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South Africa's land redistribution: an agent-based model for assessing structural and economic impacts

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ABSTRACT

South Africa's land redistribution aims to redress the historical injustices of apartheid. This paper evaluates the efficacy of an agent-based model to support and refine the process. Using the Impacts of Land Use Patterns in South Africa model, developed from surveys of 658 commercial farmers and 833 commercially oriented smallholders, we simulate three scenarios: the current willing seller, willing buyer mechanism as our baseline, a second scenario that includes land subdivision to produce emerging farm parcels, and a third scenario that includes expropriation of underperforming farms. We find that the current mechanism is likely to redistribute only 14% of the targeted 30% of commercial farmland. Including land subdivision increases the number of beneficiary farms from 4,383 to 73,600, improving access to land but reducing farm sizes and thus possibly economic sustainability. Including expropriation adds about 2.4 million hectares, mainly for grazing, with a small allocation for field crops and horticulture. All three scenarios could reduce production volumes, with marked differences in impact across agricultural subsectors in the subdivision scenario. Realising these scenarios over an eight-year period is projected to require substantial financial investment, with estimated costs ranging from R422 billion to R626.9 billion, heavily weighted towards operational capital to maintain farm productivity and viability. The study demonstrates the model's value for policymakers, enabling them to explore and evaluate the outcomes of different land redistribution strategies, ensuring more informed and effective policy-making.

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1. Introduction

After apartheid ended, a priority for South Africa's new government was to create a land reform policy to distribute farmland more equitably among the country's race groups. This policy seeks to achieve restorative justice and strengthen the rights of farm workers. Guided by the mandate outlined in Section 25 of the Constitution, the policy has three sub-programmes: *land restitution*, *land tenure* and *land redistribution* (DLA 1997). Land restitution aims to return land forcibly taken from the original owners after 1913; land tenure aims to strengthen the land rights of farm workers

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and those residing and farming in the former homelands; and land redistribution, the primary focus of this study, aims to balance land access and ownership across racial lines.

Despite widespread academic support for the motives behind land redistribution (Coles 1993; Van Zyl et al. 1994; Marcus, Eales, and Wildschut 1996; Conradie 2019), the reality has fallen short of expectations. A government audit in 2017 found that 72% of the nation's private farmland is still owned by whites, who constitute only 9% of the population (DRDLR 2018). There are several reasons for this disappointing outcome, such as frequent changes to land redistribution mechanisms (McCusker, Moseley, and Ramutsindela 2016), misappropriation of funds by elites (Mtero, Gumede, and Ramantsima 2023), and an inadequate budget (Aliber 2019). The process has been a matter of trial and error, with minimal rigorous scientific support.

This paper posits that agent-based modelling could enhance the scientific support for land reform by forecasting the long-term effects of mechanisms for land redistribution. This approach involves projecting the amount of land that could be redistributed to black farmers, evaluates their performance on redistributed land, and analyses the resulting changes to the agricultural sector. We use and adapt some of the existing land redistribution mechanisms as scenarios in our ILUPSA (Impacts of Land Use Patterns in South Africa) agent-based model to explore how they might transform the agricultural sector. The agents in our study are commercial and smallholder farmers who are potential beneficiaries of land redistribution. Our study allows us to ask the following forward-looking question for the first time: How will different land redistribution mechanisms affect the structure and economy of South Africa's agricultural sector in terms of land use, farm numbers, income and food production?

2. Land reform in South Africa

The South African agricultural sector is a dual system made up of just over 40,000 mostly white commercial farmers and more than two million black smallholders primarily located in the former homelands without freehold land titles (Stats SA 2016, 2020). Commercial farmers produce about 90% of the total agricultural output and the rest comes from smallholders and land reform beneficiaries, often referred to as "emerging" farmers (Greyling, Vink, and Mabaya 2015; Sihlobo 2023).

The South African land reform programme, as outlined in the 1997 White Paper, has the objective of correcting this imbalance and comprises three main components: restitution, redistribution and tenure reform. The primary goal of land redistribution is to correct racially unbalanced land ownership. Since the launch of the land reform initiative in 1994, several policies have been introduced to facilitate land redistribution, including the Settlement Land Acquisition Grant (SLAG) (1997–2000), the Land Reform for Agricultural Development (LRAD) (2001–2010), the Proactive Land Acquisition Strategy (PLAS) (2006), and the State Land Lease and Disposal Policy (SLLDP) (2013).

The SLLDP categorises beneficiaries into four groups: those with limited land access, commercially oriented subsistence farmers, medium-scale commercial farmers poised for expansion, and large-scale commercial farmers with significant resources. Our study concentrated on commercially oriented smallholders, whom we identified as particularly suitable beneficiaries for agricultural land redistribution (DRDLR 2013). Land reform is multifaceted, involving issues of social justice, equity and different farming models. Despite its complexity and the diverse perspectives on its implementation, our research adopted the commercial farming model.

Progress in land redistribution has been slow, with only about 10% of South Africa's agricultural land having been redistributed since 1994 (Sihlobo and Kirsten 2021). What is of great concern is the stagnant productivity. A recent nationwide study that analysed 1,956 land redistribution farms acquired under the PLAS programme found that only 7% of these farms operated at a commercial scale (Verschoor et al. 2023).

The low productivity on these redistributed farms has been attributed to a number of interconnected factors. Beneficiary selection has been poor (Zantsi and Greyling 2021). Beneficiaries lack adequate and timely post-settlement support, such as funding for purchasing inputs and paying labourers (Zantsi 2023). As a result, some farms remain vacant for extended periods, sometimes up to five years (Verschoor et al. 2023). The period of support is undefined, and some beneficiaries receive continuous support while others receive none (Mtero, Gumede, and Ramantsima 2023). Inexperienced emerging farmers find the large size of the current commercial farms (on average 2,000 hectares) difficult to manage, leading them to become solely dependent on government post-settlement support. On smaller farms, however, beneficiaries can purchase production inputs from their own funds (Rusenga 2020).

3. The potential of agent-based farm sector models for simulating land reform scenarios

It is challenging to model the structural and economic impacts of land reform policies at both the farm and sectoral levels. Farmers, both commercial and small-scale, who acquire redistributed commercial farms are likely to adjust their production, investment and farm-exit decisions in response to the policies. In addition, the entire sector is expected to react to these changes. The interconnected nature of the system complicates the modelling process and the heterogeneity of the South African agricultural landscape complicates it further.

As South Africa's landscape varies widely, from deserts to forests, so does its agricultural sector vary. Farm sizes range from 10 to 100,000 hectares, production intensities from intensive horticulture to extensive sheep farming, and annual incomes from below R300,000 to over R100 million. Consequently, we expect farmers' responses to the land reform policies to vary widely as well.

Agent-based models (ABMs) have been used to simulate scenarios in various sectors in South Africa, such as transportation (e.g., Van der Merwe 2011), fisheries (e.g., Cooper and Jarre 2017) and agricultural economics, particularly with regard to climate change and food security (Bharwani et al. 2005). They have also been used in land reform studies. For example, Woyessa, Welderufael, and Kinyua (2008) developed a conceptual model for land-use decision-making related to water resources in the Modder River basin in the Free State province, and Olubode-Awosola, van Schalkwyk, and Jooste (2008) developed a regional mathematical model for land redistribution in the same province.

ABMs provide a conceptual framework that allows for the simulation of complex responses to policy changes. These models adopt a bottom-up approach by modelling individual farms and their decision-making processes in response to policy changes (Happe, Kellermann, and Balmann 2006). They can handle heterogeneous farm populations and their interactions, along with feedback to simulate emergent properties of the system (Matthews et al. 2007; cited in Huber et al. 2018). The greater the heterogeneity in the farming population, the more advantageous ABMs become (Happe, Kellermann, and Balmann 2006).

Over the past two decades, several agricultural ABMs have been developed (for overviews and reviews, see Groeneveld et al. 2017; Huber et al. 2018; Kremmydas, Athanasiadis, and Rozakis 2018; Reidsma et al. 2018; Ziv et al. 2020). These models are highly sophisticated and capable of simulating complex changes in the farming sector, but they have limitations. For instance, in a review of European agricultural ABMs, Huber et al. (2018) shows that most of them still assume that primarily socio-economic or purely economic factors drive individual farmers' decisions, while factors such as social norms, learning, adaptation or uncertainty are rarely included.

Accurately modelling the observed heterogeneity of a farming sector remains a challenging task. Various methods have been used to build the agent population in agricultural ABMs. Some of the pioneering models have included all the farms in a region using cloning or Monte Carlo simulation techniques (Berger 2001; Berger and Schreinemachers 2006; Happe et al. 2008). National-scale ABMs have used a representative farm sample from the entire country as the agent population (Möhring et al. 2016). For consistent model results at both farm and sectoral scales, farm-level results must be extrapolated to the sectoral scale (Zimmermann et al. 2015).

Some of the limitations of agricultural ABMs can be mitigated by applying additional measures to adjust the model results to real-life situations. At the individual farm scale, this can be achieved using positive mathematical programming (PMP), which calibrates the land use and livestock of individual farms to observed levels in the base year (Mack et al. 2019); at the sectoral level, sector-consistent upscaling methods can be applied (Zimmermann et al. 2015).

4. The ILUPSA model

The ILUPSA model, a multidisciplinary and country-wide agricultural agent-based model, is the first of its kind constructed for South Africa. It was created in collaboration with Agroscope, the Swiss Centre of Excellence for Agricultural Research, affiliated with the Federal Office for Agriculture. It serves as a platform or virtual laboratory where various policy scenarios can be tested while accommodating the reality of farm diversity and allowing for subjective behaviour by farmers as they make their decisions. How scenarios differ from the baseline is measured by the output of the variables over a specified period, such as the number of farms, farm size, farm ownership, income distribution, investment and operational land reform budget required, production output and labour use. The impact of each scenario on each agent's income and expenditure and on aggregated income and expenditure is estimated using a non-linear mathematical programming model implemented using the General Algebraic Modelling System (GAMS) software system. These models, in turn, are connected to each other using JAVA modules. These modules also allow the models to account for smallholder production characteristics and aspirations and the bidding for available farm parcels so that the policy scenarios can be tested.

4.1 Data

The ILUPSA ABM is based on three datasets: two sets of survey data, from commercial and smallholder farmers (the agents), and a set of standardised crop and livestock budgets for the items included in the model.

The first dataset is derived from a national survey of 658 commercial farmers that we commissioned in 2017–2018. This survey was conducted using a self-administered questionnaire distributed via email, completed by commercial farmers affiliated with various industry bodies, farmer organisations and willing farmers. The survey achieved a response rate of 41% over an 18-month period. Table 1 shows the distribution of the farmers in the survey.

The survey data from the commercial farmers provides the foundation for the model in terms of the heterogeneity of agricultural production. It includes demographic data (such as age and education), geographic location, cultivated area and method (i.e., dryland or irrigated), size and scope of crop and livestock enterprises, and the employment of permanent and seasonal labourers.

To improve national representation, we performed an initial stage of upscaling to correct the underrepresentation of farmers in certain provinces and to ensure that the farmers accurately reflect the overall distribution of commercial farms across provinces, resulting in a new total of 2586. Essentially, individual farms, as agents, were duplicated to make the model nationally representative.

Table 1. Study areas and sample size distribution of commercial farmers.

Province	Count	Actual %	Ideal %	Add	New total	New %
Eastern Cape	68	10	11	186	254	10
Free State	23	3	20	478	501	19
Gauteng	12	2	6	98	110	4
KwaZulu-Natal	91	14	8	138	229	9
Limpopo	49	7	8	139	188	7
Mpumalanga	43	7	7	183	226	9
North West	18	3	12	269	287	11
Northern Cape	26	4	12	304	330	13
Western Cape	328	50	17	133	461	18
South Africa	**658**	**100**	**100**	**1928**	**2586**	**100**

The second dataset is derived from a multi-stage survey of 833 smallholders across three provinces (Eastern Cape, KwaZulu Natal and Limpopo), which are collectively home to over 60% of South Africa's smallholders. "Smallholder" or "small-scale" farmer refers to a black farmer operating within a communal tenure system in the former homelands. The survey was conducted in 2017 and 2018. However, smallholders are not a homogeneous group (Pienaar and Traub 2015). The largest group is purely subsistence-oriented, farming primarily to provide food for household consumption. If they raise animals, it is typically for household slaughter needs and ritual ceremonies. Another group farm primarily for commercial purposes, selling most of their produce. We refer to this group as "commercially oriented smallholders", as individuals who seek to generate a livelihood from farming (Aliber 2019; Conradie 2019).

The respondents in this survey were commercially oriented smallholders, specifically those who had sold at least 60% of their produce in the previous season. They were also assumed to be the target group for our land reform scenarios. This aligns with the SLLDP under the land redistribution component, which identifies such farmers as suitable candidates for land redistribution. Once these commercially oriented farmers are selected as beneficiaries of land redistribution to farm on freehold land previously owned by white farmers, they are generally referred to as "emerging" farmers (Gwiriri et al. 2019).

Table 2 shows the distribution of the sample. We used purposive sampling at the national and provincial levels and random sampling at the household level. However, the sample is not proportionally distributed to the population of agricultural households in the respective provinces. Furthermore, as the definition of smallholder categories is contested (Zantsi, Greyling, and Vink 2019), our sample may not be fully representative, but it is sufficiently large to provide a useful overview. Given these challenges, we opted not to upscale smallholders to the sectoral level like commercial farmers. However, we know from previous studies that more than 50% of commercially oriented smallholders are willing to relocate to commercial farms (Zantsi, Mazwane, and Greyling 2022). We use this second dataset to characterise the attributes and aspirations of potential land redistribution beneficiaries.

The third dataset includes farm budgets (average cost, yield and income per hectare per crop) for each of the 31 crop types modelled, including all major field crops, horticultural crops (including fruits, nuts and vegetables) and planted pastures. The budgets depend on whether the cultivation is dryland or irrigated. For livestock, the model incorporates an industry average cost per livestock unit, and the yield and income per animal for nine livestock types and 18 livestock products, covering the majority of commonly farmed animals, large and small, including poultry (DAFF 2019; BFAP 2020).

4.2 Model design

Figure 1 shows the design and process of the ILUPSA ABM. The model is structured to accommodate both commercial and smallholder farmers, the agents in the model. From the survey data, we identified several subtypes of farmers based on their exit decisions. On the commercial side, we find some who, according to their responses, are planning to fully or partially exit the industry within the next ten years, some who plan to maintain the status quo, and some who plan to expand. On the smallholder side, we find some who are willing to relocate with government assistance, some who are

Table 2. Study areas and sample size distribution of smallholder farmers.

Eastern Cape	(n)	KwaZulu-Natal	(n)	Limpopo	(n)
Amathole	175	uMkhanyakude	125	Vhembe	89
Chris Hani	120	King Cetshwayo	80		
OR Tambo	84	Harry Gwala	56		
		Zululand	104		
Total	**379**	**Total**	**365**	**Total**	**89**

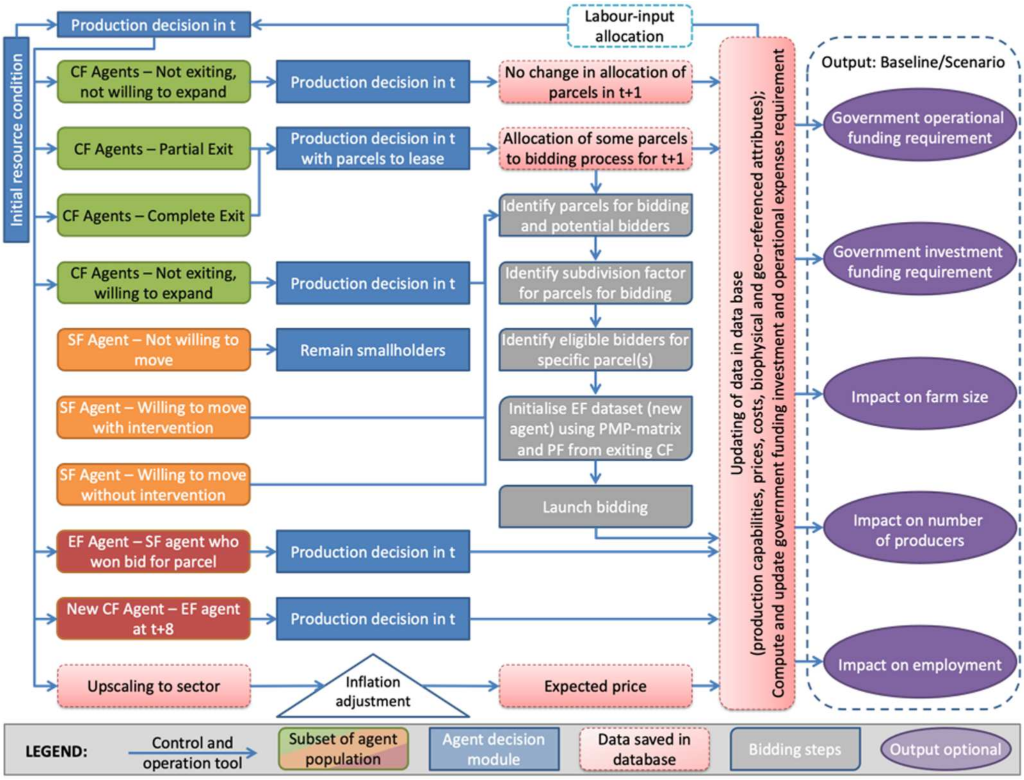


Figure 1. Design and process overview of ILUPSA ABM (Impacts of Land Use Patterns in South Africa agent-based model).

willing to relocate without assistance, and some who are not willing to move. Thus, we have seven types of agent represented in the model at time *t*.

The objective of the ILUPSA model is to maximise net farm income, as shown in Equation 1, subject to the constraints shown in Equations 2 and 3. We thus used a goal optimisation rule to model agents' production decisions on the basis of this objective and subject to the constraints. The resource-constraint balance, which controls the model to optimise production within the capacity of available resources, is shown in Equation 4. This income maximisation objective reflects the reality of the surveyed farmers (agents), both commercial farmers and commercially oriented smallholder farmers, the latter being those who produce a surplus above their own consumption needs. As the government does not support commercial farmers who are not beneficiaries of land redistribution, these farmers use the open market to generate income. We therefore assume that making a profit is their main reason for farming. Most of the smallholders in our sample also said their main objective was profit. Hence the objective of the ILUPSA model is to maximise profit.

The land redistribution policy, as outlined in the State Land Lease and Disposal Policy (SLLDP), aims to support beneficiaries who pursue commercial farming, as do the Land Reform Beneficiary Selection criteria (DRDLR 2015, 2020). The model's income maximisation function also incorporates government funding provided over a seven-year period to emerging farmers (new black commercial farmers).

$$Max\ Nett\ Farm\ Income_{a,t} = \sum_g p_{a,g} * LAND_{a,t,g} + \sum_l p_{a,l} * ANIMAL_{a,t,l} + \sum p_a * \ Funding_{a,t} - COSTFUNCTION_{a,t} \quad (1)$$

subject to

$$\sum_{g} \omega^{LAND}_{a,g,w} * LAND_{a,t,g} \quad \leq \; Area_{a,t} \tag{2}$$

$$\sum_{l} \omega^{ANIMAL}_{a,l,w} * ANIMAL_{a,t,l} \quad \leq \; Grazing\ Area_{a,t} \tag{3}$$

$$\sum_{f} \omega^{LABOUR}_{a,f,w} \quad (LABOUR_{a,t,f} * LAND_{a,t,g} + LABOUR_{a,t,f} * ANIMAL_{a,t,l}) \; \leq \; LABOURCAP_{a,t} \tag{4}$$

Each of the 2629 commercial agents' farm models was optimised in GAMS, after which the simulations of subdivision and land redistribution policy scenarios were executed in the JAVA module. The model is designed to accommodate both smallholder and commercial farmers in a bidding process where other commercial farmers are planning to exit. Various scenarios can be incorporated into the bidding process, such as different subdivision factors for the farm becoming available, government budget allocation (closed-ended or open-ended) and restrictions on which agents are allowed to bid. The recursive dynamic function integrates these changes post-bidding into the model.

When a smallholder acquires land use rights, he or she becomes an emerging farmer, creating a new agent with characteristics derived from both the exiting commercial farmer's land use patterns and the social characteristics of the smallholder. We thus derive the production costs and yields for the emerging agent from the production function of the exiting commercial agent's subdivided farms. This function is intended to mirror the integration of farm production plans redistributed to new owners, as described by Anseeuw and Mathebula (2008, 44); however, this integration does not always occur in reality. Once these emerging farmers reach the eighth year of their tenure, they are recognised as commercial agents in our ILUPSA model.

The baseline scenario for the model follows the willing seller, willing buyer approach currently used in the SLLDP (DRDLR 2015). In the commercial farmer survey, 20% of respondents said they planned to stop farming and sell their land within the next ten years and were willing to sell half their land during that time. For modelling purposes, we set the exit rate at an annual 2%, correlating to this 20%. The bidding process in the model mirrors the SLLDP process in which the emerging farmer rents the land from the government. This process aligns with the SLLDP, where farms are purchased by the state and then redistributed. Throughout the model, we use annual rent as an indicator of land cost, even when commercial farmers have existing private property rights. This rent expense simplifies the model and is analogous to mortgage repayments, or an opportunity cost. We compute these rents according to the sale of farms on the open market in South Africa, taking into account geographical location, water availability and land use type. Our method for deriving rent from land value was adapted from Middelberg (2014).

To model government support for smallholder agents willing to relocate, we assumed that rent paid by the smallholders, indicating land investment cost, and a production cost subsidy, representing operational cost, would be externally paid to them. The funding period of seven years and a 25% reduction in production cost support are modelled on the Massive Food Production Programme that aims to commercialise smallholder maize farmers in the Eastern Cape and other relevant recommendations from land reform studies (Tregurtha 2009; Vink and Kirsten 2019). For the first three years, the grants cover all rent costs, allowing the emerging agent to make mistakes, learn and adapt, while also accumulating reserves to begin financing their own production and rent expenses. From year four, financial support is annually reduced by 25% until the emerging agent graduates and becomes a commercial agent, at which point no further assistance will be available. This seven-year timeframe allows the emerging farmer to adapt to the new land and manage finances while support is gradually phased out. We apply the same approach to directly allocable costs required to finance production on the emerging farms.

4.3 Data and model validation

We took two validation steps, based on McCarl and Nelson (1983) and McCarl (1984). In the first we validated single farms in the JAVA model against a combination of formal and informal datasets. This step included, but was not limited to, secondary data and consultation of data from Statistics South Africa, Bureau for Food and Agricultural Policy (BFAP) reports, the then Department of Agriculture, Forestry and Fisheries, farmer and commodity organisations, and statistics from the then Department of Rural Development and Land Reform regarding the number of redistributed lands and policies.

In the second step, we focused on stakeholder involvement. We presented our preliminary results from the baseline scenario and the other two scenarios to government officials, academics and experts from farmer organisations. The stakeholders approved of our model and its potential and guided us on improving our model's output and impact.

5. Policy scenarios

Agent-based models are typically used as experimental or virtual laboratories where scenarios are simulated. Using the ILUPSA model, we developed three scenarios based on an aggregation of existing land redistribution policies, a review of the scientific literature, and recommendations from the Advisory Panel on Land Reform and Agriculture (APLRA). In all three scenarios, the number of simulation years, sample size, the moderate subdivision factor and the uncapped budget are the same. The assumptions of and motivation for the respective scenarios are described below and summarised in Table 3.

Scenario 1 broadly represents the status quo. It assumes that 2.8% of commercial farmers opt to exit each year, as established in our survey and discussed by Cloete, Möhring, and Zantsi (2023). In addition, it assumes that the state purchases 50% of the land that becomes available and distributes it as is, not subdivided.

The limited progress in land redistribution has led some stakeholders to question the efficacy of the willing seller, willing buyer approach (for examples, Lahiff and Li 2012). Others argue that the problem is not the approach but the flawed implementation (Vink and Kirsten 2019). Hence the objective of Scenario 1 is to project the current reality to establish what is possible, assuming that the State has the capacity to purchase and distribute half of the commercial farmland that becomes available.

Scenario 2 builds on Scenario 1 but modifies it by assuming that acquired farms are subdivided into units that align better with smallholder preferences. We assume sizes of three hectares for horticultural farms, 500 for livestock and 142 for crops. These sizes represent the median preferences of smallholder farmers who are willing to relocate to a land reform farm, categorised as "moderate aspirants" by Zantsi, Mack, and Vink (2021, 103).

This scenario is informed by several studies demonstrating that many potential beneficiaries of land reform prefer smaller farms than those typical of current commercial operations (Aliber and Cousins 2013; Cousins 2015; Zantsi 2021). Many failures of redistributed farms have been attributed to their large sizes, which exceed the aspirations and capabilities of emerging farmers (Aliber and

Table 3. Summary of scenarios, simulated for 2586 agents over eight years.

Technicalities	Scenario 1	Scenario 2	Scenario 3
Subdivision	No	Yes	No
Annual exit rate	2.8%	2.8%	2.8% plus least productive share
Share of voluntary exit land purchased by the state	50%	50%	50%
Expropriation of least productive land	No	No	Yes
State budget constraint	Uncapped	Uncapped	Uncapped

Cousins 2013; Aliber 2019; Vink and Kirsten 2019; Cousins et al. 2020). Zantsi (2021) found that most potential beneficiaries would like to own farms smaller than 100 hectares, far less than the average commercial farm.

Recognising these preferences, the Land Reform and Agriculture Panel has advocated for revising or repealing the Subdivision Act of 1970 to enable commercial farms intended for redistribution to be subdivided into smaller, more manageable units (Mahlati et al. 2019). The state could then reconfigure these farms to suit beneficiaries' needs better. In support of these changes, the Agricultural Research Council, under the directive of the Department of Agriculture, Land Reform and Rural Development (DALRRD), is revising the norms and standards governing the subdivision of agricultural land (Zantsi and Verschoor 2024).

Scenario 3: This scenario is a permutation of Scenario 1. It does not include subdivision but accelerates the transfer of land by including the expropriation of the bottom 15% of the least productive farms. These are underperforming farms, defined as those that achieve below-average yields relative to their district peers. Thus, transferred land is the sum of willing exits and expropriated land.

The slow pace of land redistribution in South Africa has intensified calls for the expropriation of land without compensation. This issue has been central in discussions in the National Assembly and various proposals have been made, including amendments to the Constitution. To date, no definitive law has been enacted (Akinola 2020). Debates continue around the specifics of such policies, including which lands might be targeted. Proposed legislation would apply expropriation to lands not actively used for development or income generation, where the owner seeks primarily to benefit from market value appreciation. Some have called for the expropriation of the least productive farms. However, these discussions are ongoing, and at the time of writing no final legislation had been passed (DALRRD 2020, 5).

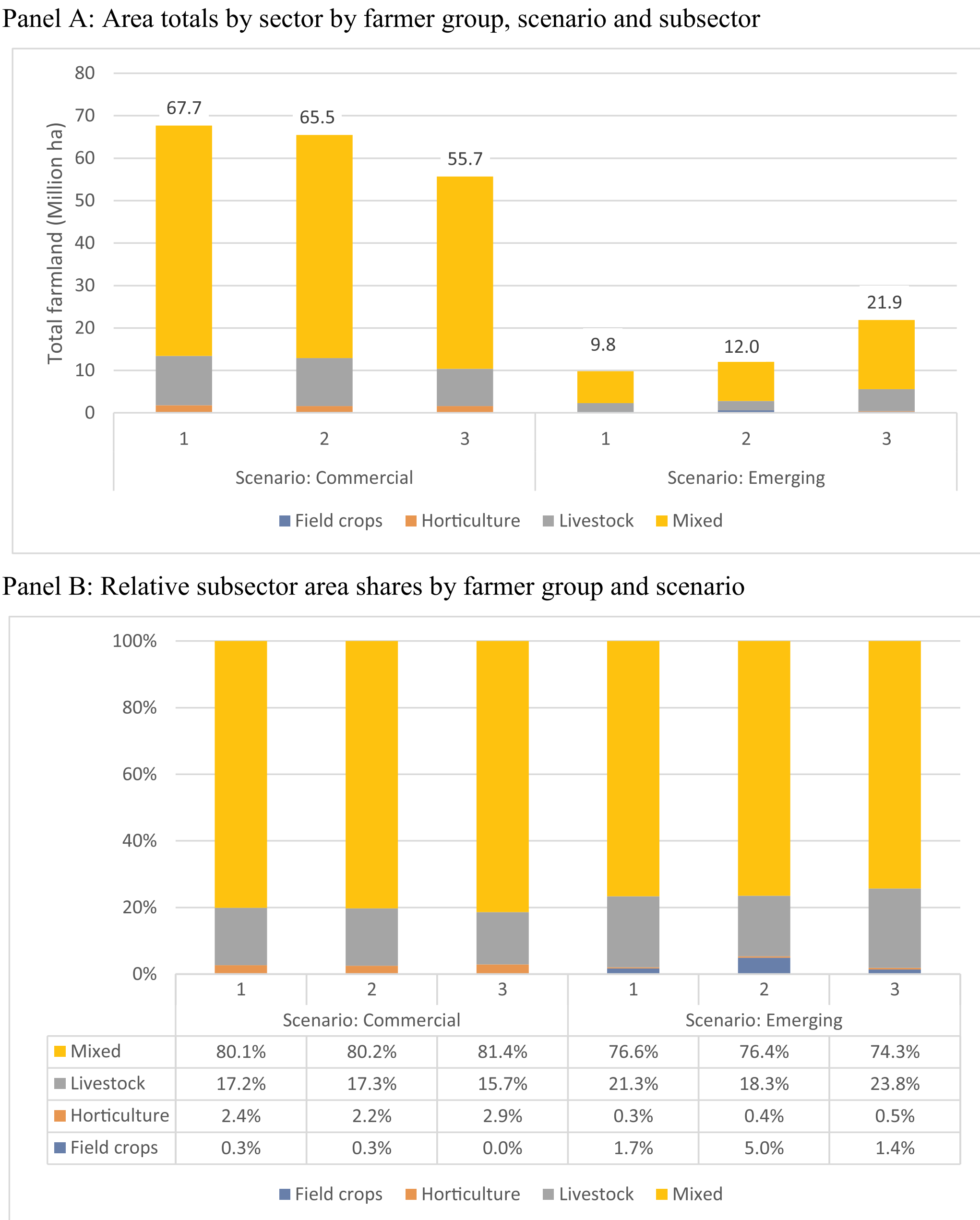
6. Results and discussion

6.1 Land ownership patterns after redistribution

In Scenario 1, the baseline scenario, we aimed to quantify the amount of land that could be redistributed under the status quo, as discussed in Section 5. In this scenario, almost 10 million hectares are transferred to emerging farmers over eight years, as shown in Figure 2, Panel A. Given that more emerging farmers can compete for the smaller parcels, 12 million hectares are transferred in Scenario 2, the variation of Scenario 1 that includes subdivision. As expected, the most land is transferred in Scenario 3, a modified version of Scenario 1 that makes more land available by expropriating the least productive farms. In Scenario 3, 21.9 million hectares are transferred.

Figure 2, Panel B, shows the composition of the redistributed land from a sub sectoral perspective. Mixed farming dominates consistently across the scenarios, constituting 80.1%, 80.2% and 81.4% of commercial farming in Scenarios 1, 2 and 3, respectively, and 76.6%, 76.4% and 74.3% for emerging farmers. Emerging farmers have a higher area share of livestock farming, at 21.3%, 18.3%, and 23.8% in Scenarios 1, 2 and 3, while commercial farmers hold smaller shares at 17.2%, 17.3%, and 15.7%. The prevalence of mixed and livestock farming is expected, given that these land types are the most affordable and thus attract the largest number of potential smallholder beneficiaries. The literature corroborates this finding: numerous studies find that livestock farms are the most frequently redistributed type, predominantly involving low-quality grazing land (e.g., Graham and Lyne 1999; McCusker 2004; Malatji and Phago 2018). Further supporting this trend, a significant study by Cousins et al. (2020), on enhancing employment through land redistribution, advocates for developing extensive livestock and vegetable farming because their lower capital intensity aligns well with the government's fiscal limitations.

Consistent with the affordability theme, very little horticultural land is transferred, with this subsector representing only 0.3%, 0.4% and 0.5% of emerging farming in Scenarios 1, 2, and 3 and 2.4%, 2.2%, and 2.9% of commercial farming. These figures underscore the problems of affordability and



	Scenario: Commercial			Scenario: Emerging		
	1	2	3	1	2	3
Mixed	80.1%	80.2%	81.4%	76.6%	76.4%	74.3%
Livestock	17.2%	17.3%	15.7%	21.3%	18.3%	23.8%
Horticulture	2.4%	2.2%	2.9%	0.3%	0.4%	0.5%
Field crops	0.3%	0.3%	0.0%	1.7%	5.0%	1.4%

Figure 2. Land distribution model results after eight years by scenario and subsector.

divisibility associated with horticultural land. Share equity schemes have helped to solve these problems, enabling more equitable access and participation in this high-value subsector.

Some studies suggest that equity share schemes are more effective than solely black-owned models because they help solve the affordability problem. These schemes are also considered a mechanism for bridging the expertise gap between seasoned commercial farmers and land reform beneficiaries, as well as facilitating connections to markets and financial institutions (e.g., Oertle 2017; Chamberlain and Anseeuw 2018). However, others, such as Vaca (2003), who used the Peterson Wysocki Harsh Model, offer a nuanced analysis of the advantages and disadvantages of these schemes in the fruit and wine industry. Vaca argues that while these schemes mostly benefit commercial farmers, they fail to empower farm workers beyond providing dividends, leaving power relations unchanged and expertise sharing minimal. Moreover, farm workers, often low-skilled and lacking managerial abilities, represent a specific class of beneficiaries; the model's application to other land redistribution beneficiaries with commercial farming aspirations remains limited. Nevertheless, with appropriate modifications, equity share schemes could serve as a potent strategy for empowering a wider range of land redistribution beneficiaries, particularly on horticultural farms.

The model results for the transfer of field crop farmland (Figure 2, Panel B) are surprising, especially the much higher percentages for emerging farmers. This could be partly because emerging farmers are underrepresented in the horticultural subsector; however, this alone does not fully account for the observed discrepancy.

6.2 Land redistribution by numbers of farms

Land redistribution is often quantified and reported in farm numbers, a "farm" being a unit transferred to an emerging farmer. Figure 3 shows how the number of farms changes under the different scenarios. In Scenario 1, only 4,383 farms are transferred. This number increases almost six-fold (324.5 thousand) in Scenario 2, when the farms available for redistribution in Scenario 1 are subdivided. This means that the impact of land subdivision could be significant as more commercially oriented smallholders will benefit per unit of the transferred farm. When the least productive land is expropriated (Scenario 3), 77.9 thousand farms are transferred.

6.3 Land redistribution by farm size

Figure 4, panels A and B, shows the changes in average farm size under the three scenarios. For the commercial sector, the average size is 1,916 hectares in Scenario 1. This aligns with Liebenberg's national estimate of 2000 hectares (2013). In Scenario 2 it drops slightly, to 1,853 hectares, followed by a more substantial decrease to 1,403 hectares in Scenario 3. For the emerging sector the average size varies more widely, from 2,277 hectares in Scenario 1 to just 37 hectares in Scenario 2 because of

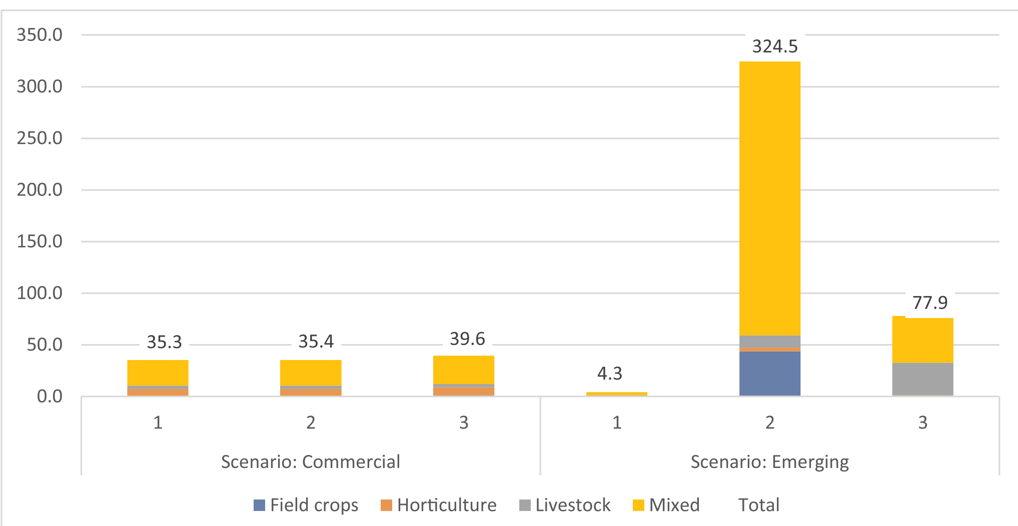


Figure 3. Number of commercial and emerging farmers by scenario and subsector.

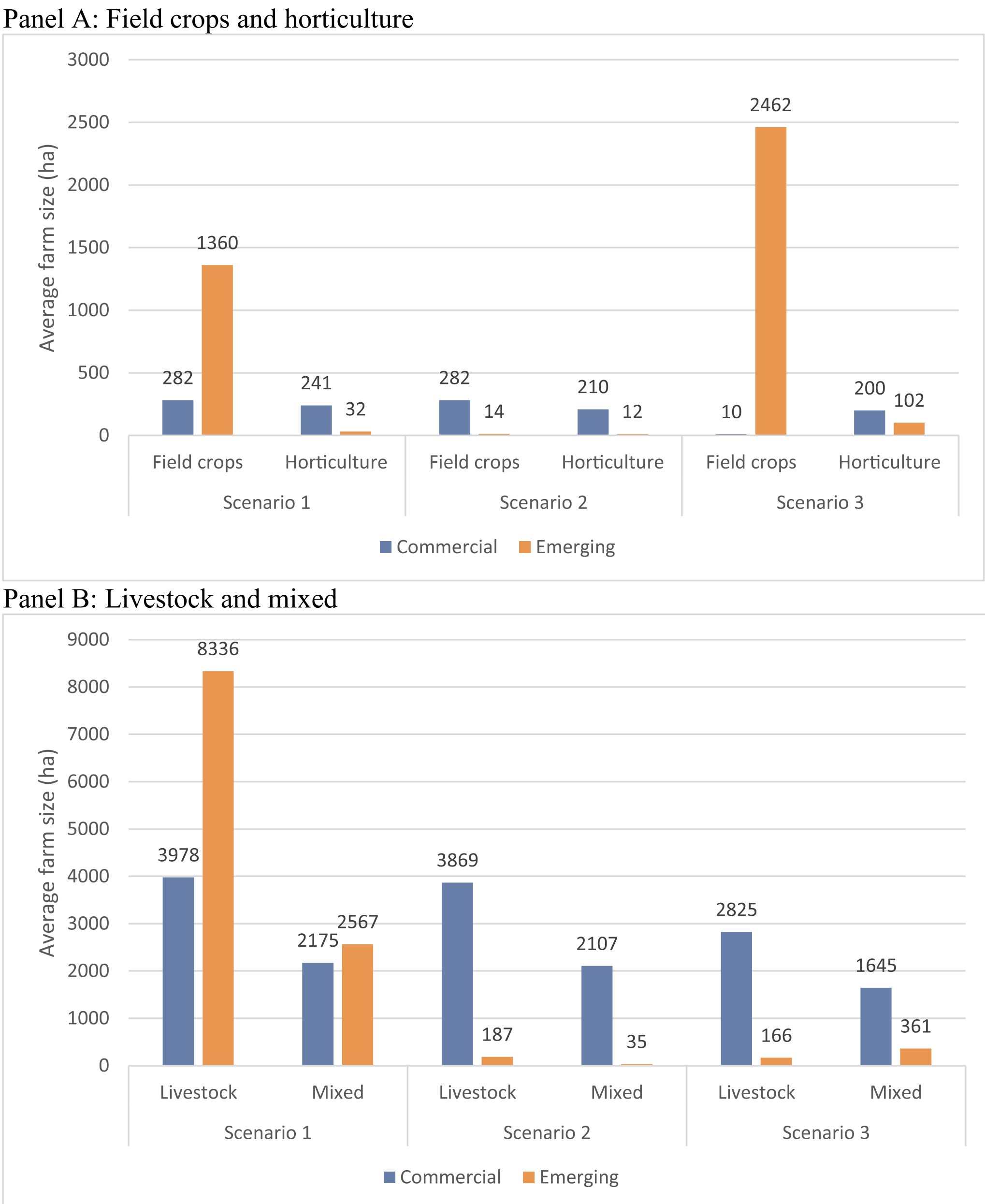


Figure 4. Average farm size by farmer group after eight years by scenario and subsector.

subdivision, reflecting a major shift in land distribution strategy. In Scenario 3 the average size is 282 hectares, suggesting a more moderate approach.

Average farm sizes vary across the agricultural subsectors. In Scenario 1, the average size for field crops is 282 hectares for commercial farms, much less than the 1,360 hectares for emerging farms. For horticulture the average is 241 hectares for commercial farms and 32 hectares for emerging farms. For livestock it is 3,978 hectares for commercial farms, much less than the 8,336 hectares for emerging farms. For mixed agriculture it is 2,175 hectares for commercial farms and slightly more for emerging farms at 2,567 hectares.

In Scenario 2, the average size for field crops is 282 hectares for commercial farms and 14 hectares for emerging farms, a substantial decrease for the latter. For horticulture the average is 210 hectares for commercial farms but only 12 hectares for emerging farms. For livestock it is 3,869 hectares for commercial farms, contrasting sharply with 187 hectares for emerging farms. For mixed agriculture the contrast is also noticeable, with 2,107 hectares for commercial farms but only 35 hectares for emerging farms.

In Scenario 3, for field crops the position is reversed, with an average of only 10 hectares for commercial farms but a substantial increase to 2,462 hectares for emerging farms. For horticulture the average is a fairly stable 200 hectares for commercial farms and 102 hectares for emerging farms. For livestock it is 2,825 hectares for commercial farms, far outstripping the 166 hectares for emerging farms. For mixed agriculture it is 1,645 hectares for commercial farms and 361 hectares for emerging farms.

Importantly, subdivision of land promotes a demand-led land redistribution strategy, as recommended by Mahlati et al. (2019), aligning with beneficiary aspirations as advocated by Hebinck, Fay, and Kondlo (2011) and Aliber and Cousins (2013). It means more manageable farm sizes for inexperienced land recipients. Scholars like Aliber (2019) and Rusenga (2020) suggest that smaller farms could make land more affordable for emerging farmers capable of independent purchases without government assistance, potentially accelerating the transformation of South African commercial agriculture, which remains predominantly under white ownership, as noted by Lyne and Ferrer (2006).

6.4 Changes in production after land redistribution

Land redistribution affects food production, a critical element of food security (Olubode-Awosola, van Schalkwyk, and Jooste 2008; Mukarati, Mongale, and Makombe 2020). Figure 5 shows that food production by transferred farms in the eighth year after transfer, serving as an indicator of the food supply, would decrease under the three scenarios. This would affect not only the primary agricultural sector but also the entire value chain and jobs in agriculture.

The changes in production volume are not uniform across farm types or scenarios. Figure 5 shows a general decline in production, particularly for field crops. Production varies for different types of livestock farms, with a slight decrease in beef production (Panel B) and a smaller reduction in mutton and lamb (Panel A). Beef and mutton and lamb were chosen here to allow for a direct comparison, omitting other livestock not predominantly farmed by emerging farmers.

Between Scenarios 1 and 2, commercial beef production stayed almost constant but with a decline in emerging farmer production from 1.5 to 1 million tons. The mutton and lamb model results for Scenario 1 and 2 are broadly similar between farmer groups. Subdivision leads to some improvements in productivity for grain and oilseed farms. From Scenario 1 to Scenario 2, commercial grain production decreases slightly from 10.23 million tons to 9.89 million tons for commercial farms and increases from 0.20 million tons to 0.36 million tons for emerging farms. Oilseed production decreases for commercial farms from 2.34 million tons to 1.79 million tons but increases from 0.07 to 0.26 million tons for emerging farms.

The projected decrease in beef productivity, alongside an increase in grain and oilseed productivity due to land subdivision among emerging farmers, suggests that this group may successfully farm smaller mixed farming units. However, the decline in beef productivity suggests that these units are already at an optimal size, particularly given that they are often farmed by communities rather than individuals. This outcome underscores the importance of careful planning in land redistribution policies to ensure that they not only meet land equity objectives but also sustain or enhance agricultural productivity. The projected changes highlight the complex dynamics within the sector and the strategic considerations necessary to ensure that land redistribution positively contributes to farmer welfare and national food security.

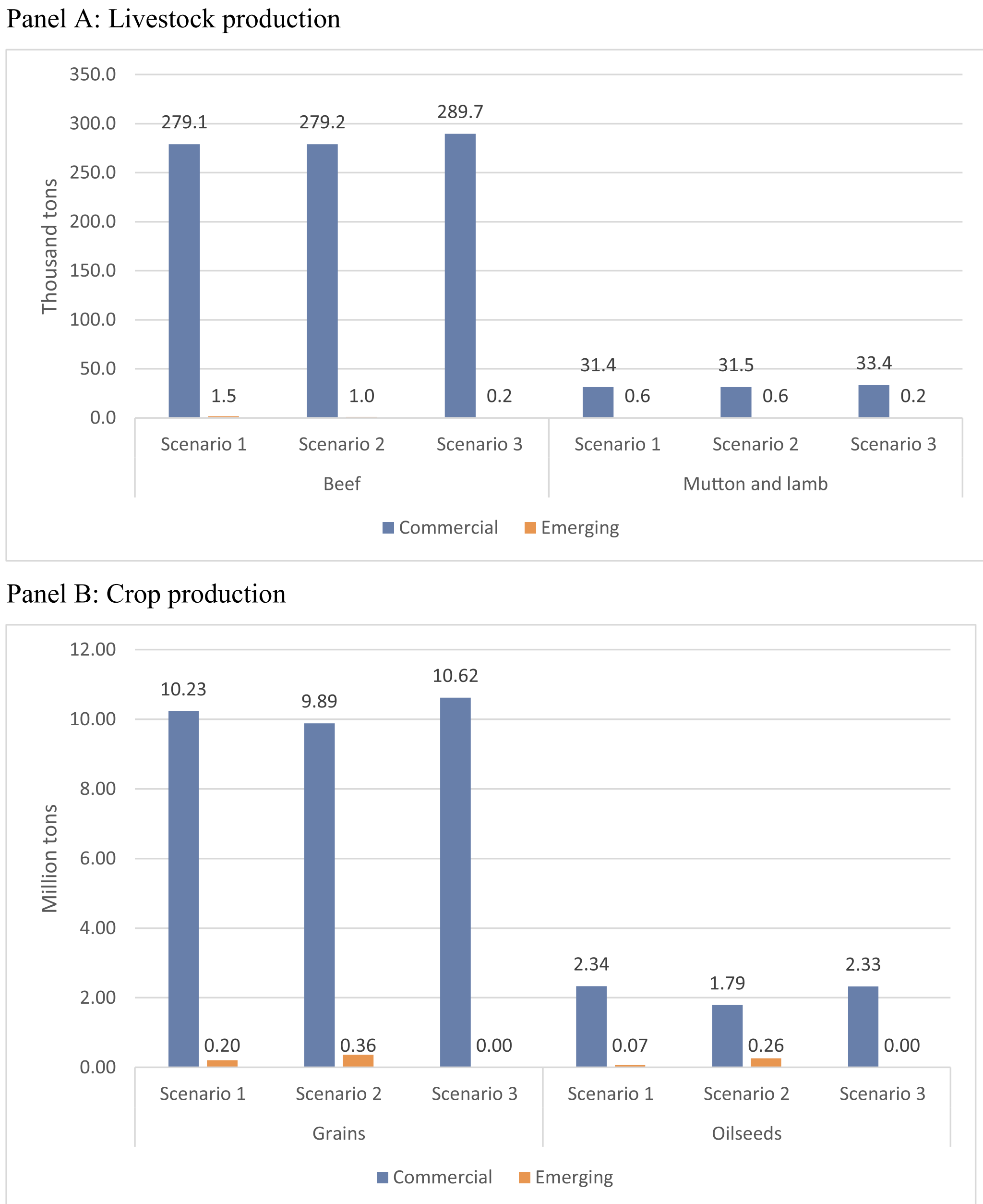


Figure 5. Total production volumes by farmer group after eight years by scenario and subsector.

From Scenario 1 to Scenario 3, beef production increased from 279.1 thousand tons to 289.7 thousand tons for commercial farms, while it decreased from 1.5 thousand tons to 0.2 thousand tons for emerging farms. Mutton and lamb production shows a slight increase for commercial farms, from 31.4 thousand tons to 33.4 thousand tons, but a decrease from 0.6 thousand tons to 0.2 thousand tons for emerging farms. Commercial grain production increased slightly from 10.23 to 10.62 million tons between Scenarios 1 and 3, while oilseed production remained largely stable. However, grain and oilseed production by emerging farmers declined to zero, with the reason for this model outcome remaining unclear.

6.5 Changes in income after land redistribution

Figure 6 compares income in year eight on redistributed farms with income on farms retained by commercial farmers, revealing large disparities.

In Scenario 1, income for commercial farms is R26.53 million, substantially higher than the R6.90 million for emerging farms. In Scenario 2 income for commercial farms decreases slightly to R25.68 million. The decrease is more severe for emerging farms, to just R0.14 million, because of the subdivision.

In Scenario 3, income for commercial farms increases to R27.28 million, possibly because the least productive farms have been expropriated. Alarmingly, emerging farms have a negative income of R-0.33 million, indicating an inability to generate profit and possible losses. This scenario highlights the critical need for robust support systems to ensure the viability and sustainability of emerging farms, especially those established on historically underperforming farms.

6.6 Budget for redistributing land to emerging farmers

Land reform comes at a cost, usually borne by the state, as most beneficiaries cannot afford to purchase land independently (Binswanger-Mkhize, Bourguignon, and van den Brink 2009). In South Africa, the government purchases land on the market and redistributes it (Aliber 2019; Mahlati et al. 2019). Historically, the budget for land reform has been minimal. During the first decade of implementation, only 0.5% of the national budget was allocated to land reform (Kariuki 2004). Aliber (2019) notes that recent estimates put this allocation at approximately 1% of the national budget. He says this insufficient budget allocation is compounded by unrealistic projections and targets based on secondary data for the number of beneficiaries, i.e., the number of farms needed, and the budget.

To investigate the funding problem, we estimated the funds required from the state to finance access to land based on simulations of land availability for redistribution. The model calculated the budget required to finance rent and inputs on the redistributed farms. Our simulated results suggest it would cost approximately R2 million to support one emerging farmer from year one to year eight, after which the farmer would graduate to commercial status.

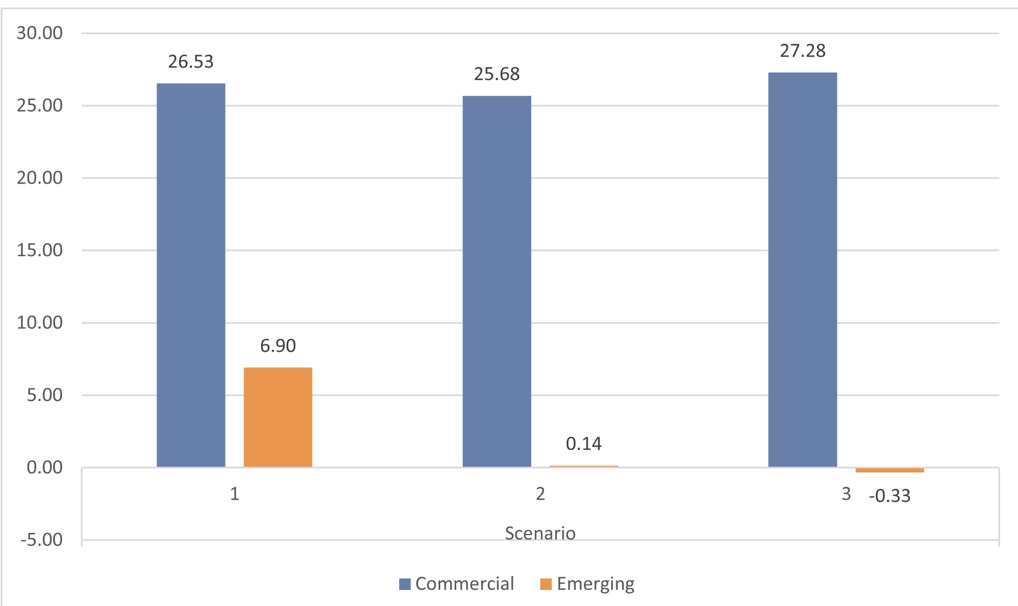


Figure 6. Average net farm income by farmer group in year eight by scenario.

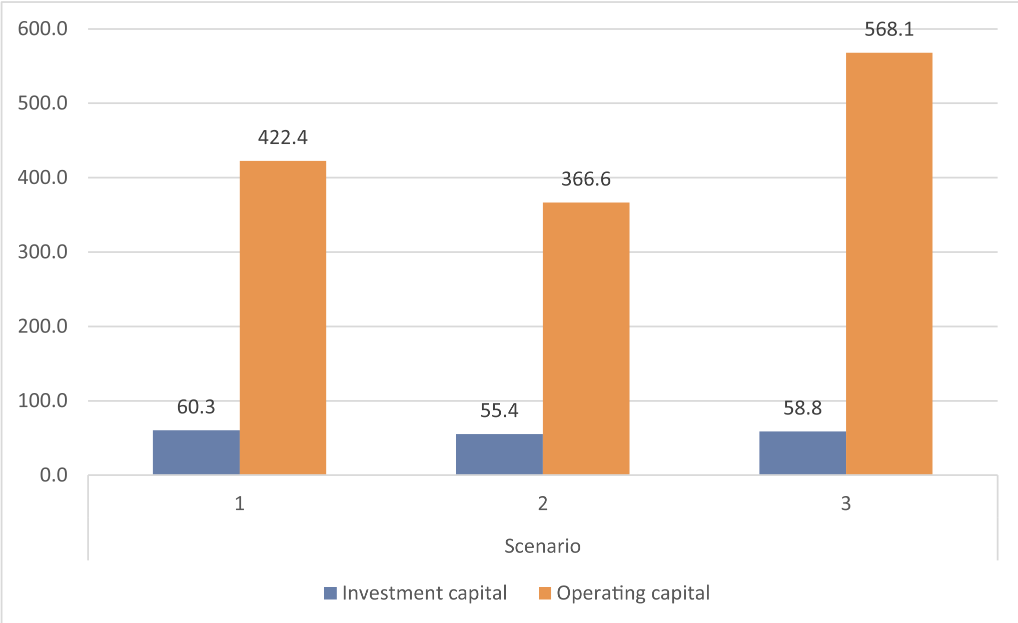


Figure 7. Government expenditure required to finance land redistribution in year eight.

The total budget required over seven years is substantial: R482.7 billion under Scenario 1, R422.0 billion under Scenario 2, and R626.9 billion under Scenario 3 in year eight. Figure 7 shows the composition of the budget across sectors. In Scenario 1, investment capital (rents) accounts for 12% of the total budget (R60.3 billion), and operating capital (inputs) 88% (R422.4 billion). The corresponding figures for Scenario 2 are 13% (R55.4 billion) and 87% (R366.6 billion), and for Scenario 3 they are 9% (R58.8 billion) and 91% (R568.1 billion).

As the bulk of the budget in each scenario is allocated to operating capital, a sizable operational budget will be needed keep the redistributed farms viable and maintain the current production levels. While subdivision and expropriation supply more land, at the same time they amplify the challenge of securing adequate operating capital. Vink et al. (2013) observed that the Free State province had received only 1.3% of the total restitution spending from the programme's inception. Of this amount, 76% was used to settle claims through financial compensation, and the remainder for land acquisition (10.6%) and support grants (13.3%). Given the current allocation trends, there is a clear need to reassess the total budget and its distribution between investment and operating costs.

Our findings indicate that breaking the budget into successive years will help manage funds, track beneficiary progress, and avoid repeating past mistakes, such as giving indefinite support to the same farmers while cutting budgets in some years, which hampers progress (Hall and Aliber 2010). Consolidating the management of this process under a single department, as suggested by Mahlati et al. (2019), would further streamline efforts to achieve equitable land redistribution.

7. Conclusion

The South African government's land reform initiatives, aimed at rectifying the injustices of apartheid, require substantial resources and pose complex challenges. This paper demonstrates the utility of an agent-based model (ABM) in evaluating the potential impacts of diverse land redistribution policies on South Africa's agricultural sector. The model's ability to simulate scenarios with heterogeneous agents makes it an invaluable resource for policymakers in a country as agriculturally diverse as South Africa. By enabling the testing of various policy scenarios, the model can help policymakers avoid the pitfalls of poorly planned or untested reforms.

Our findings indicate that the willing seller, willing buyer mechanism (Scenario 1, the baseline, modelled on the current approach) is likely to fall short of the government's goal of redistributing 30% of commercial farmland by 2024. We find that modifying this approach by adding land subdivision (Scenario 2) and the expropriation of the least productive farms (Scenario 3) could alter this trajectory and meet redistribution targets more effectively.

However, while subdividing land could dramatically increase the number of beneficiaries, it could also reduce farm sizes, threatening the economic sustainability of emerging farms. Thus, policy adjustments need to carefully consider both the quantity and the quality of redistributed land to ensure long-term viability. While expropriation solves the land availability problem, it creates a new one, the need for substantial amounts of operating capital support to emerging farmers if output levels are to be maintained. This result is in line with expectations since, in the United States, land rental or servicing long-term loans for land acquisition accounts for approximately 6% to 7% of total farm production expenses (USDA 2022).

Financial considerations are also pivotal; our projections, with costs varying across scenarios, suggest that a large financial commitment will be needed to support the transition of emerging farmers to commercial viability, productivity and sustainability. Our model also shows that funds will have to be carefully allocated between investment and operating capital.

We acknowledge some limitations of our model. particularly its exclusion of unused land and the assumption of ideal support services. Future research should expand on these areas to examine the socio-economic and ecological dynamics of land reform more comprehensively. Incorporating environmental variables could offer deeper insights into the sustainability of agricultural practices post-redistribution.

By refining agent-based models and continuously integrating empirical data, researchers can help policymakers develop precisely planned land reform strategies that achieve redistribution targets and are both equitable and pragmatic. Insights from our ILUPSA agent-based model can give policymakers a clearer idea of the amount of land that can be redistributed over a specific period, the potential number of beneficiaries, and the necessary investments. The lack of such data-driven insights in the current policy has contributed to the failure to meet ambitious targets, such as redistributing 30% of agricultural land by 1999 and again by 2014.

Our results also draw attention to the value of a support system for land redistribution. They show clearly that the budget allocated to farmer support (inputs) is a much larger cost component and success driver than acquiring the actual land (investment). A "one-stop-shop" model, as suggested by researchers (e.g., Aliber 2019; Vink and Kirsten 2019) and advocated by the Mahlati et al.(2019), could streamline processes and resources, enhancing the overall efficiency and impact of land reform initiatives. Such a model would centralise support services, providing a coherent framework that could advance land redistribution efforts.

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