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Production decisions and food security outcomes of smallholder's livestock market participation: empirical evidence from Zimbabwe

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Smallholder market participation is an important pathway to improving the productivity and livelihoods of farm households. Despite several studies documenting the effect of market participation on crop production, relatively little is known about the effect of smallholder participation in livestock markets. We investigate effects of smallholder market participation on livestock production and household food security in Zimbabwe. Using survey data collected from 625 households and an instrumental variables strategy to address endogeneity concerns, we find that households participating in livestock markets are more likely to engage in market-oriented livestock production, use improved livestock inputs, and have better food security outcomes. While market participants are more likely to consider market conditions in their decisions, most farmers are needs-driven and cannot afford to adopt commercial-oriented behavior. Overall, smallholder livestock production systems respond to market incentives and can support food security strategies, particularly in drylands where crop production is risky.

KEYWORDS

livestock production, market participation, improved livestock inputs, food security, instrumental variables, Zimbabwe

1. Introduction

The commercialization of smallholder agriculture is considered a critical pathway for improving the productivity, food security and resilience of farmers (Pingali and Rosegrant, 1995; Barrett, 2008; Ochieng et al., 2016). Welfare gains of market participation are expected to accrue from sales and savings due to larger-scale production opportunities in the face of fixed production costs, technological improvements related to market-based exchanges, and the associated total factor productivity growth (Barrett, 2008). The underlying argument is that smallholders respond to market incentives. Despite a large literature showing that smallholder crop production responds to market incentives (e.g., Fafchamps, 1992: Zeller et al., 1998; Alene et al., 2008), empirical evidence on whether and how smallholder livestock production responds to market incentives, such as output prices and input costs, remains scarce (Abay and Jensen,

2020). Studies largely focus on infrastructural and socioeconomic determinants of smallholder participation in livestock markets (e.g., Uchezuba et al., 2009; Cheelo and van der Merwe, 2021). Also, little is known about impacts of livestock markets on smallholder welfare. This study investigates effects of livestock market participation on livestock production decisions and household food security in Zimbabwe, where livestock production is a crucial source of rural livelihoods.

Understanding the interaction between market development and livestock production is appealing in Zimbabwe for several reasons. In many areas, smallholders lack access to functioning markets, information and livestock inputs, such as veterinary, feeds, and breeds (Dube et al., 2014). Relatively developed cattle markets and auction facilities are dominated by large commercially-oriented farms (Dube et al., 2014). Indeed, low market integration and participation are commonly invoked as a reason for smallholders' low investment in livestock inputs, poor livestock management, and low productivity of the sector (Tavirimirwa et al., 2013). Development of local input and output markets is an important entry point for raising and stabilizing farm incomes. This should go along with improving feed quality and digestibility and health systems that ensure that the investment in livestock is leveraged and made profitable (Valbuena et al., 2015; Herrero et al., 2016). In this paper, we characterize and measure livestock production decisions using production-orientation and investment in improved livestock inputs, as is common for mixed crop-livestock systems in the Global South. The most important livestock production-orientations and purposes in rural economies are sales of live animals and animal products, provision of food for the family, support to crop farming, precautionary savings and insurance, and social status (Powell et al., 2004; Salmon et al., 2018; Abay and Jensen, 2020). Moll (2005) offers a framework for holistic cost–benefit analyzes of livestock production. This framework considers sales of live animals and livestock products as market-oriented production motives, while other purposes are non-market-oriented goals. We also hypothesize that market participants are more likely to engage in market-oriented livestock production and raise livestock productivity, compared to non-market participants. The comparison is relevant because it can highlight the potential for market opportunities and incentives to improve the efficiency of smallholder livestock production through increasing productivity and market offtakes and reducing losses from high mortality, while also reducing compounded impacts of climatic and market risks (Homann et al., 2007; Government of Zimbabwe, 2021).

Investment in improved livestock inputs is widely promoted to increase productivity and to meet the growing demand for livestock products in developing countries (Salmon et al., 2018). The development of the livestock sector requires appropriate combinations of supplementary feed, animal health management, and improved breeds (McDermott et al., 2010; Korir et al., 2023). Livestock market participation can provide incentives for increased use of improved inputs and the capital needed for investments in these technologies. We also hypothesize that market participation is more likely to increase the use of improved livestock inputs.

Livestock production contributes to household food security through direct access to meat, dairy and eggs, which are sources of high-quality protein and micro-nutrients essential for human nutrition (Feyissa et al., 2023). In developing countries, livestock ownership and production mitigate missing markets for some food, such as dairy products (Hoddinott et al., 2015). Alternatively, livestock production contributes to food security through increasing purchasing power of households. Livestock is a critical buffer for farm households to mitigate income risks and food shortages (Powell et al., 2004). Even without food deficits, income from sales of livestock and products supplements household food production and dietary diversity (Powell et al., 2004). For instance, Homann et al. (2007) report that farmers in Zimbabwe primarily used income from livestock sales for food expenses. Under conditions of chronic food insecurity and high poverty levels as in semi-arid Zimbabwe, improved livestock production and market access can provide more reliable income, food stability and risk mitigation as compared to crop production. Most interventions, however, focus on crop production to mitigate food insecurity. Thus, we hypothesize that livestock market participation in semi-arid areas of Zimbabwe increases incomes and improves food security through increasing food expenditure and household dietary diversity (HDD).

Using instrumental variables (IV) technique to address the potential endogeneity of market participation, we find that households participating in livestock markets are more likely to engage in market-oriented livestock production and use improved livestock inputs. Livestock market participation significantly improves household food security. The findings underscore the potential of market participation to incentivize livestock production and improve the welfare of livestock producers. The remainder of the paper is organized as follows. Section 2 provides the study context. Section 3 describes the data and outlines the empirical strategy. Section 4 presents empirical results and sensitive analyzes of the main results. Section 5 concludes.

2. Study context: livestock ownership and marketing in Zimbabwe

Agriculture occupies a central place in the Zimbabwean economy. Agriculture contributes approximately 15–18 percent to Zimbabwe's gross domestic product (GDP) and is a source of livelihoods for over 70% of the country's population (Government of Zimbabwe, 2021). Despite a large national livestock herd, livestock production in Zimbabwe remains below its potential, limiting its contribution to the national economy (Tavirimirwa et al., 2013; Ndlovu et al., 2020). Livestock and livestock products account only for about 35% of the GDP contributed by the agricultural sector (Government of Zimbabwe, 2021). In Zimbabwe, livestock production is primarily driven by smallholder farmers in mixed crop-livestock systems. The bulk of the animals are raised in the semi-arid regions, which make up more than two-thirds of Zimbabwe. These regions are characterized by severe dry spells during the rainy season and seasonal droughts, where extensive livestock production is the recommended form of land use, along with dryland crops (Vincent and Thomas, 1960). The human population density is fairly low. Households in these areas are more labor constrained and vulnerable to the effects of variable climate and economic shocks (ZRBF, 2021).

Cattle and goats are the most important livestock types (Tavirimirwa et al., 2013). The cattle population is estimated at 5.5 million heads, while the goat stock is 4.7 million (FAO, 2020). Smallholders own 90% of the national cattle herd and 97% of the goat stock (Tavirimirwa et al., 2013; Ndlovu et al., 2020). Indigenous cattle and goat breeds constitute an extensive reservoir of genetic materials

(Ndlovu et al., 2020). Livestock production depends on natural pasture and crop residues, and dry season feed and water shortages are critical bottlenecks that continuously increase the systems' vulnerability and cause high losses from livestock mortality (Tavirimirwa et al., 2013; Dube et al., 2014; Melesse et al., 2021). A decline in crop production owing to poor production and land becoming unsuitable for crop production emphasize the importance of livestock production as climate is further projected to become drier in Zimbabwe (Government of Zimbabwe, 2022). Despite a large national livestock herd, livestock production in Zimbabwe has remained below its potential (Tavirimirwa et al., 2013; Ndlovu et al., 2020). Smallholders lack access to information and livestock inputs, veterinary services, feeds, and breeds (Dube et al., 2014), reflected in low productivity, low calving rate (45% against a national target of above 60%), low off-take rate (<5%), high mortality rates (often around 10%) and poor-quality outputs (Homann et al., 2007; Government of Zimbabwe, 2021).

Smallholder participation in livestock markets is an outcome of several physical, sociocultural and behavioral factors, beyond market availability or orientation. Smallholder farmers rely on informal livestock market channels, with poorly maintained infrastructure, where pricing is based on an arbitrary scale, with reference to visual assessment of animals. Sometimes, local intermediaries purchase livestock from weekly rural markets, in most cases, from farmers that sell in small quantities. In this market system, intermediaries play a vital role in buying livestock from markets in remote areas that are not accessible to bigger traders from the urban areas, though they tend to exploit farmers by offering them low prices. Selling livestock is often a coping strategy and an adaptation to variable and extreme weather risks (Government of Zimbabwe, 2022). At the same time, high livestock price fluctuations lead to inadequate farm income and unaffordability of food (UNDP, 2016). These factors influence farmers' perceptions and attitudes toward livestock as a subsistence means instead of a viable business opportunity. Generally, smallholder farmers perceive practicing farming as a result of lack of better options (Giller et al., 2021). Many of these barriers and their interplay coupled with a lack of market opportunities result in crisis-coping behavior and needs-driven livestock sales and do not instill a business-oriented mindset among smallholder farmers to regularly participate in markets (Tavirimirwa et al., 2013; Giller et al., 2021). Given resource constraints under high risk and low returns on limited market opportunities, poor farmers, especially with small cropland sizes and small herds, rely on off-farm activities to provide food and income for their families (Ritzema et al., 2017).

Zimbabwe recognizes institutional barriers and other challenges in its national vision for agriculture and food systems transformation. Zimbabwe's National Agriculture Policy Framework (2018–2030) commits to improving smallholder market linkages and the sector's contribution to the national economy (MLAWRR, 2018). The Livestock Growth Plan (MLAWRR, 2020) specifies production and marketing strategies to address the multiple challenges in the livestock sector. Further, the Fourth National Communication to the United Nations Convention on Climate Change (UNCCC) emphasizes the need to improve livestock feeding to reduce methane emissions of the livestock sector (Government of Zimbabwe, 2022). Although government plans and ambitions highlight the need for functional livestock markets, the implementation remains unresolved. Evidence on market incentives and impacts of market participation can inform such implementation efforts. While this study focuses on livestock market participation in Zimbabwe, the insights are typical for mixed crop-livestock systems in the Global South, with limited resources for coordination and capacity development and associated incentives. The results thus can be useful to inform transitioning livestock production to market-oriented systems in the Global South, particularly in Sub-Saharan Africa (SSA).

3. Descriptive statistics and methods

3.1. Data

Data were collected from Gwanda and Mangwe districts of the Matabeleland South province of Zimbabwe in 2019. The districts are semi-arid, in the same agro-ecological zone IV (<450 mm annual rainfall). A multistage sampling procedure was used to select households, who were mainly representatives of communal farming areas of the study districts (Figure 1). First, 10 wards (municipalities)–four from Gwanda and six from Mangwe–were selected using a probability proportional to size (PPS) sampling approach. Second, three villages were randomly selected to represent sampled wards of communal farming communities, resulting in 30 study villages. Following this, a sampling frame was developed in selected villages with the help of extension agents and local administrative offices. The overall sampling frame covered 6,780 households, with a sampling frame for specific villages ranging from about 150 households in the smallest village to 300 households in the largest village. In the final stage, study households were selected proportional to population using systematic random sampling. With an equal probability of households in the sampling frame being selected, a random number was generated by dividing the total number of households in the sampling frame of a village by the target sample size of the village. This random number was then used a denominator of counting to select participants until the target sample size was reached in each village. This process produced a proportionate representation in the sample where samples from larger villages were more frequent than those from smaller villages. Following this procedure, 645 households were interviewed using a semi-structured questionnaire. However, this paper used data from 625 households due to missing market participation and outcome data.[1]

Sixty percent of the households were male-headed, with an average age of about 57 years and 7 years of completed schooling (Table 1). The average household had six family members, two hectares of land and 11 tropical livestock units (TLU).[2] Farming was the main occupation for 78% of households. The average *per capita* income from all sources was about 3,137 Zimbabwean dollars (Z$) (US$1 = Z$15.60 on average at the end of 2019), while the average household asset value was about Z$21,938. About 46% are members of farmers' groups. Moreover, 76 and 29% reported, respectively, accessing extension and credit services. Grazing rangelands was the dominant livestock feed, with 32% of the farmers receiving feed support during drought seasons.

1 Simple statistics tests revealed that missing households did not statistically differ from study households.

2 Tropical livestock unit is a common unit used to quantify various livestock species to a single value. We employed a tropical livestock unit applicable for sub-Saharan Africa (SSA).

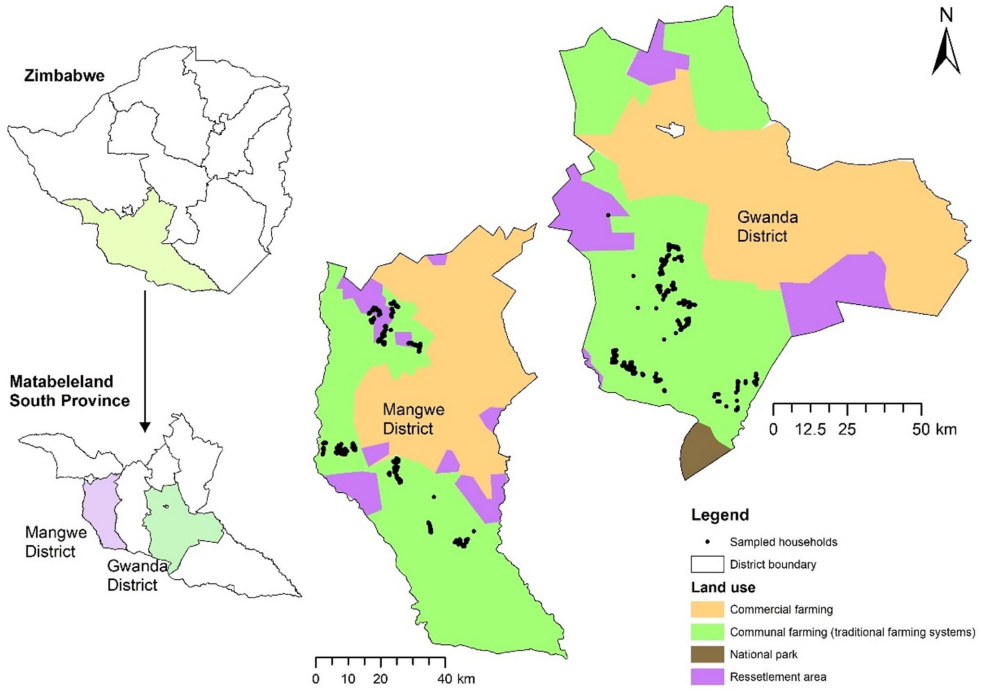

FIGURE 1
Map of Matabeleland South in Zimbabwe showing study districts along with distributions of individual respondents.

The livestock module elicited households' livestock ownership, most important livestock keeping purpose, livestock input use and marketing related to cattle and goats. Livestock market participation was defined as whether a household sold live animals and livestock products over the 12 months before the survey. About 49% participated in livestock markets. Supplementary Tables A1 and A2 in the Supplementary material present information used to construct the outcome variables. On average, 63 and 93% of the households owned cattle and goats, respectively. All households reported owning at least one type of livestock. Households' livestock production-orientation is elicited using the most important purpose for each type of livestock: (1) sale of live animals, (2) sale of animal products, (3) food consumption, (4) crop farming (draft power and manure), (5) precautionary savings and insurance, and (6) signaling social status.

Supplementary Table A1 describes the distribution of main purposes of livestock ownership and production. The sales of live animals and livestock products were considered as market-oriented purposes (Moll, 2005). As shown in Supplementary Table A1, the principal motivation for keeping livestock is income from the sale of live animals (72%), while a few households also sell livestock products (3%). About 15% reported keeping livestock for food consumption, and 9% kept livestock for precautionary savings and self-insurance against shocks. But livestock services for crop farming were rare. Overall, about 76% of livestock ownership is market-oriented (Table 1). As hypothesized, livestock market participants are more likely to engage in market-oriented production.

The remaining rows of Supplementary Table A1 provide information on improved livestock inputs. About 53% vaccinated their livestock, but only about 24% fed their livestock supplementary commercial concentrates. Most households own indigenous breeds, with only about 15% exotic or hybrid breeds. In this study, improved livestock input use is defined as adopting at least one of the modern livestock inputs: vaccination of livestock, feeding commercial concentrates, or keeping exotic or hybrid breeds. Overall, 63% of the farmers used at least one of the improved livestock inputs (Table 1). Market participants are more likely to use modern livestock inputs than non-participants.

As outlined, household dietary diversity (HDD) and *per capita* food expenditure are jointly used to measure food security. The HDD is a qualitative measure for nutrient adequacy and quality of the household diet (Swindale and Bilinsky, 2006). HDD is based on households' food consumption in the past 7 days. These food items were classified into 12 food groups. Supplementary Table A2 in the Supplementary material shows patterns in individual food groups. Table 1 shows the average household consumes from about six food groups. Market participants consume a more diverse diet than non-participants. Household food expenditure is computed as the total value of food consumed from own production, market purchase and gifts and other sources. On average, households spent Z$1,272 on food *per capita* (Table 1). However, it does not differ between market participants and non-participants.

While suggestive, simple mean comparisons can be misleading as market participants and non-participants might differ in observed and unobserved characteristics. This may be true as several covariates significantly differ between market participants and non-participants (Table 1). Below, we use empirical strategies that address this concern.

3.2. Empirical strategy

Our goal is to estimate the effects of livestock market participation on livestock production-orientation, modern livestock input use, HDD, and food expenditure. The empirical specification is:

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TABLE 1 Descriptive statistics of the study sample households by market participation.

Variables	Description of variables	Pooled data (n = 625)	Market participants (n = 304)	Non-market participants (n = 321)
Outcomes				
Livestock market-orientation	Main purpose of a household's livestock production is for sale (yes = 1, 0 = otherwise)	0.76 (0.43)	0.83*** (0.38)	0.69 (0.46)
Improved livestock production	A household supplements livestock feeding with commercial concentrates, vaccinates its livestock and/or adopts exotic/crossbreeds, (yes = 1, 0 = otherwise)	0.63 (0.48)	0.75*** (0.43)	0.51 (0.50)
Household dietary diversity (HDD)	Number of different food groups consumed by a household in the past seven days	6.25 (2.16)	6.65*** (2.06)	5.93 (2.17)
Per capita food expenditure	Total amount spent on household food consumption per person in Zimbabwean dollar (Z$)	1,272 (2749)	1,315 (94.89)	1,255 (197.81)
Covariates				
Livestock market participation	A household sold live animals and/or livestock products (yes = 1, 0 = otherwise)	0.49	100	0
Male	Respondent is male (yes = 1, 0 = otherwise)	0.60 (0.49)	0.66*** (0.48)	0.55 (0.50)
Age	Age of the household head in years	57.47 (14.59)	58.47 (14.09)	57.05 (14.91)
Household size	Number of people living in a household	5.74 (2.75)	6.12*** (2.95)	5.45 (2.46)
Education	Number of completed years of schooling	7.43 (3.43)	7.79** (3.25)	7.10 (3.55)
Farming main occupation	Main occupation of household head is farming (yes = 1, 0 = otherwise)	0.78 (0.42)	0.82* (0.39)	0.75 (0.43)
Land	Total land owned in hectares	2.05 (1.39)	2.28*** (1.42)	1.86 (1.32)
Livestock owned (TLU)	Livestock owned measured using the tropical livestock unit (TLU)	11.10 (13.82)	15.22*** (17.55)	7.85 (7.68)
Per capita income	*Per capita* income value in Zimbabwean dollar (Z$)	3136.59 (7495.81)	3461.62 (6196.18)	2828.77 (8544.96)
Household asset value	Value of the household's total asset in Zimbabwean dollar (Z$)	21937.64 (125141.5)	27663.45 (140014.2)	16515.07 (109154.2)
Group membership	Member of a farmer-based organization (ye = 1, 0 = otherwise)	0.46 (0.50)	0.53*** (0.50)	0.41 (0.49)
Extension services	Received extension services (yes = 1, 0 = otherwise)	0.76 (0.43)	0.83*** (0.02)	0.71 (0.03)
Credit access	Household accessed credit (yes = 1, 0 = otherwise)	0.29 (0.45)	0.27 (0.44)	0.30 (0.46)
Grazing on rangelands	Household fed livestock on rangelands (yes = 1, 0 = otherwise)	0.91 (0.29)	0.92 (0.28)	0.96** (0.20)
Drought feed support	Household received feed support during drought seasons (yes = 1, 0 = otherwise)	0.32 (0.47)	0.34 (0.47)	0.33 (0.47)
Gwanda	Household is from Gwanda (yes = 1, 0 = otherwise)	0.45 (0.50)	0.64*** (0.48)	0.29 (0.46)
Excluded instruments				
Distance to market	Distance to the nearest permanent market in Kilometers	25.71 (24.84)	22.43 (22.13)	28.65*** (26.78)
Livestock market perception	A farmer's perception of livestock market opportunities over the last 10 years (improved = 1 =, 0 = otherwise)	0.52 (0.50)	0.62*** (0.49)	0.45 (0.50)

Standard deviations in parenthesis; statistical significance ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Source: Zimbabwe household survey data.

$$\boldsymbol{Y}_i = \beta_0 + \beta_1 M_i + \beta_2 \boldsymbol{X}_i + \varepsilon_i \quad (1)$$

where $\boldsymbol{Y}_i$ is a vector of our outcome variables for individual i, M_i is livestock market participation status for individual i, $\boldsymbol{X}_i$ is a vector of covariates, and ε_i is a random error term. β_s are vectors of parameters to be estimated. We control for a wide range of individual, household and contextual variables. District dummies and village fixed effects are included throughout the regressions to capture observed and unobserved characteristics due to differences in local governance, market opportunities and political contexts beyond the controlled covariates. We run ordinary least squares (OLS) regressions for HDD and *per capita* food expenditure. But we estimate a linear probability model (LPM) for market-orientation and improved livestock input use, as LPM provides tests for the appropriateness of the IV approach (see below). We transform *per capita* food expenditure to its logarithmic value to address distributional issues.

As indicated, livestock market participation may be endogenous in the outcome models for different reasons. First, there may be potential reverse causality from the outcomes to market participation. Second, unobservable characteristics may drive both the outcomes and market participation simultaneously beyond the controlled covariates. For example, farmers may decide to participate in markets due to their innate entrepreneurial skills and technical abilities in understanding and profitably tapping market opportunities. Third, measurement errors in market participation may lead to a lower bound estimate (Theil, 1971), as typical in recall household surveys. Thus, estimating Equation (1) requires addressing these concerns, where $corr(M_i, \varepsilon_i) \neq 0$. We use an instrumental variables (IV) approach to address threats for identification. We estimate the following two-stage model:

$$M_i = \propto_0 + \propto_1 Z_i + \propto_2 X_i + u_i \text{ and} \quad (2)$$

$$Y_i = \beta_0 + \beta_1 \hat{M}\,\mathrm{i} + \beta_2 X_i + \varepsilon_i \quad (3)$$

where Z_i is a vector of valid instruments, u_i is the error term of the first-stage regression, and other variables are as explained in Equation (1).

As often, the challenge is to find credible instruments, Z_i. Theoretically, valid instruments are those correlated with the endogenous variable but not directly correlated with outcome variables. Using insights from the literature, we identify two relevant instruments for livestock market participation: distance to the nearest permanent market and farmers' perception about livestock market opportunities. Distance to markets is a key indicator of smallholder market access, as it influences transaction costs and ease of doing business (Renkow et al., 2004; Melesse and Cecchi, 2017). Most smallholders in remote rural areas have poor access to transport and market infrastructure, and in most cases, they must transport their livestock products themselves to the market. As a result, shorter distances to markets are likely linked with lower transaction costs and increased market participation (Key et al., 2000). In addition to access to markets, the propensity of smallholders' market participation is likely to be governed by their capacities and attitudes toward available market opportunities and benefits of participation (FAO, 2014). Smallholders would be encouraged to invest in their livestock and practice market-oriented management if they could access improved market opportunities and expect better returns from their investments. Thus, we use smallholders' perceptions about livestock market opportunities over the last 10 years to capture their attitudes toward market participation. Table 1 presents data on the two instruments. On average, farmers are located about 25 km away from the nearest major market. About 52% of the farmers believed that livestock market opportunities had improved over time, which might signal incentives to participate in livestock markets.

The validity of an IV strategy rests on two criteria: the relevance and exclusion restriction criteria. The relevance criterion is that instruments should be good predictors of the endogenous regressor. To formally examine the relevance criterion, Table 2 reports the short-hand form of the first-stage regression results. The instruments are significantly correlated with market participation, confirming that they are relevant predictors of market participation. In addition to the instruments, market participation is significantly correlated with several other control variables, including male, household size, livestock herd, household asset, *per capita* income, group membership and access to extension, with expected signs of association. This implies that farmers with larger herds, larger household sizes, more asset and income, group membership and accessing extension services, are more likely to participate in livestock markets.

The second criterion for valid instruments is the exclusion restriction. It requires that instruments should not be directly correlated with outcome variables, except via the endogenous variable. This is difficult to compellingly satisfy and more so to prove. Households have limited scope to influence distance to markets. One concern is that households concerned about market access may migrate to areas characterized by better market access. While this could violate the exclusion restriction, we believe this does not pose a threat to our data because of the land ownership structure. Zimbabwe's dominant land tenure systems, including our study areas, are communal lands managed under customary tenure (Tatsvarei et al., 2018). In most cases, households are not allowed to transfer land freely to others. Land can only be transferred generationally through marriages and in the event of the death of the landholder. The absence of active land markets restricts rural households' migration, while individual labor migration is high.

Regarding the livestock market perception instrument, it is less likely to directly affect livestock production decisions other than through market prospects. However, a potential concern with the livestock market perception instrument, which is not necessarily connected with the exclusion restriction, is that it may be endogenous in the livestock market participation model, i.e., the first-stage regression. This may be a valid concern, as their participation in markets might partly shape individual's perceptions about market opportunities. While our dataset does not include valid instruments to address this potential threat, we maintain this instrument because it helps us to capture non-infrastructure related drivers of market participation. A placebo test where the instruments are regressors of outcomes of non-market participants confirms the absence of a direct relationship between the instruments and outcome variables. Further, Supplementary Table A3 in the Supplementary material presents further standard statistical tests that support the validity of our instruments (Supplementary Table A3). The Anderson canon and Stock and Yogo (2004) tests reject that the endogenous regressor is weakly identified ($p < 0.01$). The Sargan and Hansen tests (i.e., over-identification restriction tests) fail to reject the null of zero correlation

TABLE 2 First-stage regression results: Instruments significantly correlate with market participation.

Livestock market participation	(1) LPM	(2) LPM
Distance to market	−0.003**	−0.003**
	(0.001)	(0.001)
Livestock market perception	0.085**	0.072**
	(0.039)	(0.039)
Male		0.053**
		(0.040)
Age		0.003
		(0.001)
Household size		0.012*
		(0.007)
Education		0.004
		(0.006)
Farming main occupation		0.054
		(0.048)
Land		0.013**
		(0.014)
Livestock owned (TLU)		0.005***
		(0.002)
Per capita income		0.001*
		(0.001)
Log (household asset)		0.037**
		(0.017)
Group membership		0.070**
		(0.039)
Extension services		0.004*
		(0.048)
Credit access		0.025
		(0.041)
Grazing on rangelands		−0.068
		(0.082)
Drought feed support		−0.030
		(0.039)
Gwanda		0.387***
		(0.119)
Village fixed effects	Yes	Yes
Constant	0.372***	−0.336
	(0.083)	(0.211)
Number of observations	625	625
F-Statistic of the model	6.16	5.74
Prob > F	0.000	0.000
R-squared	0.184	0.260

Statistical significance ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors in parentheses.

between instruments and the error term of the models, implying that our instruments are exogenous and valid, requiring at least one instrument to be exogenous (Murray, 2006). In our case, distance to the nearest market can largely be considered as exogenous. While these tests can help us minimize the concern that our results might be affected by this contaminated instrument, we realize that some reservations may remain about the exogeneity of the livestock market perception in the first-stage regressions. Despite this, we believe that our results remain informative, even in the presence of such contaminated causality in the first-stage regressions.

4. Results

4.1. Main results

We proceed in steps to establish the effect of market participation on the outcome variables. Table 3 presents results from simple regressions, suggesting significant correlations between livestock market participation and all outcome variables. The coefficients are strong with expected signs, ranging from 0.113 for improved livestock production to 0.444 for HDD.

Table 4 also reveals other correlates of the outcome variables. Farmers with farming as their main occupation are more likely to engage in market-oriented livestock production. Those who received feed support during drought seasons are less likely to keep livestock for market purposes. Land, livestock and asset ownership are significantly associated with improved livestock production. Similarly, male farmers are more likely to keep livestock for market purposes and use modern livestock inputs than female farmers. Households with more livestock and asset tend to consume more diversified diets and spend more on food. Household dietary diversity increases with education level and access to extension services, highlighting the importance of knowledge and information for nutrition behavior and outcome (Melesse and Van den Berg, 2021). Conversely, households led by an older head, larger in size, members of a group and primarily depending on farming a livelihood strategy were less food secure.

However, as discussed earlier, market participation may be endogenous. Indeed, the Wu–Hausman and Durbin–Wu–Hausman tests (Supplementary Table A3) confirm that livestock market participation is endogenous as exogeneity is rejected for all outcomes ($p < 0.05$). We employ an IV strategy to attenuate this concern, using distance to the nearest permanent market and household livestock market perception as instruments. Table 4 presents the IV estimation results for all outcome variables. The coefficients for market participation remain significant with the expected sign but are generally higher for the IV estimates than those from the simple regressions (Table 3). Such differences between simple regression and IV estimates are consistent with measurement errors that lead to an attenuation bias toward zero in simple regressions (Theil, 1971). IV approaches often mitigate measurement errors (Gujarati, 2003), because the identification in the IV comes from households responding to changes triggered by the instruments. Thus, the instrumented coefficients can be interpreted as Local Average Treatment Effects (LATE).

Finally, we control for district dummy and village fixed effects throughout all regressions, partially controlling for observed and unobserved community-level characteristics beyond controlled covariates, such as differences in local governance, market opportunities and political contexts. Thus, our results are less likely to be driven by omitted variables. Overall, the results indicate that market participation has a positive effect on the four outcome variables.

While other competing hypotheses cannot be ruled out, we look at smallholder livestock keepers' marketing behavior and

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TABLE 3 Correlations between livestock market participation and outcome variables.

	Livestock market orientation (LPM)	Improved livestock production (LPM)	Household dietary diversity (OLS)	Log *per capita* food expenditure (OLS)
	(1)	(2)	(3)	(4)
Livestock market participation	0.152*** (0.038)	0.113*** (0.038)	0.444*** (0.173)	0.393*** (0.129)
Male	0.088** (0.038)	0.105*** (0.038)	−0.209 (0.171)	0.103 (0.128)
Age	0.001 (0.001)	0.002 (0.001)	−0.016** (0.006)	−0.009* (0.005)
Household size	−0.001 (0.007)	−0.001 (0.007)	−0.007 (0.030)	−0.041* (0.023)
Education	0.001 (0.006)	−0.002 (0.006)	0.065** (0.026)	−0.020 (0.020)
Farming main occupation	0.137*** (0.045)	0.045 (0.045)	−0.621*** (0.202)	−0.334** (0.151)
Land	0.015 (0.013)	0.029** (0.014)	−0.058 (0.061)	−0.002 (0.045)
Livestock owned (TLU)	0.002 (0.002)	0.006*** (0.002)	0.015** (0.007)	0.001 (0.005)
Per capita income	−3.05e-06 (2.69e-06)	−8.05e-07 (2.71e-06)	−7.28e-06 (1.21e-06)	0.0003*** (0.0001)
Log (household asset)	−0.020 (0.016)	0.062*** (0.016)	0.486*** (0.074)	0.198*** (0.055)
Group membership	−0.051 (0.036)	0.067* (0.037)	0.006 (0.164)	−0.383*** (0.123)
Extension services	0.080* (0.044)	0.043 (0.044)	0.491** (0.199)	0.117 (0.149)
Credit access	−0.021 (0.038)	0.048 (0.038)	−0.171 (0.172)	−0.211 (0.128)
Grazing on rangelands	0.086 (0.076)	0.169** (0.077)	1.098*** (0.345)	0.984*** (0.258)
Drought feed support	−0.078** (0.036)	0.016 (0.037)	0.644*** (0.164)	−0.060 (0.123)
Gwanda	−0.177 (0.109)	−0.155 (0.109)	−1.497*** (0.491)	0.057 (0.368)
Village fixed effects	Yes	Yes	Yes	Yes
Constant	0.497** (0.197)	−0.490** (0.198)	1.946** (0.889)	4.579*** (0.665)
Number of observations	625	625	625	625
F-Statistic of the model Prob > F	2.45 0.000	7.21 0.000	6.70 0.000	3.94 0.000
R-squared	0.127	0.300	0.285	0.190

Standard errors in parentheses; statistical significance ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

decision-making process to get some insight into potential mechanisms for the differences between market participants and non-participants. We considered whether smallholders make marketing decisions consistent with a commercial approach, use market information for decision-making, choose formal market channels, and capture value through improved practices. For this purpose, farmers were asked to state their agreement on several statements using a five-point scale, ranging from "completely disagree" to "completely agree." Table 5 summarizes the percentage of respondents that "agree" or "completely agree" with each statement.

The results suggest that market participants are more likely than non-participants to actively look for livestock market information,

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TABLE 4 Effects of livestock market participation on livestock market orientation, improved livestock production, dietary diversity and *per capita* food expenditure.

	Livestock market orientation (IV)	Improved livestock production (IV)	Household dietary diversity (IV)	Log *per capita* food expenditure (IV)
	(1)	(2)	(3)	(4)
Livestock market participation	0.748** (0.357)	0.750** (0.365)	3.188** (1.619)	2.130* (1.159)
Male	0.057 (0.047)	0.072 (0.049)	−0.353 (0.216)	0.011 (0.154)
Age	−0.001 (0.002)	−0.001 (0.002)	−0.024*** (0.009)	−0.015** (0.006)
Household size	−0.008 (0.009)	−0.008 (0.009)	−0.039 (0.040)	−0.061** (0.028)
Education	−0.001 (0.007)	−0.003 (0.007)	0.058* (0.031)	−0.024 (0.022)
Farming main occupation	0.106* (0.055)	0.012 (0.056)	−0.764*** (0.249)	−0.425** (0.178)
Land	0.007 (0.016)	0.021 (0.017)	−0.092 (0.073)	−0.023 (0.052)
Livestock owned (TLU)	−0.001 (0.003)	0.002 (0.003)	−0.001 (0.012)	−0.010 (0.009)
Per capita income	3.06e-07 (3.69e-06)	2.78e-06 (3.78e-06)	8.17e-06 (1.68–06)	0.0004*** (0.0001)
Log (household asset)	−0.041* (0.023)	0.040* (0.023)	0.389*** (0.102)	0.137* (0.073)
Group membership	−0.093* (0.049)	0.022 (0.050)	−0.188 (0.222)	−0.505*** (0.159)
Extension services	0.068 (0.051)	0.030 (0.053)	0.438* (0.233)	0.084 (0.167)
Credit access	−0.032 (0.044)	0.037 (0.045)	−0.220 (0.201)	−0.243* (0.144)
Grazing on rangelands	0.107 (0.089)	0.192** (0.091)	1.198*** (0.404)	1.047*** (0.289)
Drought feed support	−0.061 (0.043)	0.034 (0.044)	0.720*** (0.195)	−0.011 (0.140)
Gwanda	−0.385** (0.176)	−0.378** (0.181)	−2.456*** (0.800)	−0.550 (0.573)
Village fixed effects	Yes	Yes	Yes	Yes
Constant	0.708*** (0.259)	−0.265 (0.266)	2.918** (1.178)	5.194*** (0.843)
Number of observations	625	625	625	625
F-Statistic of the model Prob > F	1.54 0.027	4.86 0.000	4.66 0.000	2.90 0.000
Centered R-squared	−0.234	−0.026	−0.0223	−0.060
Uncentered R-squared	0.698	0.619	0.893	0.944

Standard errors in parentheses; statistical significance ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

claim to negotiate market prices, keep records of their costs and returns, and sell livestock through formal market channels, which may require more commercial practices. Market participants are also more likely to capture livestock market value through formulating prices and valuing livestock according to market conditions, participating in commodity groups to get better market terms and selling livestock during high-price months (seasonal arbitrage). However, only 8% of the respondents sell livestock when market prices are high, implying that non-price factors drive most livestock sales. This suggests that livestock marketing decision-making is significantly influenced by

TABLE 5 Marketing behavior and decision-making statements, percent of respondents.

Statement	Pooled data (n = 625)	Market participants (n = 304)	Non-market participants (n = 321)
Look for and use livestock market information in decision-making	0.64	0.69***	0.59
Negotiate a good price for livestock products at the market	0.54	0.60***	0.49
The livestock market pays premium prices for quality products	0.34	0.36	0.32
Keep records for calculation of returns on investments in livestock	0.20	0.25**	0.17
Sell livestock through formal market channels	0.38	0.42*	0.35
Use farm gate selling as main livestock marketing channel	0.08	0.17***	0.00
Formulate prices and value livestock according to time of sale and market conditions	0.42	0.48***	0.37
Participate in commodity groups to get better market terms for livestock outputs	0.24	0.29**	0.21
Sell livestock during high price months	0.08	0.16***	0.00

Statistical significance ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Source: Zimbabwe household survey data.

other competing needs and interests, and socio-cultural considerations, which in many cases even overshadow the purely economic ones. The decision to sell livestock is often needs-driven; livestock sales peak during a period (November to April), when farmers are in need of cash to balance food deficits, schools reopening and hence the need to pay for children's school fees and buying inputs for the next agricultural season (Homann-Kee Tui et al., 2022). For farmers with smaller herds and less cropland in a farming context of variable climate, pests and diseases, economic upheavals, and mortality losses from previous seasons, holding back livestock to time sales with better market terms may overshadow purely economic goals.

Particularly, the sale price offered to the farmer is not the most important consideration when deciding when and to whom to sell. This is manifested in the low off-take percentage and lacking participation in commercial production. This can also reflect market imperfections, as livestock markets in rural Zimbabwe differ in effectiveness, limiting the transfer of information and incentives to smallholder farmers (Homann-Kee Tui et al., 2022). In Districts, like Gwanda, livestock markets are more commercialized and target high-income markets, as owners of large cattle and goat herds exist that regularly supply livestock, along with many smallholder farmers owning smaller livestock and selling occasionally. Efforts to improve market participation must distinguish between contexts with more and less developed livestock markets, and within those contexts, the behaviors of market-oriented farmers and those that are needs-driven.

4.2. Sensitivity analyzes

We assess the robustness of our findings in several ways. First, we consider different functional forms for some outcomes. Livestock market orientation and modern input use are binary, and the HDD is a count variable. While applying the linear model provides tests for the IV strategy, using linear models for these outcomes may not be appropriate. As such, we estimate the IV probit model for market-orientation and farming intensity and IV Poisson for HDD, which fits the exponential conditional mean and implements the generalized method of moments (GMM) estimator. The results are significant and robust (Table 6), suggesting that the non-linearity of these variables does not drive the results.

Second, because livestock market participation is a binary variable, (i) there may be a possibility for non-linear relationship between market participation and outcome variables, and (ii) it does not fit the continuous endogenous variable assumption of estimated models (e.g., the IV probit model). We apply a control function estimation, an appropriate equivalent to instrumental variables estimation in the potential presence of thresholds and non-linearity in effects. It also accounts for the binary nature of the treatment variable and addresses endogeneity by implementing the control function estimators (Wooldridge, 2010). The results presented in the Supplementary material confirm strong and significant effects of market participation on outcome variables (Supplementary Table A4). The coefficients are interpreted as improvements from potential outcomes that would otherwise be attained when farmers do not participate in markets.

Finally, we carry out multiple hypothesis testing (MHT) to assess whether reported results are true effects and can jointly be identified. We follow the procedure by Barsbai et al. (2020),[3] which is an improvement on the previous procedure (mhtexp) of List et al. (2019). The Barsbai et al. (2020) procedure is a regression-based approach that permits multiple outcomes or treatments with other control variables. For completeness, we first perform the MHT by excluding other covariates and later by including them. Results for value of ps adjusted for multiple hypotheses based on different approaches are presented in the Supplementary material (Supplementary Table A5). While there are some differences in coefficient magnitudes in the specifications with and without covariates, the effects of market participation largely remain significant and consistent. A minor difference is a slight change in the significance levels for the Bonferroni correction, which is the most conservative correction. Overall, our results are robust to the possibility of false discoveries.

5. Conclusion and policy implications

This paper presents results on the effects of smallholder livestock market participation on livestock production decisions and household

3 Available at https://sites.google.com/site/andreassteinmayr/mhtreg

TABLE 6 Robustness checks: Alternative model specifications for livestock market orientation, improved livestock production and household dietary diversity.

	Livestock market orientation (IV probit)	Improved livestock production (IV probit)	Household dietary diversity (IV Poisson)
	(1)	(2)	(3)
Livestock market perception	2.340***	1.869***	0.589**
	(0.128)	(0.400)	(0.276)
Controls	Yes	Yes	Yes
District dummy	Yes	Yes	Yes
Village fixed effects	Yes	Yes	Yes
Constant	0.674	−1.353	1.302***
	(0.526)	(0.973)	(0.196)
Number of observations	625	625	625
Wald test: χ^2 (1)	721.48	434.09	
value of p	0.000	0.000	

Standard errors in parentheses; Controls include male, age, household size, education, farming main occupation, land, livestock owned (TLU), log (household asset), group membership, extension services, credit access, grazing on rangelands and drought feed support; statistical significance ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

food security in Zimbabwe. We find robust evidence that smallholder households participating in livestock markets are more likely to engage in market-oriented livestock production and use improved livestock inputs. Similarly, our results reveal that livestock market participation significantly improves household dietary diversity and *per capita* food expenditure. We use an instrumental variables (IV) strategy to account for potential endogeneity concerns. While relevant diagnostic checks and tests support the validity of our IV strategy and instruments, we acknowledge that making neat causality based on non-experimental cross-section data remains a challenge.

Our study has important implications for policy and interventions geared toward enhancing smallholder livestock market participation in Zimbabwe. Improving the market environment by investing in functional market systems and complementary services (e.g., access to market information, feed inputs and processing, veterinary services and insurance) are all needed to improve market access and offtake rates of smallholders. Extension services operate more effectively through farmer cooperatives and groups, with farmer field school concepts introduced in many areas, linking productivity improvements with market organization. User access fees charged to smallholder farmers utilizing marketing facilities can be considered as a strategy of financing operations of agricultural market information services and marketing facilities, if cooperatives and groups can establish trust and accountability in the use of the fee for maintaining the marketing facilities. Investments in market infrastructure in isolation are, however, not enough to stimulate smallholder market participation. Equally important are transparent and rewarding price-quality mechanisms, such as auction sales or permit sales. Coordination, capacity development and control through farmer cooperatives and groups can be critical to enhance participation in these markets and avoid buyer clienteles manipulating the prices. Market participants invest more in livestock production than those who do not regularly participate in markets. As far as agricultural technologies offer productivity improvements, the relationship between livestock market participation and improved input use has profound implications for the productivity of the livestock sector in Zimbabwe.

Further, it is important to recognize that complex processes influence decisions in livestock production for commercial objectives. We found that farmers with larger herds, more cropland and larger household sizes, often male and operating in a group and accessing extension services, were more likely to participate in livestock markets. A major constraint that limits farmers full participation in livestock markets is that many of the households have insufficient livestock to meet their economic, social and cultural needs, while unforeseeable market risks and unfavorable terms of trade at the same time discourage them to have animals to sell on a regular basis. In many cases, smallholder livestock marketing decision-making is primarily influenced by coping strategies and recovery from shocks, holding back livestock to rebuild the herds, and gambling that the nucleus herd would survive the next dry period, to the extent of overshadowing profit maximizing considerations. More specifically, the sale prices offered to smallholder farmers may not be the most important consideration. While prices are considered inadequate, payment uncertainties compound the challenges to smallholder market participation, leading to low off-take rates and a lack of interest in commercial production.

We also find that market participants are more likely to actively search for market information, are more inclined to value livestock according to market conditions, more often sell livestock through formal channels, and participate more in commodity groups to get better market terms. Despite this, most smallholders lack sufficiently large herd sizes, and hence capacity, to access technical services and establish such market-orientation. Thus, smallholders may not participate effectively in market development processes, even with appropriate support, in the absence of more favorable conditions that reward market-orientation and attitudes toward commercialization. Thus, accessible and equitable decision support systems are needed for those that can invest in market-oriented livestock production, while enabling market conditions to ensure that those many farmers who sell small livestock benefit during critical periods (Audsley, 1993; Homann-Kee Tui et al., 2022). This reconfirms that transitioning smallholder farmers to market-oriented livestock production requires substantial changes in the business environment, with accessible and functional information systems and innovative business channels for more direct relations between smallholders and downstream value

chain businesses (Hernandez-Aguilera et al., 2018). For instance, smallholders' associations and collective efforts may unlock opportunities to coordinate farming practices, strategies for acquisition of inputs and sales, and sharing risks and benefits from better market terms among smaller producers who are neighbors and can act as a single farm collectively (Hernandez-Aguilera et al., 2019). Importantly, commodity groups can provide platforms for experimental group learning and observations to help accelerating changes in mindsets and attitudes toward commercialization, enhancing the wider uptake of technologies and thereby improving livestock production and supply of livestock products following market criteria.

Overall, our results provide evidence that livestock market participation enables farmers to reinvest in potentially productive improved livestock inputs. These findings contribute to the relatively thin literature on the effects of successful market-oriented livestock production on productivity, improved food security and diversity of diets, and contributing to climate change adaptation and mitigation outcomes in Africa. Taken together, our findings support that market-oriented livestock production can be an integral component of food systems in Zimbabwe, particularly in crop-livestock mixed farming systems in semi-arid areas where crop production is risky. Evidently, Sekaran et al. (2021) highlighted that the role of integrated crop-livestock systems in improving agriculture production and thereby addressing poverty and food insecurity in low-and medium-income countries.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval for research protocols, process, data management, and risks related to participation in the research was obtained from the Institutional Ethics Committee (IEC), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The study was conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1222509/full#supplementary-material

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