the inefficiency term is assumed. The parameters in Equations 1 and 2 are jointly estimated, with the former representing the efficiency frontier and the latter the inefficiency sub-model. A translog functional form is assumed for the model. All input variables are mean scaled, and all variables are logged as indicated.

In Equation 1, *Yi* represents the wheat output of farm *i* and *Xki* is the amount of input *k* applied by farm *i*. The error term is decomposed into an independently and identically distributed error term *vi* and an inefficiency component $-\ u_i$. The parameters to be estimated are represented by a_k and aj_k. The variance of the inefficiency term is measured by $\gamma = \sigma_u^2/(\sigma_u^2 + \sigma_v^2)$. Gamma (γ) represents the level of technical efficiency of a firm, with a value of 1 indicating a perfectly efficient firm and a value less than 1 indicating a less efficient firm. It is a deterministic parameter that is the same for all firms in the sample, and it can be interpreted as the maximum potential output of a firm for a given set of inputs.

Total efficiency levels *TEi* are computed according to Equation 2, where *Y** is the frontier output that shares the same factor ratios as Y.

$$lnY_i = \alpha_0 + \sum_{k=1}^{K} \alpha_k lnx_{ki} + \sum_{k=1}^{K}\sum_{j=1}^{J} \alpha_{jk} lnx_{ki}.ln_{ji} + v_i - u_i \tag{1}$$

$$TE_i = \frac{Y_i}{Y_i^*} \tag{2}$$

Equation 3 explains the observed farm-level efficiencies with a set of *z*-variables that capture farm and farmer characteristics. This is achieved by regressing a vector of farm characteristics z_i on the efficiency of Equation 1. The final term, w_i, represents an independently and identically distributed error term. For a frontier to exist, γ must be significant, and the restrictions imposed by a mean response model (OLS) must pass a likelihood ratio test. The normal error variance. represented by sigma squared (σ_v^2), captures measurement problems, resulting in low values for γ if there is deliberate or inadvertent misreporting.

$$-u_i = \delta_0 + \sum_{m=1}^{M} \delta_m z_i + w_i \tag{3}$$

Gamma (γ) in the BC model represents the level of technical efficiency of a firm, with a value of 1 indicating a perfectly efficient firm and a value less than 1 indicating a less efficient firm. It is a deterministic parameter that is the same for all firms in the sample, and it can be interpreted as the maximum potential output of a firm for a given set of inputs.

5. Results and discussion

5.1 Model specification and results

Five translog[6] models were specified, as shown in Table 3. In Model 1, wheat seed is the only input included. Model 2 expands on Model 1 by including both draught animals as workhorse equivalents. Models 3, 4 and 5 are extensions of Model 2 that explore the use of different labour types. Model 3 includes Khoe labour, Model 4 includes slave labour and Model 5 includes both.

Table 3. Stochastic frontier results; dependent variable: wheat produced.

	Model 1		Model 2		Model 3		Model 4		Model 5	
Variable name	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Frontier intercept	7.262 ***	0.102	7.281 ***	0.101	7.266 ***	0.100	7.275 ***	0.104	7.270 ***	0.104
Wheat seed	0.906 ***	0.015	0.815 ***	0.02	0.787 ***	0.022	0.829 ***	0.022	0.796 ***	0.024
Draught animals			0.200 ***	0.022	0.182 ***	0.024	0.227 ***	0.026	0.202 ***	0.028
Khoe men					0.051 **	0.017			0.054 **	0.017
Slave men							−0.018	0.017	−0.017	0.017
Wheat seed^2	0.091 ***	0.022	0.057 *	0.025	0.067 **	0.025	0.056 *	0.026	0.065 *	0.026
Draught animals^2			0.033 ***	0.005	0.028 ***	0.005	0.033 ***	0.005	0.029 ***	0.005
Khoe men^2					0.009 **	0.003			0.009 **	0.003
Slave men^2							−0.003	0.003	−0.003	0.003
Wheat seed x Draught animals			0.000	0.014	0.006	0.015	−0.014	0.016	−0.004	0.017
Wheat seed x Khoe men					−0.008 **	0.003			−0.009	0.003
Wheat seed x Slave men							0.002	0.003	0.002 **	0.003
Draught animals x Khoe men					0.001	0.002			−0.001	0.002
Draught animals x Slave men							0.005 .	0.003	0.004	0.003
Khoe men x Slave men									0.001 .	0.000
Wagons (z-variable)	−0.625 ***	0.149	−0.235 **	0.075	−0.230 **	0.079	−0.230 **	0.079	−0.227 **	0.078
Diversification (z-variable)	−0.112 *	0.043	−0.097 **	0.034	−0.086 **	0.032	−0.105 **	0.034	−0.095 **	0.033
Huguenot (z − variable)	−0.022	0.213	0.04	0.197	−0.015	0.211	0.031	0.195	−0.03	0.214
Sigma^2	1.864 ***	0.195	1.496 ***	0.153	1.454 ***	0.146	1.514 ***	0.159	1.474	0.154
Gamma	0.916 ***	0.01	0.909 ***	0.011	0.909 ***	0.011	0.910 ***	0.011	0.909	0.011
Log likelihood statistic	−2580.102		−2537.715		−2527.977		−2535.462		−2524.151	
Observations	2657		2657		2657		2657		2657	
Mean efficiency	60.83%		59.50%		59.33%		59.63%		59.55%	
District fixed effects	Yes		Yes		Yes		Yes		Yes	

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1.

All models included the same farmer and farm characteristic variables in the efficiency submodel: the number of wagons owned, to establish the effect of wealth on productivity;[7] the number of crops grown by the farm, to establish whether diversification improves or reduces productivity; and the farmer being of Huguenot origin, to establish whether a Huguenot background improves or reduces efficiency.[8]

Likelihood ratio tests were performed on all models to confirm that they are stochastic frontiers, and all passed the test. Sigma squared and gamma were statistically significant for all models. District fixed effects were included for all models, to account for differences between districts.

All the first-order parameters are monotonic and statistically significant except for slave labour, in both Model 4 and Model 5. We next explore why this might be.

5.2 Slave labour

A surprising finding is the economic and statistical *in*significance of the slave labour coefficient. One way to quantify the unimportance of slave labour is to consider the relative marginal rate of the draught animal, Khoe and slave inputs in Model 5. The median relative marginal rate of technical substitution (RMRTS[9]) between slave and Khoe labour is 2.7, meaning that one Khoe worker has to be replaced by 2.7 slave workers to maintain the same output. The interaction between draught animals and the two worker types is also revealing. If the number of draught animals used is reduced by 1%, to maintain the same output the number of Khoe workers has to be increased by 2.7% or the number of slaves by 7.8%.

Why would slave labour have such little explanatory power? There are three possible reasons. First, slaves may have been acquired not only for labour in the fields but also for domestic duties. The wealthiest families would acquire slaves to signal their affluence, employing them as servants (Ross 1999). Second, as noted by Adam Smith, the cost of supervision may have been severe. As Penn (1999) notes, slave runaways was not an uncommon occurrence at the Cape, and just as in the United States, the Colony imposed severe punishments designed to reduce the problem of fugitive slaves. And we have mentioned earlier that slaves were used not only for labour but also as capital and collateral (Fourie 2013b; Fourie and Swanepoel 2018; Green 2022).

Links, Fourie, and Green (2020) found that Khoe and slave labourers were complements rather than substitutes, suggesting that they performed different roles on Cape farms. Our results suggest that it was indeed Khoe labour, and not slave labour, that was most important for the productivity of wheat farms.

5.3 Stochastic frontier results

The average efficiency of all farms, according to the complete model (5) shown in Table 3, is 59.55%. But this total obscures the differences between districts, as shown in Table 4. The Cape, Stellenbosch and Worcester districts, as the first, second and fourth largest wheat-producing districts, had the greatest median efficiency. The fact that these districts also have some of the largest median production per farm raises the question of a possible relationship between farm size (in this case, total wheat production) and efficiency, one of the central questions of agricultural economics in South Africa and elsewhere (Alvarez and Arias 2004; Lund and Hill 1979; J. Van Zyl, Binswanger-Mkhize, and Thirtle 1995). The positive correlation we find between total wheat output and production efficiency suggests that farm size does indeed matter. Swellendam, as the second-largest wheat-producing district, reverses the trend, however, since it has the third-lowest median productivity. Why this is the case is uncertain.

Figure 4 shows the relationship between wheat output and the efficiency of each farm in the data set. The x-axis is log scaled, the dots represent individual observations, with a higher density of observations appearing darker, and the blue line represents the fitted trend using a LOESS model. Although using a log scale complicates the interpretation of the figure, it is necessary for a

Table 4. District productivity summary.

	Min	1st quartile	Median	Mean	3rd quartile	Max	CV
Cape	13	56	68	64	76	88	24
Stellenbosch	3	49	66	61	77	93	33
Worcester	4	44	66	60	78	90	37
Cradock	9	45	63	59	73	91	32
Albany	4	45	62	57	68	88	35
Beaufort	18	43	62	59	75	86	31
George	5	44	62	58	74	92	34
Graaff-Reinet	4	43	62	57	75	90	37
Swellendam	4	48	62	59	74	94	33
Uitenhage	4	41	62	57	74	89	38
Clanwilliam	11	47	61	59	74	91	33

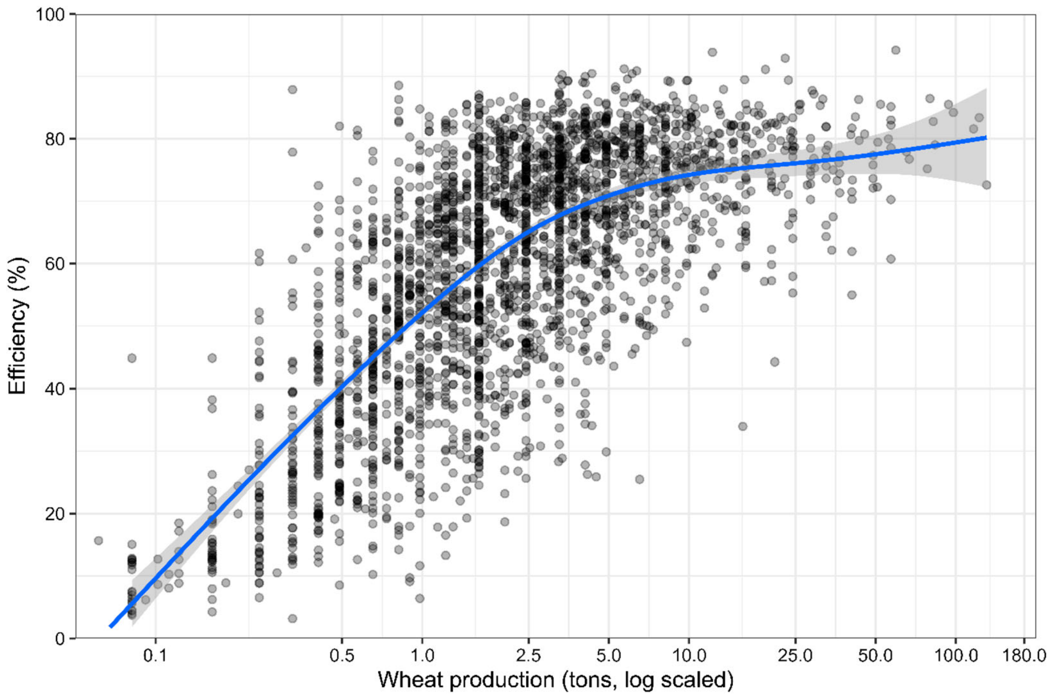

Figure 4. Farm level wheat output and efficiency.

Note: The function plotted in blue was fitted using a LOESS regression with the grey area indicating the 95% confidence interval.

meaningful representation of a variable such as wheat output per farm in a case such as this where there is a large difference between the smallest and the largest region. Movements along the 45-degree diagonal indicate an exponential increase. For output levels between 41 and 1000 kg per farm, efficiency increases exponentially with an increase in output. However, the marginal rate of return to size begins to flatten between 1 and 5 tons of output but remains positive.

Figure 5 shows the relationship between farm wheat output and efficiency at the district level. As with Figure 4, the dots represent individual farms, but now coloured to represent the districts: light to dark blue for those with the smallest median output (Albany, Uitenhage, Beaufort) and yellow through orange to dark red for those with the largest (Cape, Stellenbosch, Worcester). As with Figure 4, trend lines were fitted using a LOESS regression but now by district. The beginnings and ends of the trend lines indicate the districts' minimum and maximum farm size (wheat output level).

Two observations can be made for Figure 5. Firstly, we can see that the individual districts exhibit a trend similar to the collective trend plotted in Figure 4. However, the marginal rate of return to size

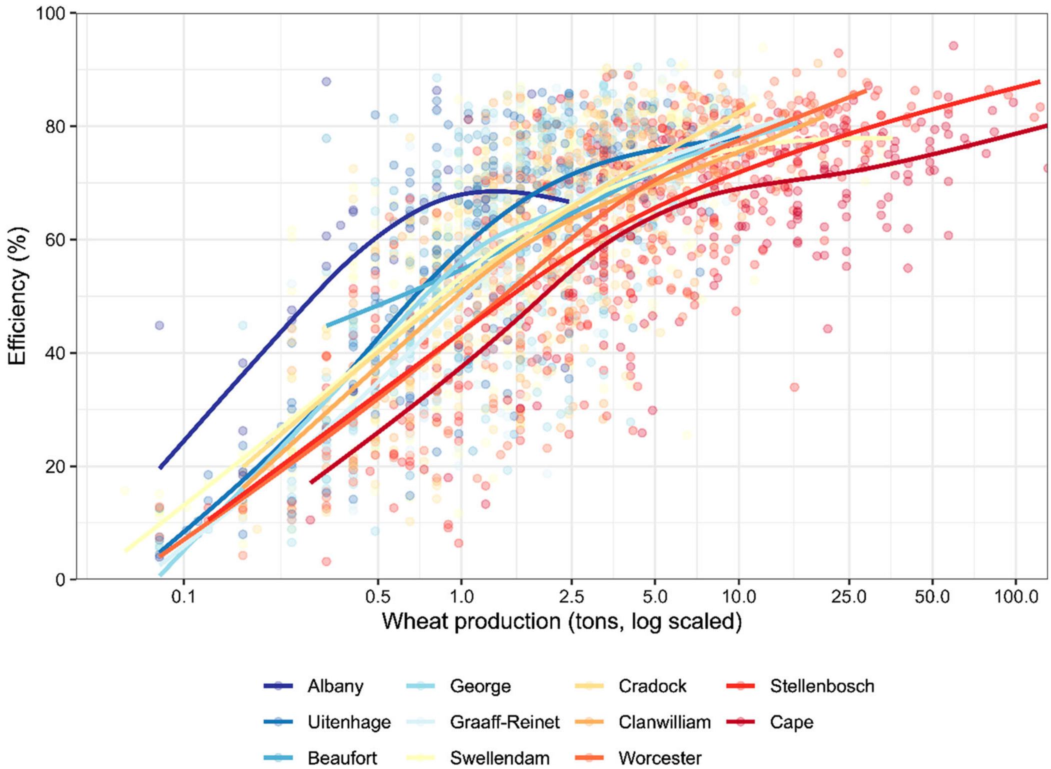

Figure 5. District level wheat output and efficiency.

Note: The functions were fitted using a LOESS regression.

flattens at different output levels and even starts to decline for Albany. Secondly, if we compare the same farm size (output level) across districts, then we can see that, on average, farms in districts with a lower median output level are more efficient than farms in districts with a larger median farm size. An output level of 1 ton per farm can be used as an example for illustrative purposes: at this output level, farms in the Cape district are almost 40% efficient, whereas farms of the same size in Albany are almost 70% efficient. This relationship holds even at an output of 100 tons per hectare where farms in the Cape district are on average 80% efficient. In contrast, farms in Stellenbosch, the only comparable district at this output level, are almost 90% efficient.

The existence of an inverse relationship between farm size and productivity in developing countries has been debated extensively by the agricultural economics fraternity, and particularly the possible reasons for this relationship. Henderson (2015) offers five competing hypotheses: (i) decreasing returns to scale, (ii) land quality heterogeneity, (iii) differing responses to uncertainty, (iv) labour market imperfections, and (v) differences in technical and/or allocative efficiencies.

Henderson (2015) says hypotheses (i),[10] (ii) and (iii) have not received much theoretical and empirical support, and that (iv) and (v) have received more support. The argument for (iv) is that land-to-labour ratios increase with land endowments, which implies an inverse relationship between land productivity and land endowments. Several empirical studies have supported the notion that supervision and transaction costs associated with hired labour on large farms are the likely cause of the inverse relationship (see for example Binswanger, Deininger, and Feder 1995; Deininger, Zegarra, and Lavadenz 2003; Heltberg 1998; Zyl et al., 1995). Support for (v) in the technical and allocative efficiency sub-literature of this debate is mixed. Yotopoulos and Lau (1973), for example, constructed an empirical model to test for the relative technical and allocative efficiency of Indian farmers and found that small farms exhibited a 20% greater technical efficiency than large farms. Much later, Bravo-Ureta and Pinheiro (1997) found that medium-sized farmers in the Dominican Republic (those operating between 3.25 to 6.5 hectares) were the most technically, allocatively and economically efficient. Similarly, Helfand and Levine (2004) found a U-shaped relationship between farm size and technical efficiency among farmers in Centre-West Brazil.

Given that we do not know the sizes of the farms in our dataset and have to use total wheat output as a proxy, and the fact that the Cape Colony was a coercive-labour economy at the time, this paper cannot offer anything very substantial to support or contest the labour market imperfections hypothesis (iv). But we could argue, in support of hypothesis (v), that in this frontier economy the limiting factor was not land but labour; hence farmers with a greater wheat output would be less capital constrained and could access more labour, thereby increasing their efficiency. This possibility seems to be supported by our efficiency results since only one of the districts in our dataset (Albany) exhibits a U-shaped relationship between output and technical efficiency. In contrast, all the other districts exhibit a positive relationship between output and allocative efficiency for all output levels. However, why the efficiency of farms with a similar output level differs substantially between districts is unclear. The efficiency effects discussed in Section 5.4 below offer some explanations for the efficiency differences we observe between farms.

5.4 Efficiency effects

Three efficiency effects, which we called z-variables, were included in our model. These variables capture farm and farmer characteristics that could explain the efficiency differences between them. Wagons were included as a proxy for wealth since they were the main capital item, other than slaves, that farmers could invest in.[11] Owning more wagons resulted in a statistically significant reduction in farm-level inefficiency (or an increase in efficiency) in all of the models tested, as shown in Figure 3. Wealthier farmers in the nineteenth century had a significant advantage over their less-well-off counterparts regarding access to capital, labour, production technologies and markets. Furthermore, wealthier farmers could have had better access to education and information about new farming techniques, allowing them to adopt new and innovative methods, thereby increasing their efficiency and productivity.

Our model also tested whether farms that produced a larger number of products and thus were more diversified were also more efficient. We find that a larger number of crops grown has a statistically significant inefficiency reduction in all models tested. Diversification, it seems, led to greater efficiency. Diversification of crops and livestock could have allowed farmers in the eighteenth century to manage their production risk more effectively, by spreading their risk across different products, which protected them from potential losses due to crop failures or market fluctuations. They could possibly also take advantage of different market opportunities and generate more income, by growing a variety of crops and raising different types of livestock. Additionally, diversification could have allowed farmers to use their labour force more productively throughout the year, as different crops have different planting and harvesting seasons. Furthermore, rotating different crops could have helped to improve soil fertility.

Finally, we considered whether being of Huguenot origin had a statistically significant impact on efficiency. Around 150 Huguenots arrived at the Cape of Good Hope in 1688 after the revocation of the Edict of Nantes. As mentioned earlier, Fourie and Von Fintel (2014) showed, using tax censuses for the eighteenth century, that Huguenots who originated from wine-producing regions in France tended to be the more productive winemakers at the Cape but had no such advantage as wheat farmers and may even had been less efficient. Our hypothesis is thus that a Huguenot dummy more than three generations after settlement would have a null result. And this is indeed what we find: Huguenot farmers are statistically no different from other farmers, and the symbol of the coefficient is inconsistent across models, thereby casting even more doubt on the indicator's relevance. There do not seem to be origin-country effects in explaining wheat productivity differences.

6. Conclusions

This paper investigated the productivity of Cape settler wheat farmers in 1825. There were two main findings. First, we found considerable heterogeneity in wheat productivity at the farm level between and within districts in the Cape Colony of 1825. The larger districts were more likely to be more productive, but even within these districts, some farmers were substantially more productive than others. Aggregate district-level statistics can only reveal differences between districts. Our analysis, however, using farm-level tax censuses, reveals the extent of within-district variation in productivity.

Secondly, our results revealed the correlates of high-productivity farmers. We found that draught animal ownership and Khoe labour, but not slave labour, were positively correlated to wheat farm output. Slaves, it seems, were acquired for purposes other than field labour. Two other factors, wagon ownership (as a proxy for wealth) and output diversification, made for more productive wheat farming. We find no effect that by 1825 cultural factors – proxied for by having a Huguenot surname – contributed to wheat productivity.

Our analysis can be extended in several directions. First, the tax censuses could be used as a panel to investigate productivity dynamics across the eighteenth and nineteenth centuries. For example, were the most productive wheat regions also the most productive during the eighteenth century? Determining the persistence of productivity would help identify the causes: if regions remained productive throughout the period of settlement, then environmental factors, such as rainfall or soil quality, or geographic location, like proximity to Cape Town's market, must surely matter. But if there is considerable variation across time, then other factors, perhaps technology, or the profitability of competing crops and other market conditions, could matter more.

A second direction would be to incorporate spatial information. The lack of information about farm size limits our productivity interpretations. One way to resolve this is to match the tax censuses to the 1850 valuation rolls, as Cilliers, Green, and Ross (2022) have done for a single district, Graaff-Reinet. Although this would require immense effort, it enable us to test several additional hypotheses.

A third direction would be to match the 1825 tax censuses to other series. These include probate inventories, auction rolls, manumission records, slave registrations and valuations, and others. By offering additional information about asset allocation and labour relations on farms, such records would enhance our understanding of productivity in the early nineteenth-century Cape Colony.

Notes

1. For a more extensive discussion about the creation and continued popularity of the idea of Cape settler poverty, see Fourie (2014).
2. Higher output does, of course, not necessarily reflect higher productivity. If land was essentially free in the Cape, then optimal farm sizes would be larger than in the long-settled states of Maine, Massachusetts and Virginia. Maine and Massachusetts are also based on poor granitic soils. We thank an anonymous referee for this point.
3. A mud is equal to three bushels (Martin 1839), which in turn is equal to 27.216 kg (SAGIS 2022).
4. Of the 3112 observations, only 2657 were usable because the others had omitted variables.
5. New York, Pennsylvania, Virginia, Massachusetts, North Carolina, Kentucky, Ohio, Connecticut, Maryland, Maine
6. Likelihood ratio tests were performed to establish the preferred functional form. The Cobb-Douglas functional form was rejected in favour of the translog functional form at the 1% significance level.
7. Slave labour is often used as a proxy for wealth at the Cape (Fourie and Von Fintel 2010). Because we include only farmers in our sample, wagons are likely to be a better predictor of total wealth than slaves.
8. We use the surnames of the Huguenots who arrived in 1688/89 as proxy for Huguenot status. See Fourie and Von Fintel 2014).
9. $RMRTS = \frac{\in_{slave}}{\in_{Khoe}}$ where $\in_{slave}$ is the output elasticity of slave labour and $\in_{Khoe}$ is the output elasticity of Khoe labour both calculated by $\in_i = \alpha_i + \sum_j \alpha_{ij} ln_{x_j}$
10. The farms in our dataset exhibit constant returns to scale, which is to be expected from the literature (see Henderson 2015).
11. Wagons were tested as variable in the production function but were found to be statistically insignificant in all models and violated the monotonicity assumption. This result is because during this period waggons were primaliry used for the provision of transport services and not farming.

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