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Informal Cattle Rental Markets as a Source of Draft Power:

Productivity Gains, Allocative Efficiency, and Constraints among Maize Farmers in Zambia

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Abstract

Despite the potential productivity gains from using draft animals in African agriculture, evidence on the role of cattle rental markets in household production remains scarce. This study examines whether rental markets for draft cattle used in land preparation improve borrower productivity and promote efficient factor allocation, using household survey data from maize farmers in rural Zambia. The results show that cattle borrowers achieve approximately 47% lower maize yields than cattle owners, primarily due to greater production intensification among owners. In contrast, yield differences between borrowers and hand-hoe users are insignificant, suggesting frictions that inhibit efficient allocation. Consistent with this interpretation, less productive farmers are more likely to borrow cattle without payment, indicating that unpaid cattle borrowing serves as a form of social support within agrarian communities. Further analysis shows that both the allocative-efficiency benefits of paid rental and the social-support function of unpaid borrowing are concentrated among farmers located near the village center. Overall, the dual functions of informal cattle rental markets—promoting allocative efficiency and providing social support—are spatially constrained.

Keywords: animal draft power, factor markets, productivity, maize, Zambia
JEL Classification: O12, O13, Q12

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1. Introduction

Despite tremendous efforts to facilitate technology diffusion through extension services, crop yields in sub-Saharan Africa (SSA) remain low and have grown slowly. For example, the average maize yield in Africa is approximately 2.1 tons per hectare, well below the world average of 5.8 tons per hectare (FAO, 2024). One potential explanation for the stagnated yield growth SSA farmers face is their limited access to productive assets used for crop production (e.g., land, draft animals, and machinery), which constrains efficient farm production. As evidence, most farm operations are small-scale (Jayne et al., 2022), with an average farm size of 1.6 hectares per farm household (Lowder et al., 2019), excluding South Africa; family labor is the primary labor source, and mechanized farming remains limited in rural SSA.

One promising channel to overcome this barrier is procuring production factors through rental markets, allowing farmers to access them without bearing the full cost of ownership. The rich literature on land rental markets has theoretically argued that participation in rental markets can improve farmers' welfare through efficiency and equity gains (Deininger & Feder, 2001; Holden et al., 2008). Previous work has also provided empirical support for this theoretical claim (e.g., Jin & Deininger, 2009; Jin & Jayne, 2013; Chamberlin & Ricker-Gilbert, 2016). For example, Chamberlin and Ricker-Gilbert (2016) find that land rental markets in Malawi and Zambia enhance allocative efficiency by allowing more productive farmers to rent land from less productive farmers and reallocate land from relatively land-rich to land-poor households.

In addition to land assets, cattle are also an essential productive asset in many parts of rural SSA because of their use as draft power, as well as their other important roles in savings, self-insurance, and cultural values (e.g., as symbols of wealth, in bride prices, and in funeral rites).

Since cattle share many characteristics with land (i.e., both are productive assets whose ownership is often constrained by household endowments and liquidity constraints), cattle rental arrangements can improve allocative efficiency, as in land rental markets. In contrast, draft animals also have specific properties: First, there is a narrow window for optimal use, as land preparation must be completed within a short period at the onset of the rainy season, leading to substantially high search costs (Pingali, 1987). Second, cattle are fragile and valuable assets, and their rental imposes high monitoring costs to prevent misuse or damage (Binswanger & Rosenzweig, 1986). These distinctive features raise empirical questions about whether cattle rental markets generate efficiency gains and how such markets function. However, empirical examinations of the implications of rental markets for draft cattle remain scarce despite their importance in African agriculture.

This study investigates the productivity consequences of cattle rental arrangements, the role of informal cattle rental markets in promoting allocative efficiency, and potential constraints on access to these markets, using household survey data from approximately 600 maize farmers in Southern Province, Zambia. Southern Province provides a particularly relevant setting for this analysis because animal draft power has historically been prevalent, and cattle rental arrangements remain an important means for local farmers to access draft animals for land preparation during the early rainy season.

The analysis first compares maize yields across three land cultivation modes: ploughing with owned cattle, ploughing with borrowed cattle, and manual ploughing with hand hoes. Descriptive regression results show that cattle borrowers achieve approximately 47% lower maize yields than cattle owners. This seemingly counterintuitive ownership-based yield gap appears to be driven by greater production intensification among cattle owners: owners spend, on average, 55% more on maize seeds and apply 29% more top-dressing chemical fertilizers and 39% more manure to maize fields than borrowers. The analysis also tests the following two alternative explanations for the observed yield gap: (1) delayed planting resulting from reliance on cattle borrowing from thin rental markets, and (2) potential incentive problems arising from limited monitoring of borrowed cattle. The empirical results provide no evidence supporting either explanation. In contrast, maize yields do not differ significantly between cattle borrowers and farmers who prepare land manually using hand hoes. The absence of productivity gains from borrowing cattle suggests that the existing rental arrangements fail to allocate draft power efficiently. As a result, productive but asset-poor farmers may be unable to fully realize their yield potential because limited access to draft power leads to factor misallocation. In contrast, lower-productivity farmers may obtain access to draft cattle for reasons other than economic efficiency.

To test allocative efficiency directly, we estimate a maize production function with household fixed effects and use the estimated household fixed effects as a proxy for household-specific farming productivity. Consistent with the above interpretation, we find that less productive farmers are more likely to borrow cattle without payment, suggesting that some cattle rental arrangements are motivated less by efficiency considerations and more by redistribution or mutual support within agrarian communities. In contrast, we find no significant evidence that paid rental arrangements facilitate the efficient allocation of draft animals. Overall, observed empirical patterns suggest that while informal cattle rental markets do not necessarily generate economic benefits, unpaid cattle borrowing serves as a mutual aid institution for lower-productivity farmers.

Further analysis examines potential social and spatial constraints on access to local cattle rental markets that may contribute to factor misallocation. Cattle rental arrangements in the study context are geographically localized and often occur within kinship networks. To reflect these features, the empirical analysis uses the number of relatives in the village as a proxy for social connectedness and Mahalanobis distance as a measure of spatial proximity. Specifically, Mahalanobis distance captures a household's relative centrality within the village by measuring the adjusted distance from its homestead to the village's geographic centroid.

The results show heterogeneous patterns in the allocation of draft animals across proximities to the village's center. On one hand, cattle rental markets promote the efficient allocation of animal draft power among central households: relatively productive farmers are more likely to access borrowed cattle through paid rental when they live near the village center. On the other hand, such efficiency gains are not observed among peripheral households, indicating greater misallocation in access to draft power. Moreover, the social-support function of unpaid cattle borrowing is also concentrated among farmers located near the village center. This contrast suggests that physical access to potential lenders is crucial to the role of cattle rental arrangements. Overall, the dual functions of informal cattle rental markets—promoting allocative efficiency and providing social support—are spatially constrained.

This study makes three key contributions to the existing literature. First, it provides one of the first empirical analyses of rental markets for draft animals in rural SSA. A handful of previous studies examine the productivity gains from cattle ownership, the profitability of animal traction, and potential constraints on its utilization (e.g., Deininger & Olinto, 2000; Smith, 2008; and Sakala et al., 2021 for Zambia; Jaeger & Matlon, 1990; Savadogo et al., 1998; and Mugabe & Ferrara, 2026 for other SSA countries). However, empirical evidence on whether cattle rental arrangements promote allocative efficiency remains scarce. While land rental markets have been extensively studied (e.g., Jin & Jayne, 2013; Chamberlin & Ricker-Gilbert, 2016), this study examines draft-animal rental markets as an understudied setting in which rental arrangements can relax farmers' resource constraints in accessing productive assets. The results indicate efficiency gains among farmers who use paid rental arrangements, consistent with findings from the land rental literature. However, these gains are concentrated among farmers with relatively easy access to rental opportunities, as proxied by proximity to the village center, and are not observed among remote households. The central contribution of this study is to provide novel evidence on the role of cattle rental markets in promoting allocative efficiency and on the spatial heterogeneity of their market functions.

Second, this study contributes to the literature on redistributive norms and mutual assistance in rural African societies by highlighting productive-asset sharing as a form of informal support (Platteau, 2014). The extensive literature on consumption insurance examines the extent to which informal transfers function as risk-sharing mechanisms within close-knit village communities (e.g., Townsend, 1994; De Weerdt & Dercon, 2006). Another strand investigates informal labor-sharing institutions as a response to failures in rural labor markets (e.g., Mekonnen & Dorfman, 2017). Complementing a small body of research on the role of social networks in factor allocation (e.g., Krishnan & Sciubba, 2009; Beck et al., 2019), this study provides empirical evidence on how mutual assistance operates through the sharing of productive assets in general and draft power in particular. By distinguishing between unpaid borrowing and paid rental transactions, the analyses highlight how informal cattle rental alleviates constraints faced by disadvantaged households with lower agricultural productivity or greater spatial remoteness, thereby underpinning agriculture-based livelihoods in rural Africa, where egalitarian norms prevail. This study therefore provides direct evidence that cattle rental arrangements function as social support institutions, deepening our understanding of how factor rental arrangements operate in rural African settings.

Third, our empirical results speak to the literature on agricultural mechanization among SSA farmers by examining animal draft power as an intermediate stage between hand-hoe cultivation and tractor-based mechanization. Previous studies have shown that profitability, and thus the adoption of tillage methods, are closely linked to farming systems (Boserup, 1965) and to agroecological conditions such as climate and soil characteristics (Pingali et al., 1987), underscoring the importance of location-specific mechanization strategies (Daum & Birner, 2020). By quantifying yield gains from animal traction and examining the institutional and practical constraints of cattle rental arrangements, this study offers new insights into the transition of agricultural production systems. The empirical results suggest that smooth transitions towards mechanized farming are unlikely without accounting for the social value embedded in existing cattle rental arrangements, which help support agricultural livelihoods within the community.

The rest of this paper proceeds as follows. The next section reviews the role of cattle as draft power in agricultural production to motivate the subsequent empirical analysis. Section 3 describes the study settings and household survey data. Section 4 presents results on yield differences across cultivation methods and provides potential mechanisms underlying these yield gaps. Section 5 tests production-based explanations for the observed yield gaps. Using estimated household fixed effects from the production function estimates as a proxy for household-level productivity, Section 6 investigates efficiency gains from cattle rental arrangements and explores constraints on households' access to them. Section 7 concludes.

2. Cattle as a Source of Draft Power

2-1 Animal Draft Power in Agriculture

Land preparation is the first essential step in the agricultural production process, and ploughing must be completed within a very narrow operational window driven by the following timing trade-off (Ehui & Polson, 1993). On the one hand, farmers must wait for the first rains to soften soils that have hardened during the dry season in semi-arid and arid regions. On the other hand, because most rural SSA farming systems rely on rain-fed cultivation, ploughing must then be completed quickly after those early rains to avoid missing the relatively short planting window that provides a series of subsequent rains necessary for germination. More recently, conservation farming practices have promoted the use of ridges, requiring more careful management and further increasing the time demands needed for land preparation. Consequently, ploughing and related arrangements (e.g., securing draft animals) must be organized on time. Another important feature is that preparing large fields is physically demanding, and such work has traditionally been regarded as part of the male labor domain, shaping gender roles in the long run (Alesina et al., 2013).

Given these features of land preparation, the previous literature highlights three primary motivations for the transition from manual hoeing to animal-drawn ploughs: (1) potential gains in crop yields, (2) the expansion of cultivated land, and (3) labor savings (Pingali et al., 1987; Pingali, 2007). Building on this literature, this study examines the effects of cattle ploughing on three corresponding outcomes: yields per unit of land, cultivated area, and labor use.

Animal draft power is expected to generate yield gains by improving the quality of land preparation, for example, through deeper tillage that increases soil porosity or by enabling farmers to cultivate fertile but heavier soils (Pingali, 2007). However, previous studies provide mixed evidence on whether improvements in tillage quality translate into higher crop yields (e.g., Savadogo et al., 1998; Daum & Birner, 2020).

Relying on manual labor limits the size of land households can cultivate. However, animal draft power (or mechanization) can overcome such labor bottlenecks, enabling farmers to expand the area they cultivate. Although this depends on the availability of underutilized arable land in the region, empirical work reports land expansion effects (e.g., Pingali, 2007; Kirui, 2019; Daum, 2022). For example, Kirui (2019) reports that animal- and tractor-powered mechanization are associated with larger cropland per household by about 2.3 ha and 3.8 ha, respectively, compared to using hand-held tools, among Zimbabwean households. At the same time, the literature also emphasizes the reverse relationship, whereby farmers with larger cropland are more likely to adopt such technology (Kirui, 2019; Sakala et al., 2021). Nevertheless, this land expansion effect may be limited when subsequent tasks, such as weeding, are performed manually and create labor bottlenecks in later stages (Sims & Kienzle, 2006). Taken together, mechanization and operational farm size are closely interrelated, with each potentially reinforcing the other.

Animal draft power and mechanical tillage can also reduce drudgery and labor input per unit of land (Pingali et al., 1987; Sims & Kienzle, 2006). However, they may also increase total labor requirements due to the above land-expansion effects (Daum, 2022). As farmers expand their cultivated areas, labor demand for non-mechanized activities (e.g., weeding and harvesting) can rise accordingly (Pingali, 2007). In addition, the literature suggests that mechanical tillage may lead to greater use of modern inputs and improved crop management practices, thereby increasing labor requirements for other complementary tasks (Mano et al., 2020). Therefore, the net effect of adopting cattle ploughing on farm labor demand is theoretically ambiguous.

2-2 Cattle Rental Markets

As in other production activities, the use of physical capital is crucial in agricultural production. Leading examples of capital used in farming include land, draft animals, and machinery (e.g., tractors and combine harvesters). Limited access to these production factors is a fundamental constraint on efficient farm management. In this context, rental markets for productive assets can improve household welfare among non-owning households through two channels. First, rental transactions reallocate productive capital to more efficient users, allowing high-productivity farmers to use more factor inputs; this channel generates efficiency gains. Second, beyond these efficiency gains, rental markets may also mitigate asset inequality by enabling asset-rich households to rent out surplus capital to asset-poor households, thereby generating equity gains.

The extent to which rental markets deliver these theoretically expected efficiency and equity gains depends on how they function and on contextual factors, making this an important empirical question. Recent studies have reported substantial factor misallocation in African agriculture—situations in which the allocation of factors (e.g., land, capital, labor, and variable inputs) deviates from the allocation that would maximize the aggregate output. Prior work often attributes these misallocations to inactive factor transactions or restricted access to rental markets (Chen et al., 2023; Acampora et al., 2025). In particular, a large body of empirical research has examined whether participation in land rental markets generates efficiency and equity gains (e.g., Deininger & Feder, 2001; Holden et al., 2008; Jin & Jayne, 2013). For example, Jin and Jayne (2013) find that land markets promote farm productivity and significantly raise the incomes of land-constrained farmers in Kenya.

These arguments can also extend to cattle rental markets, as cattle share important characteristics with land in agricultural settings: both are productive assets whose ownership is often constrained by household endowments and liquidity constraints. Specifically, cattle rental arrangements can improve efficiency by enabling productive farmers who lack cattle to access animal traction. Additionally, by relaxing constraints on cattle ownership, rental markets may promote more equitable access to animal draft power among small-scale farmers.

However, cattle rental markets may face two constraints inherent to draft animals: a narrow window for optimal use and high monitoring costs. First, the potential productivity gains from rental-based access to draft power may be limited by the short land preparation period (Pingali, 1987). This timing constraint is particularly salient in semi-arid and arid regions of SSA. In such environments, farmers must wait for the first onset of rain to begin ploughing because soils remain too hard during the dry season, yet delayed sowing can lead to substantial yield losses. This trade-off creates a very narrow operational window for draft power.

Second, cattle are relatively fragile productive assets, and their rental requires close monitoring to prevent misuse or damage (Binswanger & Rosenzweig, 1986). Consequently, cattle owners may be willing to rent out their animals only to farmers whom they trust, making it difficult for potential borrowers to find owners willing to provide rental services. Compared with land or other relatively durable capital assets, these search and monitoring requirements raise the transaction costs associated with cattle rental. Given these characteristics, cattle rental arrangements may be geographically localized and depend heavily on social relationships within village communities. As a result, productive farmers with limited social connectedness may face greater difficulty accessing cattle rental markets, potentially exacerbating factor misallocation.

These distinctive features raise important empirical questions about whether participation in cattle rental markets generates efficiency gains and how household characteristics, including social connectedness and spatial remoteness shape access to these markets. This study addresses these outstanding questions as a central contribution.

3. Settings

3-1 Study Site

The data used for the subsequent analysis come from Sinazongwe district in Southern Province, Zambia. This region is prone to droughts, with annual average rainfall below 800 mm (Ministry of Agriculture and Ministry of Fisheries and Livestock (Zambia), 2016), and it exhibits the highest rainfall variability in the country (Okamura et al., 2025). The main agricultural cycle is a single rainy season between November and April. Irrigation is unavailable, except at a few sites near Lake Kariba; most farm households in the region depend on rain-fed maize cultivation for subsistence, making their agricultural production highly sensitive to rainfall variability.

Southern Zambia has a long history of cattle keeping for farming operations (Mwenya et al., 1994), providing an exceptional context for studying animal draft power.[1] Specifically, Gwembe Tonga, people living in the valley areas in Southern Province (including the study site), began raising cattle following their forced relocation due to the dam construction in Lake Kariba (Okamoto, 2009; Ito, 2015). Crossbreeding between indigenous and exotic cattle breeds has occurred, and humped cattle are commonly observed in the study area.

Despite the historical importance of cattle ploughing, not all households own cattle because they are costly to acquire. Manual ploughing with hand hoes remains the traditional method of land preparation, but it is highly labor-intensive and time-consuming. Given the substantial labor requirements and the narrow time window for land preparation, ploughing with cattle can provide an important labor-saving technology.[2] Thus, despite limited cattle ownership, cattle

[1] This stands in sharp contrast to many other SSA regions, where cattle rearing has historically been constrained by trypanosomiasis (Alsan, 2015).

[2] At the time of the survey, mechanized tillage was rarely seen in the study area.

ploughing is widespread through informal cattle rental arrangements. In Southern Province, local farmers typically use a pair of oxen for ploughing, although cows are also sometimes used despite their lower pulling power. Farmers without a pair can borrow oxen from neighbors within the same community, usually in exchange for payment, although some arrangements are made without payment. Farmers who own only one ox may also rent an additional ox to form a working pair. Nevertheless, despite the prevalence of these informal cattle rental arrangements, location-specific evidence on the productivity implications of borrowing oxen remains scarce.

3-2 Data

This study uses household survey data collected as part of a research project on sorghum cultivation in Sinazongwe district. The project used enumeration areas (EAs) from the national 2010 Census of Population and Housing by the Zambia Statistics Agency (ZamStats) as the sampling frame.[3] The project first identified five target wards from the eight wards in the district where sorghum was reported to be grown according to the 2021 Crop Forecast Survey conducted by ZamStats. These five wards contained 98 EAs in total. Although sorghum is cultivated in these areas, most households also cultivate maize, generally on larger areas than those devoted to sorghum. The sample was stratified by sorghum-growing status, after which EAs were randomly selected within each stratum. In total, 12 target EAs were selected for the survey.

Data collection started with a village census survey. Conducted in April 2022 in collaboration with ZamStats, the census targeted all the households residing in the 12 selected EAs at the time of the survey. As a result, the survey team covered 55 villages and interviewed 999

[3] For the population census, ZamStats defined and demarcated EAs so that each EA contained 60-120 households in rural areas.

households. The census recorded the geographic location of dwellings using GPS coordinates and collected information on village social networks for each household, providing essential data for the analyses presented in Section 7.

After the census, the project conducted three rounds of household panel surveys in September 2022, July 2023, and August 2024, following up with the original 999 households. The survey questionnaire collected detailed socioeconomic information on agricultural production, economic activities, asset ownership, and demographics.

To analyze the production consequences of using cattle for ploughing, this study primarily uses data from the 2023 round, which collected information on agricultural practices during the 2022/23 rainy season, as the 2022 survey lacks key information on land preparation and the 2024 survey reflects unusual harvest conditions following a historically severe drought during the 2023/24 rainy season. For context, total rainfall at the Choma meteorological station, the closest weather station to our study sites, during the rainy season from November to April was 443.6, 744.9, and 392.3 mm in the 2021/22, 2022/23, and 2023/24 rainy seasons, respectively. Over the 35 agricultural years from 1989/90 to 2023/24, the average rainy-season rainfall at the station was 696.3 mm, with a standard deviation of 215.5 mm. Thus, the 2022/23 season experienced relatively normal rainfall conditions, making the 2023 survey round particularly suitable for examining the relationship between ploughing methods and agricultural outcomes.

The 2023 survey successfully collected information from 846 households across 53 villages.[4]

[4] After randomly dividing the sample into two groups, the project distributed 2.5 kg of either red or white sorghum seeds to each household, with 406 households receiving red seeds and 440 receiving white seeds. The amount of seed distributed was sufficient to cover approximately 0.25 hectares. Thus, maize production in the survey year may have been affected by the sorghum seed intervention and may not fully reflect households' usual production practices. However, because sorghum varieties were assigned randomly, this should not systematically influence

The sample is further restricted to households with maize yields of 5 tons/ha or less to exclude outliers, and to those that planted maize between November 1, 2022 and January 31, 2023. After applying these sample restrictions, the analytical sample consists of 601 maize-farming households.

We classify cultivation methods into three categories: (1) animal traction using the household's own cattle (Own Cattle), (2) animal traction using cattle borrowed from villagers (Borrowed Cattle), and (3) manual ploughing using hand hoes (Handhoe). Cultivation methods are recorded at the plot level and then aggregated to the household level. When a household cultivates multiple plots using different cultivation methods, we classify the household according to the following priority rule: Own Cattle takes precedence over Borrowed Cattle, which in turn takes precedence over Handhoe.

[Table 1]

Table 1 reports descriptive statistics by cultivation method employed during the 2022/23 rainy season. As shown in Table 1, households that use their own cattle for ploughing achieve the highest maize harvests, while their operational cultivated areas are comparable to those of households that manually prepare their fields using hand tools. In contrast, households using borrowed cattle have, on average, the lowest levels of productive assets and the smallest operational cultivated areas.

farmers' decisions regarding maize production, including their choice of ploughing method. Thus, the intervention is unlikely to introduce systematic bias into our analysis of maize production and ploughing methods.

4. Does Cattle Rental Improve Agricultural Productivity?

4-1 Specification

This subsection outlines the empirical specification used to examine the relationship between cultivation methods and three agricultural outcomes: maize yields, family labor input for land preparation, and cultivated area. We estimate the following regression equation using OLS:

$$y_{\mathrm{i}} = \beta_0 + \beta_1 Owned_i + \beta_2 Borrowed_i + \boldsymbol{\beta_3 W_i} + \beta_4 EA_i + u_i \qquad (1)$$

where subscript i represents households. $Owned_i$ and $Borrowed_i$ are binary indicators for whether household i uses its own cattle or borrowed cattle as draft power, respectively.[5] $\boldsymbol{W_i}$ denotes a vector of household-level controls (e.g., asset holdings and household heads' characteristics including age and years of education), EA_i is the dummy for the enumeration area to which household i belongs, and u_i is an error term. We use information on household assets and livestock from the 2022 survey round to capture households' economic conditions prior to the start of the 2022/23 rainy season. To examine whether ploughing with borrowed cattle yields different outcomes from ploughing with owned cattle, we conduct a Wald test of the null hypothesis $\beta_1 - \beta_2 = 0$. Standard errors are clustered at the village level. Appendix Table A1 reports descriptive statistics for all variables used in the regression analysis.

4-2 Results

[Table 2]

Table 2 shows the regression results on agricultural outcomes associated with using cattle for land preparation.[6] The coefficient differences between owned cattle and borrowed cattle

[5] Unlike the grouping used in Table 1, we assign all the cultivation methods to the household for this regression analysis when a household cultivates multiple plots using different cultivation methods. For example, if a household uses borrowed cattle on one plot and hand hoes on another, the household is included in both the Borrow Cattle and Handhoe categories.

[6] Of the 601 maize-farming households, 4 observations are dropped because the households were not surveyed in

dummies, along with their statistical test results, are also reported at the bottom of the table.

The specification in Column 1 compares log-transformed maize yields across different land preparation methods: manual ploughing with hand hoes, animal traction with owned cattle, and animal traction with borrowed cattle. Manual ploughing with hand hoes is the omitted reference category. The results show that households using owned oxen achieve significantly higher yields, with yields approximately 58% higher than those of households relying on hand hoeing. In contrast, households using borrowed cattle do not exhibit a significant yield difference compared to households using hand hoes, despite the technical advantage of animal traction. Moreover, the coefficient on owned cattle is significantly larger than that on borrowed cattle. Specifically, cattle owners achieve approximately 47% higher maize yields than borrowers.

Column 2 reports regression results for the amount of family labor input per unit of land devoted to land preparation activities, including planting. Results show no significant differences in hours spent on land preparation activities across cultivation methods, suggesting no detectable labor-saving effects of animal traction. One possible explanation is that labor force endowments, reflected by household composition, constrain labor-saving effects. However, even when the interaction terms between cultivation methods and the number of adult family workers are included, results still detect no labor-saving effects (Appendix Table A3). Instead, households using owned cattle for ploughing—the household type with the fewest constraints on cattle use—spend more family labor on land preparation activities as the number of adults increases. This empirical pattern may suggest binding labor shortages in the study area.

the 2022 survey round and therefore lack information on household assets. An additional 2 observations are dropped due to missing information on household heads' education. The resulting analysis sample consists of 595 households.

The specification in Column 3 examines maize cultivated area across the three cultivation methods. The regression results show no significant differences, suggesting no land-expansion effects associated with animal traction. Additional regressions using non-maize cultivated land, total cultivated land, and fallow land size reveal similar null results (Appendix Table A4). Rather, households using borrowed cattle cultivate less land than households using hand hoes for land preparation. These findings suggest that land expansion through cattle ploughing is limited in our research context, potentially due to labor constraints despite the relative abundance of land resources.

Overall, the empirical findings do not support the theoretically plausible benefits of animal traction: borrowers' maize yields neither catch up with those of owners nor exceed those of hand-hoe users. The following subsection proposes four possible explanations for the absence of productivity gains from animal traction.

4-3 Explaining No Productivity Gains from Animal Traction

Why do only the cattle owners achieve substantially higher yields, even though borrowers use the same traction technology for land preparation? The following four provide possible constraints faced by cattle borrowers that may explain the observed productivity gap by cattle ownership: (1) insufficient use of farm inputs, (2) suboptimal timing of land preparation, (3) incentive and management problems in cattle rental, and (4) misallocation of cattle assets via existing cattle rental arrangements. This subsection explains each in detail.

4-3-1 Insufficient Use of Farm Inputs

Cattle borrowers may struggle to obtain productivity-enhancing farm inputs. In the study area, the land preparation period coincides with a time when households face low cash inflows due to limited cash-earning opportunities and high cash demands to buy back maize as food stocks decline (Miura & Sakurai, 2021). In addition to such seasonal liquidity constraints, payments for cattle rental may further tighten borrowers' budgets and crowd out expenditure on agricultural inputs (e.g., seeds, fertilizers, and weed killers). Moreover, manure is a byproduct of cattle ownership, making access to manure inherently different across households: owners can freely use manure from their own herds, whereas non-owners must purchase it or obtain it through alternative means. Such underinvestment in productivity-enhancing agricultural inputs among cattle borrowers may explain the lack of productivity gains from animal traction.

4-3-2 Suboptimal Timing of Land Preparation

As the second possibility, borrowers may struggle to complete land preparation at the agronomically optimal time while waiting for access to rented cattle, potentially resulting in substantial yield losses compared with cattle owners (Smith, 2008). Demand for cattle rental services is likely to be concentrated within a relatively narrow window if the optimal timing of land preparation is similar across farmers in the same area. In practice, however, cattle owners generally rent out their animals only after completing tillage on their own fields (Deininger & Olinto, 2000). This sequential pattern of cattle use may therefore create a mismatch between the timing of borrowers' demand and the availability of rented cattle, despite the synchronous demand for rental services. As a result, borrowers may face delays in land preparation and consequently plant later than cattle owners. Given the inherently sequential nature of agricultural production, timely completion of each task is crucial for achieving potential yields, particularly in African farming systems where most production is rain-fed. Supporting this argument, agricultural trials conducted in the same study area demonstrate significant yield gains from timely planting in maize production (Shimono et al., 2012). Thus, delays in land preparation, and consequently in planting, provide another plausible explanation for the absence of yield gains among cattle borrowers.

4-3-3 Incentive and Management Problems in Cattle Rental

Land preparation using borrowed cattle may be less effective than using owned cattle due to incentive and management problems. Depending on the arrangement between owners and borrowers, either party may serve as the driver. However, incentive problems arise in both cases. When the owner acts as the driver, he becomes a hired laborer, and his effort provision may be suboptimal because payment is typically not tied to performance or work quality (Binswanger & Rosenzweig, 1986). In addition to such traditional moral hazard issues, even when the borrower operates the cattle, productivity may still be compromised because the borrower lacks the experience or skill necessary to handle the animals efficiently, preventing the cattle from reaching their full working potential.

4-3-4 Misallocation of Cattle via Rental Arrangements

As a final possible explanation, high transaction costs and frictions in cattle rental markets may hinder smooth rental arrangements and exclude productive farmers from borrowing cattle, leading to misallocation of draft power within the community. As discussed in Section 2-2, borrowers face substantial transaction costs because of the narrow and uncertain time window for ploughing and the need to supervise animals during land preparation. These frictions may incentivize cattle owners to preferentially rent to relatives or close acquaintances—who are not necessarily the most productive farmers—thereby generating allocative inefficiencies. Moreover, rental arrangements may not always be based on economic rationale. In many cases, as in labor exchange, cattle rental can serve as a form of mutual assistance, enabling vulnerable households (e.g., widows, widowers, and elderly farmers) to access draft power at affordable rates or even free of charge. Field observations also support this view. Thus, the inefficient allocation of draft power—driven by high transaction costs and the social functioning of cattle rental—may help explain the puzzling absence of productivity gains from animal traction.

The next two sections test the empirical validity of these four explanations. Section 5 examines the first three production-related explanations, and Section 6 investigates the remaining rental market-based explanation.

5. Testing Production-Based Explanations for Yield Gap

5-1 Insufficient Use of Farm Inputs

5-1-1 Specification

To understand the mechanisms behind the yield advantage of using owned cattle over other tillage methods, this section examines whether cattle owners apply more farm inputs—seeds, fertilizer, and manure—beyond animal traction. We also examine differences in participation in agricultural cooperatives and national input subsidy programs, which help farmers access subsidized modern inputs, across three cultivation methods.

Regarding fertilizer use, the analysis focuses on Compound D and urea, which are widely used in maize production in Zambia. Compound D is a basal fertilizer containing 10% nitrogen and 20% phosphoric acid, typically applied at planting. Urea is a top-dressing fertilizer containing 46% nitrogen and is usually applied three to four weeks after planting.

The national input subsidy program, commonly known as the Farmer Input Support Programme (FISP), aims to improve small-scale farmers' access to agricultural inputs at subsidized prices and thus enhance their productivity. Under the program, participating farmers receive hybrid maize seeds and chemical fertilizers, including Compound D and urea. Participation requires membership in an agricultural cooperative and a cash contribution of 400 ZMW.[7] Agricultural cooperatives also typically charge membership fees. Thus, participation in FISP entails both cooperative membership and an upfront cash contribution, which may pose a substantial barrier for poorer households. If cattle borrowers are more likely to face these financial constraints, their limited access to subsidized inputs could help explain the observed productivity gap.

The empirical analysis tests whether the observed yield advantage of cattle owners is associated with greater input intensification by replacing the outcome variable in Equation (1) with household-level agricultural investments in inputs (e.g., the value of maize seeds planted in monetary terms and the quantity of fertilizer applied in kilograms). In contrast to the previous specification, these regressions for inputs additionally control for FISP participation and cooperative membership to capture household-level access to modern inputs. The analysis also estimates the same specification using indicators of FISP participation and cooperative membership as dependent variables to test whether borrowing cattle constrains households' ability to finance the fees required for FISP participation.

5-1-2 Results

[Table 3]

Table 3 reports the regression results for differences in input use across three cultivation methods. Column 1 uses log-transformed seed expenditure as the outcome, which may reflect investment in hybrid seeds. Columns 2-4 use log-transformed quantities of Compound D, urea, and manure in kilograms as the outcome variables, respectively. Columns 5 and 6 present OLS regression results for cooperative membership and FISP participation.

[7] At the time of the 2023 survey in July 2023, 100 ZMW = 5.4 USD.

The estimated coefficient on the own-cattle dummy is significantly positive across all specifications except Column 6. Notably, cattle owners spend 60% more on seeds (Column 1), use almost twice as much fertilizer as farmers who use hand hoes (Columns 2 and 3), and apply 69% more manure (Column 4) than those using hand hoes. These results indicate substantially greater investments in intermediate inputs among cattle owners. Cattle owners are 17.9 percentage points more likely to participate in agricultural cooperatives than hand-hoe users (Column 5). However, we find no statistical differences in FISP participation (Column 6).

The row testing the null hypothesis $\beta_1 - \beta_2 = 0$ further indicates that cattle owners use significantly more farm inputs, especially seeds, urea, and manure, than cattle borrowers. Although cattle borrowers tend to use more variable inputs, particularly soil-fertility-enhancing inputs such as manure, than hand-hoe users, their input use remains substantially lower than that of cattle owners, placing them between the two groups.

Taken together, these results indicate that households using their own cattle apply more farm inputs. Combined with the absence of a significant difference in cultivated land size across cultivation methods (Column 3 in Table 2), these findings suggest that cattle owners practice more input-intensive production. This result is consistent with the existing literature showing that draft power can improve the profitability of fertilizer application (Xu et al., 2009) and that mechanized land preparation can complement input- and labor-intensive production systems in SSA (Takeshima et al., 2013; Mano et al., 2020; Otsuka, 2024). Although these previous studies primarily focus on tractor use, animal traction is also a form of mechanization (Pingali et al., 1987), suggesting that similar complementarities may operate in production systems relying on draft animals.

5-2 Suboptimal Timing of Land Preparation

5-2-1 Specification

This subsection examines planting timing across cultivation methods to test whether cattle rental delays planting, thereby preventing cattle borrowers from achieving potential yields. The survey questionnaire asked about the planting dates for maize seeds for each plot.[8] Under the assumption that households that use their own cattle face minimal constraints in land preparation and thus can freely choose the planting time, the optimal date is defined as the median planting date (December 24th, 2022) among these households.[9]

We use the deviation from this optimal planting date as the outcome for this exercise. Specifically, the dependent variable $Planting_{jit}$ represents the number of days between the actual planting date and December 24th, with positive values indicating later planting and negative values indicating earlier planting. This outcome is compared among (1) households that use their own cattle, (2) households that borrow cattle, and (3) households that use hand hoes for ploughing. Appendix Figure A1 shows the distribution of maize planting dates by cultivation method.

We model the deviation from the optimal planting date as follows:

$$Planting_{ji} = \beta_1 Own_{ji} + \beta_2 Borrow_{ji} + \boldsymbol{\beta_3 W_i} + \boldsymbol{\beta_4 X_{ji}} + \beta_5 EA_i + \varepsilon_{ji} \tag{2}$$

where subscript j and i represents plots and households. Own_{ji} and $Borrow_{ji}$ are binary indicators for whether household i uses owned or borrowed cattle as draft power in the plot j, respectively. $\boldsymbol{W_i}$ is a vector of household-level controls (e.g., asset levels and head characteristics). $\boldsymbol{X_{ji}}$ is a vector of plot-level controls, such as plot size, a series of dummies for

[8] Unfortunately, the direct information on the timing of land preparation is unavailable. Planting date is the most relevant observable outcome of land preparation timing.

[9] The median date is used to minimize the influence of outliers.

topological positions, and distance from the homestead to the plot. ε_{ji} is an error term. Descriptive statistics for plot-level variables used in the regression are reported in Appendix Table A2.

5-2-2 Results

[Table 4]

Column 1 of Table 4 reports the regression results for the "distance" from the defined optimal planting date. The results show no systematic differences in planting timing across cultivation methods, suggesting that planting delays due to cattle rental may not explain the observed yield gaps across cultivation methods.

5-3 Incentive and Management Problems in Cattle Rental

5-3-1 Specification

We next examine whether incentive and management problems—particularly insufficient effort provision by borrowers or hired drivers—contribute to the lower productivity of borrowed cattle. Directly testing these mechanisms is empirically challenging because neither workers' effort nor the productivity of draft animals is observable. Instead, we adopt an indirect approach by exploiting variation in the distance between households' homesteads and plots. Plot distance serves as a proxy for monitoring costs, as supervising land preparation is more difficult on more distant fields. Under imperfect monitoring, hired drivers have weaker incentives to exert effort, potentially reducing the effectiveness of ploughing with borrowed cattle.

The central hypothesis is that, if monitoring constraints are salient, the negative effect of plot distance on yields should be more pronounced for plots cultivated using borrowed cattle than for those cultivated using owned cattle. To test this hypothesis, the regression equation uses log-transformed maize yield as the outcome variable. Explanatory variables now include interaction terms between plot distance (denoted by $Dist_{ji}$) and dummies for owned and borrowed cattle using plot-level data. Formally, the empirical specification is:

$$Yield_{ji} = \beta_1 Owned_{ji} + \beta_2 Borrowed_{ji} + \beta_3 Dist_{ji} + \beta_4 Owned_{ji} \times Dist_{ji} + \beta_5 Borrowed_{ji} \times Dist_{ji} + \boldsymbol{\beta_6 W_i} + \boldsymbol{\beta_7 X_{ji}} + \beta_8 EA_i + v_{ji} \quad (3)$$

where subscript i represents household and subscript j denotes plot. v_{ji} is the error term, and standard errors are clustered at the household level. The regression is estimated for plots on which maize was cultivated during the 2022/23 rainy season. Under the monitoring hypothesis, the coefficient on the interaction term between plot distance and borrowed cattle, β_5, is expected to be negative, indicating that maize yields decline more steeply with distance when using borrowed cattle for land preparation.

5-3-2 Results

Before showing the regression results of Equation (3), we first test whether plot locations systematically differ by cultivation method (Column 2). Empirical results show no systematic differences in plot distance across cultivation methods, indicating that cattle borrowers do not use rented cattle on closer plots to mitigate monitoring problems.

While Column 3 presents regression results for plot-level yield differences by cultivation method without interaction terms, the main specification in Column 4 corresponding to Equation (3) introduces interaction terms between plot distance and cultivation methods. As shown, the results do not support the monitoring hypothesis: the coefficient on the interaction term between plot distance and the dummy for using borrowed cattle is statistically insignificant, suggesting that plot distance does not differentially reduce maize yields for plots cultivated with borrowed cattle.

Overall, the analysis provides no prima facie evidence that distance-related monitoring constraints disproportionately reduce the productivity of borrowed cattle. These findings suggest that monitoring costs are also unlikely to be a primary mechanism underlying the observed yield gap between cattle owners and borrowers.

6. Testing Allocative Efficiency through Cattle Rental Arrangements

As discussed in Subsection 4-3, the absence of significant yield differences between cattle borrowers and hand hoe users may reflect the misallocation of draft power through existing cattle rental arrangements. Such misallocation would arise if productive non-owners cannot borrow draft animals while less productive farmers gain access to them. This section examines whether such misallocation occurs through informal cattle rental arrangements in the study area and, if so, identifies the constraints that hinder the efficient allocation of draft power among local farmers.

To do this, this section proceeds in three steps. First, we estimate a maize production function using panel data from the three survey waves and recover household fixed effects as a proxy for household-specific productivity. Second, we link the estimated productivity measures to participation in informal cattle rental arrangements to test whether the rental market allocates draft power according to farmers' productivity. The empirical pattern indicates evidence of misallocation. Accordingly, the final step explores potential sources of misallocation by examining the role of social and spatial networks, which may raise transaction costs associated with search, coordination, and monitoring, in informal cattle rental arrangements.

6-1 Empirical Strategy

6-1-1 Measuring Household-Level Agricultural Productivity

Following Mundlak (1961) and Jin and Jayne (2013), household-specific farming productivity is proxied by the estimated household fixed effects recovered from a production function. In particular, we model the maize production function in the Cobb-Douglas form:

$$lnQ_{jit} = \alpha_i + \beta_1 \ln A_{jit} + \beta_2 \ln L_{jit} + \beta_3 lnK_{it} + D_t + \epsilon_{jit} \tag{4}$$

where Q_{jit}, A_{jit}, and L_{jit} denote the maize harvest quantity, total maize cultivated area, and family labor of household i on plot j in year t, respectively. K_{it} represents the value of productive assets of household i in year t. All variables are log-transformed. The coefficient α_i captures the time-invariant household fixed effect and serves as the proxy for household-level farming productivity. D_t denotes year fixed effects to account for aggregate climate shocks.

In contrast to Jin and Jayne (2013), intermediate inputs such as fertilizer are excluded from the current specification. Because the use of modern inputs reflects managerial ability or underlying farm productivity, controlling for these inputs could introduce bad controls by conditioning on potential mediators and thereby underestimating household-specific productivity terms. We estimate equation (4) using the three rounds of panel data collected between 2022 and 2024. Standard errors are clustered at the household level. Table 5 reports summary statistics for the variables used in this analysis.

[Table 5]

6-1-2 Testing the Misallocation of Draft Power

The analysis then examines the allocative efficiency of draft power through rental arrangements by linking the productivity estimates from the first step to household participation in cattle rental markets. To do so, the subsequent analysis distinguishes between two types of cattle rental arrangements—rentals involving payment and those provided free of charge—because they likely reflect different underlying mechanisms. Field observations indicate that unpaid borrowing typically occurs among relatives or among vulnerable households (e.g., elderly- or widow-headed), functioning as a form of mutual assistance.

The outcome variable is a categorical measure of access to rented cattle ($Choice$). The choice set consists of: (1) using hand hoes for ploughing, (2) unpaid cattle borrowing, and (3) paid cattle rental. When a household cultivates multiple plots using different cultivation methods, we classify the household according to the following priority rule to ensure mutually exclusive categories: unpaid cattle borrowing takes precedence over paid cattle rental, which in turn takes precedence over hand hoes. Because households select one mutually exclusive cultivation option, the empirical specification adopts a multinomial logit framework to examine how household-level productivity is associated with participation in cattle rental. The model is specified as follows:

$$Pr_i(Choice = j) = \frac{\exp \eta_i^j}{\sum_{k=1}^{3} \exp \eta_i^k}$$

$$\eta_i^k = \beta_0 + \beta_1 \widehat{HHFE_i} + \boldsymbol{\gamma_4 W_i} + \gamma_5 EA_i + v_i \tag{5}$$

where the subscript i denotes household. $\widehat{HHFE_i}$ represents the standardized household fixed-effect from the production function estimates. As in the previous regression model, $\boldsymbol{W_i}$ is a vector of the same set of household controls and EA_i is an enumeration-area dummy. v_i is an error term. Standard errors are clustered at the village level. We apply the multinomial logit model to households' participation in cattle rental arrangements during the 2022/23 rainy season. Because cattle-owning households rarely borrow draft animals, we exclude households that use their own cattle for ploughing during the 2022/23 rainy season from the analysis sample.

6-1-3 Social and Spatial Proximity as Constraints on Rental Market

The final analysis examines the constraints on access to cattle rental. We hypothesize that access to cattle rental markets depends not only on a household's economic status but also on its embeddedness in social and spatial networks. Social ties (e.g., kinship) may foster trust and facilitate informal lending arrangements. Geographic proximity may reduce transaction costs, improve information flows, and enable more efficient coordination, particularly because cattle are typically kept near homesteads and are costly to move over long distances. Motivated by these considerations, the empirical analysis investigates the role of social and spatial factors in shaping household access to cattle rental markets.

To capture spatial proximity, we use Mahalanobis distance as an indicator of a household's relative centrality within the village. Mahalanobis distance adjusts a household's distance from the village's centroid by considering the spatial distribution of neighbors' locations. A higher Mahalanobis distance indicates a greater peripheral location within the village. We calculate this measure separately for each village using the 2022 census data. In doing so, we restrict the analysis sample to 12 villages with at least 30 households to ensure sufficient within-village variation. In contrast, we use the number of relatives living in the same village as a proxy for social connectedness.

By incorporating proxies for social and spatial networks into the previous specification about the choice of cattle borrowing in Equation (5), we modify the model as:

$$Pr_i(Choice = j) = \frac{\exp \eta_i^j}{\sum_{k=1}^{3} \exp \eta_i^k}$$

$$\eta_i^k = \gamma_0 + \gamma_1 SpacialNet_i + \gamma_2 SocialNet_i + \gamma_3\, \widehat{HHFE_i} + \boldsymbol{\gamma_4 W_i} + \gamma_5 EA_i + v_i \qquad (6)$$

The key explanatory variables are the Mahalanobis distance ($SpatialNet_i$) as a proxy for spatial remoteness and the number of relatives within the same village ($SocialNet_i$) as a proxy for ties to social networks. The Mahalanobis distance ($SpatialNet_i$) is standardized at the village level. Access to cattle rental continues to refer to the 2022/23 rainy season. We restrict the analysis sample to households in the 12 villages with at least 30 households at the time of the village census in April 2022. As in the preceding analysis, we exclude households that used their own cattle for ploughing during the 2022/23 rainy season.

To further examine the implications of spatial remoteness and associated transaction costs in cattle rental arrangements, the additional analyses split the sample by Mahalanobis distance and re-estimate the same regression. Specifically, the analysis sample is divided into two groups: households located closer to the village centroid (Mahalanobis distance < 0) and those located farther from the village centroid (Mahalanobis distance ≥ 0). Since the Mahalanobis distance is standardized for each village, zero corresponds to the village-average location.

6-2 Results

6-2-1 Household-level Farm Productivity

[Table 6]

Table 6 reports the estimation results for the Cobb-Douglas production function used to recover household-level farm productivity. For comparison, Column 1 shows the results from OLS estimation, including village dummies and their interactions with year dummies. Column 2 presents the results from a fixed effects model with household fixed effects, year fixed effects, and the interaction between year and village fixed effects.

In Column 1, most coefficients, except for family labor, are statistically significant at the 5% level or higher. The insignificance of family labor may be explained by small variations in the number of adult members across households. This limited across-household variation reduces the precision of the estimated coefficient on family labor. In addition, the number of adult household members may be a noisy proxy for effective labor input because it does not capture actual time allocation or effort, attenuating the estimated coefficient in the OLS specification.

In Column 2, the fixed-effect estimates show results qualitatively similar to OLS estimates. The results indicate that a 1% increase in cultivated areas is associated with a 0.58% increase in total harvest. In comparison, a 1% increase in productive asset value is associated with a 0.084% increase in the outcome. The relatively large coefficient on land and the smaller coefficient on assets are consistent with previous findings in the literature; for example, Jin and Jayne (2013) report coefficients of 0.499 and 0.046, respectively. In contrast, the coefficient on family labor is significantly negative. This result may reflect limited within-household variation in the number of adult family workers over time, which is largely absorbed by household fixed effects.

6-2-2 Misallocation of Draft Power

[Table 7]

The analysis turns to examining whether misallocation of draft power exists in the cattle rental market, namely, whether informal rental arrangements efficiently allocate rented cattle to more productive farmers. Table 7 reports the average marginal effects for the choices of using hand hoes (Column 1), borrowing cattle without payment (Column 2), and borrowing cattle with payment (Column 3) from a multinomial logit model, with estimated household fixed effects as the key explanatory variable. If the rental markets function efficiently, a positive association between farming productivity and the probability of borrowing cattle would be expected.

The regression results show negative or insignificant associations between household farming productivity and participation in cattle rental arrangements. Thus, this empirical pattern indicates the misallocation of draft animals in the study context. Column 2 indicates that less productive farmers are more likely to borrow cattle at no cost. Specifically, a one standard deviation increase in farming productivity reduces the probability of unpaid cattle borrowing by 5.2 percentage points. While free borrowing often reflects strong mutual aid characteristics, the absence of a positive correlation between farming productivity and rental activities—including those involving monetary exchange—suggests that informal cattle rental markets may operate largely independently of borrowers' managerial capabilities. Given the evidence of allocative inefficiency, the inefficient allocation of draft power through the current rental arrangements may help explain the observed yield gap across cultivation methods documented in Section 4.

6-2-3 Social and Spatial Proximity as Constraints on Rental Market

[Table 8]

Finally, we examine the factors underlying misallocation in cattle rental markets. The hypothesis is that social and spatial networks are key mechanisms shaping access to rented draft power. Table 8 presents the average marginal effects from the multinomial logit model estimation, examining how social connectedness and spatial proximity are associated with each borrowing choice. Columns 1–3 report the regression results for the full sample, Columns 4–6 for households with negative Mahalanobis distance (hereafter, central households), and Columns 7–9 for those with non-negative Mahalanobis distance (peripheral households). The sample is thus divided by households' spatial positions within the village to explore heterogeneity in the role of informal cattle rental markets by spatial remoteness. Since the Mahalanobis distance is standardized for each village, negative values indicate households located closer to the village geographic centroid than the village average. In contrast, non-negative values indicate households located farther from the centroid.

Estimation results from the full sample in Columns 1-3 show that the Mahalanobis distance is significantly positively associated with the probability of borrowing cattle without payment, suggesting that the social-support function of unpaid cattle borrowing is concentrated among households with spatial disadvantages. Consistent with the previous results, less productive farmers are more likely to borrow cattle without payment. The average marginal effect of our proxy for household-specific productivity is comparable in magnitude to that reported in Table 7, although it does not reach conventional levels of statistical significance, likely reflecting the lower statistical power associated with the smaller sample size. In contrast, we find no significant association between social connectedness, proxied by the number of relatives in the village, and access to cattle rental arrangements.

However, re-estimation by spatial group reveals substantial heterogeneity in the factors shaping access to cattle rental arrangements and in the market and social-support functions they serve among local farmers. For central households (Columns 4-6), both social and spatial factors significantly affect access to rented cattle. The number of relatives in the village, used as a proxy for social ties, is positively associated with the probability of borrowing cattle without payment but negatively associated with the probability of paid rental. Spatial proximity also matters: greater Mahalanobis distance, indicating greater remoteness within the village, is associated with a higher probability of unpaid cattle borrowing and a lower probability of paid cattle rental.

These results suggest that relatively more isolated households are less likely to access cattle through paid rental and instead rely more on unpaid borrowing. Columns 5 and 6 further show that less productive households tend to borrow cattle without payment, whereas more productive households are more likely to use paid rental arrangements. Taken together, these findings suggest that unpaid cattle borrowing primarily serves disadvantaged households, such as those with lower agricultural productivity or those located farther from the village center. In contrast, despite potential transaction frictions, paid cattle rental arrangements appear to contribute to more efficient allocation of draft power, consistent with the theoretically expected role of factor rental markets (Column 6). Moreover, the contrasting signs of the average marginal effects of our proxy for social ties across unpaid borrowing and paid rental suggest that social connectedness may influence which type of cattle rental arrangements local farmers access. In particular, households with fewer social connections may have less access to informal borrowing networks and therefore rely more heavily on market-based transactions.

For peripheral households (Columns 7-9), the patterns differ. In this specific sample, remote households are more likely to borrow cattle for free, consistent with the results for the central household sample. However, neither spatial position nor social network variables are significantly associated with the likelihood of paid cattle rental. In addition, household agricultural productivity shows no significant association with any cattle rental choice, suggesting that draft-power misallocation may be more pronounced among peripheral households.

In sum, spatial proximity to the village center strongly shapes the functions of cattle rental markets. Paid rental arrangements appear to promote more efficient allocation of draft power among productive farmers only in areas close to the village center. In contrast, neither paid nor unpaid arrangements yield such efficiency gains among peripheral households. Near the village center, less productive farmers are instead more likely to rely on unpaid cattle borrowing, suggesting that it serves as an important institution of mutual assistance and constitutes another essential function of cattle rental arrangements in the study context. Although greater remoteness is associated with a higher probability of unpaid borrowing among peripheral households, this association is larger in magnitude among central households. Thus, the social-support function of unpaid cattle borrowing is also more pronounced among households located near the village center. Overall, the dual functions of informal cattle rental arrangements—promoting allocative efficiency and providing social support—are spatially constrained.

7. Conclusions

This study examines the productivity consequences of draft-animal rental, assesses whether cattle rental arrangements promote allocative efficiency, and identifies the constraints that hinder efficient factor allocation among maize farmers in Southern Province, Zambia.

The analysis highlights three main findings. First, cattle owners achieve substantially higher yields than borrowers. Supplemental analyses suggest that greater production intensification among cattle owners explains this yield advantage. In contrast, we find no supporting evidence for two alternative explanations: delayed planting by borrowers and potential incentive problems arising from limited monitoring of borrowed cattle.

Second, we find no evidence that borrowing cattle improves yields relative to manual hoeing, suggesting the misallocation of draft power in the study area. Consistent with this interpretation, the empirical analysis provides no evidence that cattle rental arrangements generate overall efficiency gains. Instead, less productive farmers are more likely to borrow cattle without payment. Households located farther from the village center are also more likely to rely on unpaid borrowing. Taken together, these findings suggest that unpaid cattle borrowing serves as a form of social support for disadvantaged households, including those with lower agricultural productivity or those located farther from the village center, in our study context.

Finally, we find that the dual functions of informal cattle rental arrangements—promoting allocative efficiency and providing social support—are spatially constrained. On the one hand, informal cattle rental markets promote more efficient allocation of draft power among central households: relatively productive farmers are more likely to access cattle through paid rental when they live near the village center. In contrast, such efficiency gains are not observed among peripheral households, indicating greater misallocation of draft power in more remote areas.

On the other hand, the social-support function of unpaid borrowing is also more pronounced among central households with lower agricultural productivity. Although greater remoteness is associated with a higher probability of unpaid borrowing even among peripheral households, this association is larger in magnitude among central households. Thus, informal cattle rental arrangements serve both allocative and social-support functions more effectively in areas with better spatial access to the village center.

This study has three main limitations, which also point to directions for future research. First, our empirical execution relies primarily on cross-sectional variation to estimate yield gaps across cultivation methods. The results should therefore be interpreted as descriptive rather than fully causal. Future work could use data from multiple periods and exploit exogenous shocks to the supply of cattle (e.g., livestock disease outbreaks) to more rigorously identify the causal effects of access to draft animals on agricultural productivity.

Second, the details of cattle rental arrangements cannot be fully observed in the data. While information on rental payments is available, key features remain unobserved, such as whether households rent a full pair of oxen or make a pair through single-ox exchanges. This arrangement likely involves higher search and coordination costs, as it requires matching with another single-ox owner and coordinating joint use. Moreover, rental arrangements may involve non-monetary or intertemporal contracts, including labor exchange or delayed payment after harvest (Ito, 2015). As a result, classifying rental transactions based solely on monetary payments may understate the flexibility of local rental arrangements. Finally, the data do not include information on the renters' side; thus, this study illustrates cattle rental markets only from borrowers' perspectives. Future research combining quantitative data on cattle renters with qualitative fieldwork would help better understand transaction costs and incentives in cattle rental markets, providing a more comprehensive picture.

Finally, the data indicate a rapid decline in reliance on hand hoes over the study period (from 22% to 11%, then to 9.5% as shown in Table 5), with borrowing cattle as the most common transition pathway. However, the motivations underlying this technological transition remain unclear. A key question for future work is what causes household technological shifts. Possible factors include changes in relative costs, labor availability, and structural changes in the village. At the same time, accounting for recent climate change is crucial for land preparation decision-making. The onset of the rainy season has shifted from November toward late December and January, shortening the effective growing period. These environmental changes would reshape decisions on land preparation, planting, and crop maturity. Future research examines how climate-induced shifts in rainfall patterns interact with access to draft power and rental markets to shape farmers' technology adoption and production strategies in transition periods.

Despite its limitations and unresolved questions for future research, the main contribution of this study is to provide empirical evidence that informal cattle rental markets serve dual functions in agrarian communities. While their contribution to allocative efficiency is constrained by spatial frictions, unpaid cattle borrowing serves as a form of mutual aid, particularly for disadvantaged households, including those with lower agricultural productivity and those located in remote areas. Policy interventions that reduce transaction costs associated with spatial remoteness could help improve access to cattle rental markets and mitigate factor misallocation, thereby enhancing aggregate agricultural productivity. More broadly, the findings suggest that policy efforts to promote mechanized farming should account for the social functions embedded in existing cattle rental arrangements, which provide an important means of supporting vulnerable households within rural communities.

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Tables

Table 1. Descriptive Statistics by Cultivation Method, 2022/23 Rainy Season

Variable	(1) Own Cattle	(2) Borrowed Cattle	(3) Handhoe	(1) - (3) Mean Diff.		(2) - (3) Mean Diff.	
Farming Characteristics							
Maize Harvest (kg)	679.492	381.886	319.544	359.948	***	62.342	
Area Cultivated (ha)	0.828	0.621	0.787	0.041		-0.165	*
Productive Asset Value (ZMW)	3031.0	576.41	1614.7	1416.3	***	-1038.2	***
Non-productive Asset Value (ZMW)	3280.6	1494.4	1017.9	2262.6	***	476.45	
Tropical Livestock Unit	6.676	1.024	1.604	5.073	***	-0.579	
Number of Oxen Owned by Households	2.300	0.249	0.569	1.731	***	-0.320	
Demographic Characteristics							
Household Size	6.419	5.309	5.655	0.764	*	-0.346	
Gender of Head (Male = 1)	0.857	0.826	0.741	0.116	*	0.084	
Head's Age	46.148	44.153	49.517	-3.370		-5.364	**
Head's Years of Education	6.014	6.060	5.759	0.256		0.302	
Number of Observations	210	333	58				

Notes: ZMW, Zambian Kwacha. 100 ZMW = 5.4 USD (July 2023). The sample is restricted to maize farmers with yields of 5 tons/ha or less who planted between November 1, 2022, and January 31, 2023. Productive assets include ox-drawn ploughs, harrows, cultivators, hand hoes, scotch carts, sledge carts, sprayers, water pumps, and hammer mills. Non-productive assets include bicycles, TV, radio, mobile phone, and solar panel sets. The tropical livestock unit (TLU) is a standardized measure of livestock holdings that converts different types of livestock (cattle, goats, pigs, and poultry) into a common unit, with one ox equivalent to one TLU. P-values are adjusted for multiple testing using the Benjamini–Hochberg procedure. * Significant at 10%; ** significant at 5%; *** significant at 1%.

Table 2. Determinants of Maize Yield, Labor Input, and Cultivated Area, 2022/23 Rainy Season

Variables	(1)	(2)	(3)
	Log (Yield (kg/ha) + 1)	Log (Family Labor (hrs/ha) + 1)	Land Size (ha)
Own Cattle Dummy: β_1	0.577**	0.318	-0.068
	(0.257)	(0.275)	(0.156)
Borrowed Cattle Dummy: β_2	0.103	0.298	-0.151
	(0.262)	(0.304)	(0.152)
Land Size	-0.182*	-0.457***	-
	(0.106)	(0.123)	-
Log of Productive Asset Value	-0.018	0.025	0.021
	(0.038)	(0.046)	(0.021)
Log of Non-productive Asset Value	-0.013	0.011	-0.016
	(0.024)	(0.027)	(0.010)
Tropical Livestock Unit w/o cattle	0.222**	-0.103	0.109***
	(0.099)	(0.083)	(0.041)
Head's Age	0.010	0.032	0.004
	(0.033)	(0.027)	(0.011)
Head's Age Squared	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)
Male Head	0.390	0.345	0.152**
	(0.249)	(0.214)	(0.066)
Head's Years of Education	0.033	-0.032	0.000
	(0.028)	(0.021)	(0.012)
Household Size	-0.006	0.025	0.048***
	(0.035)	(0.036)	(0.015)
Constant	5.938***	3.204***	0.247
	(0.660)	(0.629)	(0.251)
Own - Borrowed $H_0: \beta_1 - \beta_2 = 0$	0.474***	0.020	0.083*
	(0.156)	(0.135)	(0.050)
N	595	595	595
R2	0.140	0.078	0.182

Notes: The hand hoe category is the omitted reference group. The row "Own − Borrowed" reports the difference in estimated coefficients between the "Own" and "Borrowed" categories and the associated standard errors based on a linear hypothesis test. Robust standard errors clustered at the village level are shown in parentheses. EA dummies are included in all regressions but not reported. Asset values and tropical livestock units are measured as of September 2022 (2022 survey round) to reflect conditions prior to the start of the 2022/23 rainy season. * Significant at 10%; ** significant at 5%; *** significant at 1%.

Table 3. Determinants of Input Use, Cooperative Membership, and FISP Participation, 2022/23 Rainy Season

Variables	(1) Log (Seed (ZMK) + 1)	(2) Log (Compound D (kg) + 1)	(3) Log (Urea (kg) + 1)	(4) Log (Manure (kg) + 1)	(5) Cooperative Membership (dummy)	(6) FISP Participation (dummy)
Own Cattle Dummy: β_1:	0.600*	0.975***	0.992***	0.690*	0.179**	0.004
	(0.306)	(0.315)	(0.295)	(0.367)	(0.070)	(0.035)
Borrowed Cattle Dummy: β_2	0.056	0.778***	0.706***	0.304	0.124*	-0.034
	(0.303)	(0.260)	(0.232)	(0.319)	(0.064)	(0.027)
Subsidy Join Dummy	-0.835**	2.030***	1.858***	-0.342	-	-
	(0.399)	(0.292)	(0.359)	(0.348)	-	-
Cooperative Join Dummy	0.410	0.394**	0.442***	0.532*	-	0.305***
	(0.276)	(0.164)	(0.168)	(0.293)	-	(0.045)
Land Size	1.145***	0.245*	0.472***	0.215*	0.110***	0.001
	(0.174)	(0.130)	(0.180)	(0.126)	(0.034)	(0.017)
Log of Productive Asset Value	0.049	0.060	0.052	-0.079*	0.013	-0.001
	(0.077)	(0.049)	(0.046)	(0.048)	(0.013)	(0.006)
Log of Non-productive Asset Value	0.024	0.021	0.012	0.045*	0.008	-0.004
	(0.047)	(0.029)	(0.028)	(0.026)	(0.006)	(0.005)
Tropical Livestock Unit w/o cattle	0.361***	0.125	0.220**	-0.003	0.004	0.068***
	(0.129)	(0.092)	(0.092)	(0.101)	(0.023)	(0.016)
Head's Age	-0.037	-0.030	-0.024	-0.012	0.021**	0.013**
	(0.061)	(0.029)	(0.043)	(0.045)	(0.010)	(0.005)
Head's Age Squared	0.000	0.000	0.000	0.000	-0.000*	-0.000*
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Male Head	-0.147	-0.709***	-0.771***	0.248	0.084	0.041
	(0.350)	(0.196)	(0.215)	(0.246)	(0.059)	(0.039)
Head's Years of Education	0.062	0.055**	0.060***	0.004	0.004	0.008**
	(0.039)	(0.028)	(0.022)	(0.038)	(0.007)	(0.004)
Household Size	0.036	0.075*	0.066*	0.049	0.007	-0.009
	(0.061)	(0.044)	(0.038)	(0.061)	(0.010)	(0.005)
Constant	2.072	1.325*	1.410	-0.104	-0.663**	-0.287**
	(1.696)	(0.758)	(1.097)	(0.999)	(0.265)	(0.138)
Own - Borrowed $H_0: \beta_1 - \beta_2 = 0$	0.545*	0.197	0.286*	0.386**	0.055	0.039
	(0.309)	(0.195)	(0.171)	(0.161)	(0.039)	(0.027)
N	595	595	595	595	595	595
R2	0.204	0.368	0.396	0.063	0.201	0.329

Notes: The hand hoe category is the omitted reference group. The row "Own − Borrowed" reports the difference in estimated coefficients between the “Own” and “Borrowed” categories and the associated standard errors based on a linear hypothesis test. Robust standard errors clustered at the village level are shown in parentheses. EA dummies are included in all regressions but not reported. Asset values and tropical livestock units are measured as of September 2022 (2022 survey round) to reflect conditions prior to the start of the 2022/23 rainy season. * Significant at 10%; ** significant at 5%; *** significant at 1%.

Table 4. Plot-Level Determinants of Planting Date and Maize Yield, 2022/23 Rainy Season

Variables	(1) Planting Timing	(2) Distance to Plot (min)	(3) Log (Yield (kg/ha) + 1)	(4) Log (Yield (kg/ha) + 1)
Own Cattle Dummy	-0.917	-3.233	0.456*	0.184
	(2.592)	(5.131)	(0.276)	(0.352)
Borrowed Cattle Dummy	-0.163	-1.647	0.002	0.047
	(2.356)	(5.081)	(0.263)	(0.358)
Distance to Plot	-	-	0.002	0.000
	-	-	(0.002)	(0.004)
Own Cattle Dummy * Distance to Land	-	-	-	0.008
	-	-	-	(0.005)
Borrowed Cattle Dummy * Distance to Land	-	-	-	-0.002
	-	-	-	(0.006)
Land Size	-1.329	2.534	-0.111	-0.129
	(1.460)	(3.141)	(0.121)	(0.121)
Log of Productive Asset Value	-0.041	-0.556	-0.067	-0.064
	(0.386)	(0.702)	(0.042)	(0.042)
Log of Non-productive Asset Value	0.197	0.476	-0.000	0.000
	(0.273)	(0.430)	(0.033)	(0.032)
Tropical Livestock Unit w/o cattle	-0.337	-1.140	0.235***	0.235***
	(0.844)	(1.974)	(0.084)	(0.084)
Head's Age	-0.301	0.128	0.023	0.025
	(0.271)	(0.452)	(0.033)	(0.033)
Head's Age Squared	0.001	-0.001	-0.000	-0.000
	(0.003)	(0.004)	(0.000)	(0.000)
Male Head	-3.540*	0.970	0.400	0.386
	(1.905)	(2.826)	(0.261)	(0.259)
Head's Years of Education	0.051	0.321	0.042	0.041
	(0.206)	(0.405)	(0.027)	(0.026)
Household Size	0.263	0.174	-0.054	-0.056
	(0.336)	(0.514)	(0.036)	(0.036)
Constant	11.631*	24.270*	5.449***	5.550***
	(7.062)	(13.449)	(0.878)	(0.897)
Land Controls	Yes	Yes	Yes	Yes
N	743	743	743	743
R2	0.063	0.051	0.116	0.120

Notes: The unit of analysis is the maize plot. The hand hoe category is the omitted reference group. Robust standard errors clustered at the household level are shown in parentheses. EA dummies are included in all regressions but not reported. Land controls refer to soil quality, topographic position of the plot, and distance from the homestead to the plot. Asset values and tropical livestock units are measured as of September 2022 (2022 survey round) to reflect conditions prior to the start of the 2022/23 rainy season. * Significant at 10%; ** significant at 5%; *** significant at 1%.

Table 5. Descriptive Statistics by Survey Round

	2022			2023			2024		
	Mean	SD	N	Mean	SD	N	Mean	SD	N
Farming Characteristics									
Maize Harvest (kg)	1002.5	929.3	610	479.9	553.6	601	58.2	192.6	694
Area Cultivated (ha)	1.017	0.932	610	0.709	0.576	601	0.779	0.561	694
Productive Asset Value (ZMW)	1461.5	2528.7	610	1534.3	2614.5	601	1827.0	3502.7	694
Non-productive Asset Value (ZMW)	1776.2	2703.2	610	2072.5	3088.6	601	2154.5	3129.1	694
Tropical Livestock Unit	2.952	4.621	610	3.055	4.313	601	3.070	4.701	694
Number of Adult Family Workers	2.639	1.208	610	2.889	1.309	601	2.978	1.402	694
Number of Oxen Owned by Households	0.741	1.705	610	0.997	1.901	601	0.928	1.564	694
Demographic Characteristics									
Household Size	5.377	2.411	610	5.730	2.372	601	5.993	2.625	694
% of Male Headed Household	0.790	0.408	610	0.829	0.377	601	0.787	0.410	694
Head's Age	44.06	14.92	610	45.37	14.53	601	45.72	14.66	694
Head's Years of Education	5.733	3.487	610	6.015	3.358	599	5.909	3.382	693
Rental Participation									
% of Households borrowing Cattle	0.299	0.458	445	0.349	0.477	601	0.375	0.484	694
% of Households using Owned Cattle	0.490	0.500	445	0.556	0.497	601	0.562	0.497	694
% of Households using Hand hoe	0.222	0.416	445	0.113	0.317	601	0.095	0.294	694

Notes: ZMW, Zambian Kwacha. Each sample is restricted to maize farmers with yields of 5 tons/ha or less who plant between November 1 and January 31.

Table 6. OLS and Fixed-Effects Estimates of the Determinants of Maize Output

	(1) OLS	(2) FE
Log of Total Maize-Cultivated Area	0.650***	0.582***
	(0.062)	(0.086)
Log of Number of Adult Family Workers	0.027	-0.349*
	(0.097)	(0.205)
Log of Productive Asset Value	0.134***	0.084**
	(0.024)	(0.042)
Constant	5.915***	-
	(0.231)	-
Year FE	Yes	Yes
Village * Year FE	Yes	Yes
Household FE	No	Yes
N	1905	1905
R2	0.737	0.860

Notes: Standard errors are clustered at the household level. * Significant at 10%; ** significant at 5%; *** significant at 1%.

Table 7. Determinants of Participation in Cattle Rental Markets, 2022/23 Rainy Season

	(1) Hand hoe	(2) Borrow Free	(3) Borrow Paid
Standardized Farming Ability (estimated from model results in Table 6)	0.011	-0.052*	0.041
	(0.025)	(0.027)	(0.03)
Land Size	0.028	-0.024	-0.004
	(0.029)	(0.035)	(0.042)
Number of Adult Family Workers	0.016	-0.039	0.023
	(0.016)	(0.026)	(0.026)
Log of Productive Asset Value	0.023*	0.021	-0.043*
	(0.012)	(0.021)	(0.023)
Head's Age	0.001	-0.002	0.001
	(0.002)	(0.002)	(0.002)
Male Head	-0.084*	0.015	0.068
	(0.045)	(0.057)	(0.065)
Head's Years of Education	0.001	-0.004	0.002
	(0.004)	(0.008)	(0.008)
N	389	389	389

Notes: A multinomial logit model is estimated, and average marginal effects are reported. EA dummies are included in the models but not reported. Standard errors clustered at the village level are shown in parentheses. * Significant at 10%; ** significant at 5%; *** significant at 1%.

Table 8. Heterogeneity in Cattle Rental Market Participation by Spatial Proximity, 2022/23 Rainy Season

	Total			Negative Mahalanobis Distance			Non-negative Mahalanobis Distance		
	(1) Hand hoe	(2) Borrow Free	(3) Borrow Paid	(4) Hand hoe	(5) Borrow Free	(6) Borrow Paid	(7) Hand hoe	(8) Borrow Free	(9) Borrow Paid
Number of Relatives in the Same Village	0.003	0.012	-0.014	0.016	0.051*	-0.067**	0.012	-0.045	0.033
	(0.016)	(0.023)	(0.025)	(0.028)	(0.030)	(0.033)	(0.023)	(0.035)	(0.040)
Standardized Mahalanobis Distance	-0.027	0.054**	-0.027	-0.051	0.266**	-0.215*	-0.052	0.105*	-0.053
	(0.021)	(0.028)	(0.031)	(0.075)	(0.103)	(0.114)	(0.066)	(0.063)	(0.079)
Standardized Farming Ability (estimated from model results in Table 6)	-0.004	-0.053	0.058	-0.008	-0.103**	0.111**	-0.005	0.030	-0.025
	(0.026)	(0.034)	(0.037)	(0.033)	(0.043)	(0.046)	(0.030)	(0.063)	(0.066)
Land Size	0.041	-0.008	-0.033	0.082**	0.010	-0.092	-0.143	0.118	0.026
	(0.027)	(0.062)	(0.064)	(0.034)	(0.072)	(0.075)	(0.119)	(0.144)	(0.166)
Number of Adult Family Workers	0.022	-0.022	0.000	0.036*	-0.009	-0.027	0.008	-0.019	0.011
	(0.014)	(0.030)	(0.030)	(0.019)	(0.041)	(0.041)	(0.030)	(0.041)	(0.045)
Log of Productive Asset Value	0.020	0.001	-0.022	0.018	-0.033	0.015	0.013	0.028	-0.041
	(0.016)	(0.023)	(0.026)	(0.017)	(0.029)	(0.032)	(0.023)	(0.037)	(0.039)
Head's Age	-0.001	-0.003	0.003	-0.003	0.001	0.002	0.002	-0.009**	0.006
	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)
Male Head	-0.124**	0.048	0.077	-0.206**	0.031	0.175	0.007	0.012	-0.018
	(0.049)	(0.090)	(0.097)	(0.084)	(0.129)	(0.144)	(0.083)	(0.154)	(0.161)
Head's Years of Education	-0.004	-0.001	0.004	-0.010	0.000	0.010	0.002	-0.002	0.001
	(0.006)	(0.008)	(0.009)	(0.009)	(0.010)	(0.012)	(0.009)	(0.015)	(0.016)
N	229	229	229	138	138	138	91	91	91

Notes: A multinomial logit model is estimated, and average marginal effects are reported. EA dummies are included in the models but not reported. Robust standard errors are reported in parentheses for columns (1)–(6). Model-based standard errors are reported in parentheses for columns (7)–(9). Due to the small sample size and limited variation in some choice outcomes, heteroskedasticity-robust and cluster-robust standard errors could not be computed for the marginal effects. * Significant at 10%; ** significant at 5%; *** significant at 1%.

Appendix

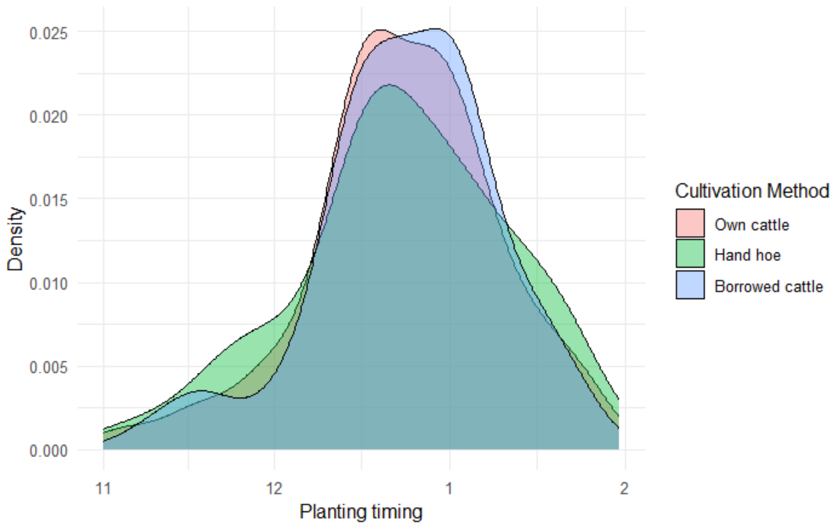

Figure A1. Distribution of Maize Planting Dates across Cultivation Methods

Notes: The x-axis shows maize planting dates ranging from November 1 to January 31.

Table A1. Descriptive Statistics at the Household Level, 2022/23 Rainy Season

Variable	N	Mean	SD
Log (Yield (kg/ha) + 1)	601	5.999	1.604
Log (Family Labor (hrs/ha) + 1)	601	4.446	1.494
Land Size (ha)	601	0.709	0.576
non-Maize Plot (ha)	601	0.460	0.429
Total Cultivated Land (ha)	601	1.156	0.776
Fallow Land (ha)	601	0.132	0.412
Log of Dcompound Input (kg)	601	1.911	2.070
Log of Urea Input (kg)	601	2.046	2.088
Log of Manure Input (kg)	601	0.704	1.841
Log of Seed Value (ZMW)	601	3.730	2.958
Cooperative Membership	601	0.126	0.333
Subsidy Program Membership	601	0.341	0.474
Own Cattle Dummy	601	0.349	0.477
Borrowed Cattle Dummy	601	0.556	0.497
Borrowed Free Dummy	601	0.180	0.384
Borrowed with Payment Dummy	601	0.376	0.485
Hand hoe Dummy	601	0.113	0.317
Log of Productive Asset Value	597	5.620	2.233
Log of Non-productive Asset Value	597	5.279	3.207
Tropical Livestock Unit w/o cattle	597	0.594	0.800
Head's Age	601	45.37	14.53
Head's Age Squared	601	2268.9	1437.1
Male Head	601	0.829	0.377
Household Size	601	5.730	2.372
Num. of Adult Family Workers	601	2.889	1.309
Head's Years of Education	599	6.015	3.358
Estimated Farming Ability	601	-0.007	0.978
Estimated Farming Ability (standardized)	601	-0.009	0.864
Mahalanobis Distance	361	1.975	1.898
Mahalanobis Distance (standardized)	361	0.006	1.047

Notes: The sample is restricted to maize farmers with yields of 5 tons/ha or less who planted between November 1, 2022, and January 31, 2023. Asset values and tropical livestock units are measured as of September 2022 (2022 survey round) to reflect conditions prior to the start of the 2022/23 rainy season.

Table A2. Descriptive Statistics at the Plot Level, 2022/23 Rainy Season

Variable	N	Mean	SD
Log (Yield (kg/ha) + 1)	750	5.850	1.856
Planting Timing	750	0.141	16.442
Distance to plot	750	31.80	26.94
Own Cattle Dummy	750	0.368	0.483
Borrowed Cattle Dummy	750	0.535	0.499
Hand hoe Dummy	750	0.097	0.297
Land Size	750	0.568	0.436
Log of Productive Asset Value	745	5.770	2.210
Log of Non-productive Asset Value	745	5.274	3.172
Tropical Livestock Unit w/o cattle	745	0.633	0.853
Head's Age	750	45.63	14.30
Head's Age Squared	750	2286.4	1421.7
Male Head	750	0.832	0.374
Head's Years of Education	748	5.953	3.318
Household Size	750	5.939	2.507
Land Soil Quality			
Poor	750	0.104	
Good	750	0.303	
Fair	750	0.593	
Land Topographic Position			
Flat land	750	0.509	
Hill bottom	750	0.152	
Hill top	750	0.081	
River bank	750	0.103	
Slope	750	0.155	

Notes: The sample is restricted to maize farmers with yields of 5 tons/ha or less who planted between November 1, 2022, and January 31, 2023. Asset values and tropical livestock units are measured as of September 2022 (2022 survey round) to reflect conditions prior to the start of the 2022/23 rainy season.

Table A3. Heterogeneity in Family Labor Input by Number of Adult Family Members, 2022/23 Rainy Season

Variables	(1) Log (Family Labor (hrs/ha) + 1)	(2) Log (Family Labor (hrs/ha) + 1)
Own Cattle Dummy	0.317	-0.876*
	(0.281)	(0.507)
Borrowed Cattle Dummy	0.304	-0.440
	(0.305)	(0.529)
Number of adult family workers	0.069	-0.201
	(0.049)	(0.152)
Own Cattle Dummy * Num of workers	-	0.391**
	-	(0.162)
Borrowed Cattle Dummy * Num of workers	-	0.243
	-	(0.179)
Land Size	-0.455***	-0.474***
	(0.127)	(0.127)
Log of Productive Asset Value	0.026	0.031
	(0.045)	(0.045)
Log of Non-productive Asset Value	0.010	0.008
	(0.027)	(0.025)
Tropical Livestock Unit w/o cattle	-0.108	-0.119
	(0.084)	(0.092)
Head's Age	0.030	0.026
	(0.024)	(0.025)
Head's Age Squared	-0.000	-0.000
	(0.000)	(0.000)
Male Head	0.317	0.317
	(0.215)	(0.216)
Head's Years of Education	-0.033	-0.031
	(0.021)	(0.021)
Constant	3.262***	4.151***
	(0.617)	(0.689)
N	595	595
R2	0.079	0.091

Notes: The hand hoe category is the omitted reference group. Robust standard errors clustered at the village level are shown in parentheses. EA dummies are included in all regressions but not reported. Asset values and tropical livestock units are measured as of September 2022 (2022 survey round) to reflect conditions prior to the start of the 2022/23 rainy season. * Significant at 10%; ** significant at 5%; *** significant at 1%.

Table A4. Determinants of Cultivated Land Area, 2022/23 Rainy Season

Variables	(1) Maize Plot (ha)	(2) non-Maize Plot (ha)	(3) Total Cultivated Land (ha)	(4) Fallow Land (ha)
Own Cattle Dummy	-0.068	-0.126	-0.215	-0.027
	(0.156)	(0.104)	(0.241)	(0.056)
Borrowed Cattle Dummy	-0.151	-0.242***	-0.404*	0.023
	(0.152)	(0.092)	(0.232)	(0.063)
Log of Productive Asset Value	0.021	0.013	0.032	0.015
	(0.021)	(0.008)	(0.027)	(0.013)
Log of Non-productive Asset Value	-0.016	0.005	-0.006	-0.002
	(0.010)	(0.004)	(0.012)	(0.007)
Tropical Livestock Unit w/o cattle	0.109***	-0.001	0.105***	-0.005
	(0.041)	(0.017)	(0.040)	(0.019)
Head's Age	0.004	0.017**	0.020	0.005
	(0.011)	(0.007)	(0.015)	(0.007)
Head's Age Squared	-0.000	-0.000**	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Male Head	0.152**	0.072	0.210**	0.042
	(0.066)	(0.053)	(0.094)	(0.049)
Head's Years of Education	0.000	-0.010	-0.008	-0.003
	(0.012)	(0.007)	(0.008)	(0.007)
Household Size	0.048***	-0.001	0.051**	0.007
	(0.015)	(0.007)	(0.020)	(0.011)
Constant	0.247	-0.082	0.175	-0.024
	(0.251)	(0.214)	(0.356)	(0.164)
N	595	595	595	595
R2	0.182	0.247	0.228	0.078

Notes: The hand hoe category is the omitted reference group. Robust standard errors clustered at the village level are shown in parentheses. EA dummies are included in all regressions but not reported. Asset values and tropical livestock units are measured as of September 2022 (2022 survey round) to reflect conditions prior to the start of the 2022/23 rainy season. * Significant at 10%; ** significant at 5%; *** significant at 1%.