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Beyond herd size: associations of births and theft losses with live animal sales among Somali pastoral households

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Live animal sales convert pastoral herds into cash income, yet models of sales decisions usually represent the herd only by its size. This study examines the associations of herd size, births, and theft losses with live sales (animals sold alive) among Somali pastoral households, separately for the decision to sell and the number sold. Using the 2022 Somali Integrated Household Budget Survey (N = 7,008 household-animal-type records from 2,521 households), a hurdle negative binomial model with region fixed effects related sales to the opening stock reconstructed from recorded herd flows, births, and any theft; household fixed-effects models compared animal types within households. Births were associated with a higher probability of selling (odds ratio, OR = 1.52 per log unit, $p < 0.001$), also within households (OR = 1.37), but not with the number sold. Theft was associated with a higher probability of selling (OR = 1.35, $p = 0.018$) and with fewer animals sold by sellers in the record-level models (incidence rate ratio = 0.76); within households, the theft OR was similar but imprecise (1.34, 95% confidence interval 0.88–2.04). The positive theft association was confined to goats and sheep, was not significant for the number of animals stolen, and was essentially unchanged by further controls, including losses to drought, disease, and predators, household shocks, and remittances. Survey-weighted models gave similar results, except that births were also associated with the number sold. The cross-sectional design precludes causal inference, and the theft association is consistent with distress selling, pre-emptive selling, or common exposure to insecurity, which the data cannot distinguish. The composition of herd change was therefore associated mainly with whether households sold, not with how many animals they sold. If the theft association reflects distress selling, herd security merits attention alongside herd size in livestock-market interventions in Somalia.

KEYWORDS
live animal sales, livestock offtake, pastoral households, herd size, hurdle negative binomial model, Somalia

Introduction

Selling animals converts pastoral herd assets into cash, but sales are only one of several flows through which a herd changes within a year. A herd serves at once as capital, insurance, and a subsistence buffer, so sales are better treated as one output of a biological stock that is continuously replenished and depleted than as a single behavioural choice. Livestock offtake is widely used as a measure of commercialisation in pastoral economies (Barrett, 2008); this study analyses one component, animals sold alive (live sales). Research on the Somali livestock economy has focused on trade, including exports from Somaliland's terminal

markets (Musa et al., 2020) and their exposure to a Saudi import ban compounded by COVID-19 (Mtimet et al., 2021), but offers no household-level evidence on live sales.

The commercialisation literature identifies herd size as a major determinant of market participation and sales volume (Belay et al., 2021; Lutta et al., 2020), alongside transaction-cost variables such as distance, extension, and price information (Nwafor et al., 2020; Mkhize et al., 2026; Barrett, 2008). Commercialisation has also been linked to welfare (Ochieng et al., 2020; Ogutu et al., 2020; Melesse et al., 2023) and to livestock accumulation (Tabe-Ojong et al., 2022), implying that herd size and sales are two observations of one stock-flow process in which births add to the stock and mortality, theft, and sales deplete it. System-dynamics and herd-dynamics models of small-ruminant and cattle production systems represent herd flows such as births, mortality, and offtake explicitly (Wanyoike et al., 2023; Li et al., 2023); the commercialisation literature rarely does. It therefore remains unsettled whether the herd-size association reflects wealth and risk-bearing capacity or a mechanical scaling of a fixed sales rate.

The composition of herd change is also rarely examined. Births depend largely on biological and management factors rather than market incentives (Nkadimeng et al., 2022), so a births–sales association may reflect passive stock availability more than active decision-making. Studies of loss have focused on mortality and disease, including camel mortality in Somaliland (Hassan and Salih, 2026), livestock mortality and household food insecurity in Somalia (Issack, 2026), and ruminant mortality, the economy-wide effects of livestock disease, and camel calf health problems in Ethiopia (Innocent et al., 2022; Countryman et al., 2024; Hussein et al., 2024). This literature documents the patterns, causes, and economic or welfare consequences of loss, and rarely asks whether shock-related loss is associated with household market behaviour differently from ordinary herd growth.

Evidence on how shocks relate to sales is mixed. In the Borana zone of Ethiopia, just over half (54.1%) of surveyed households reported destocking to cope with drought (Sintayehu et al., 2025), but livestock sales offset only a modest share of income shortfalls in West Africa (Fafchamps et al., 1998), and in northern Kenya income and asset shocks affected livestock sales in offsetting directions (McPeak, 2004). Theft removes animals directly, so a positive association with sales is not the default expectation. Livestock raiding and theft are well documented in East Africa and the Horn of Africa (Bollig, 1990; 2006; Fleisher, 2000; McCabe, 2004), including their motives and effects on livelihoods, mobility, and markets (Schilling et al., 2012), but have rarely been analysed quantitatively as a correlate of household market behaviour in nationally collected survey data.

Market participation has an extensive margin (whether a household sells) and an intensive margin (how much it sells), which households in Kenyan and Ethiopian livestock markets have been found to decide sequentially (Bellemare and Barrett, 2006). The number of animals sold is, however, a discrete count concentrated at zero, which the Heckman, probit, and Tobit estimators of earlier studies (Belay et al., 2021; Lutta et al., 2020) were not designed to accommodate. Hurdle count models, which combine a binary model for any sale with a truncated count model for the number sold (Mullahy, 1986), address both features.

This study relates live sales jointly to herd size, births, and theft losses, using 12 months of nationally collected records from the 2022 Somali Integrated Household Budget Survey. A hurdle negative binomial model separates the decision to sell from the number sold and conditions on the herd held before, rather than after, the sales being explained, extending count-based treatments of camel mortality (Hassan and Salih, 2026) to the sales decision. The objectives were to (1) quantify the independent associations of herd size, births, and theft losses with live sales among Somali pastoral households, separately for the decision to sell and the number sold, and (2) assess whether the composition of herd change (growth through births versus loss through theft) is associated with market behaviour beyond what net herd size predicts.

Materials and Methods

Study design and data source

This is a cross-sectional analysis of the 2022 Somali Integrated Household Budget Survey (SIHBS), produced by the Somalia National Bureau of Statistics (SNBS) and available at.[1] The SIHBS used a stratified multi-stage probability cluster sample of 7,212 households in 601 enumeration areas across 17 of the 18 pre-war regions (Middle Juba was not surveyed because of insecurity), covering urban, rural, and nomadic areas, with household sampling weights and a 96% response rate (SNBS, 2023a). Fieldwork took place between 10 May and 31 July 2022 (SNBS, 2023a), so the 12-month recall period spans approximately May 2021 to July 2022, which coincided with the multi-season 2021–2022 drought in the Horn of Africa (Kimutai et al., 2025). The survey records neither market prices nor market disruptions, so market conditions during the recall period cannot be described.

The analysis file comprised 7,020 household-animal-type records, each giving the stock held at interview; the animals born, purchased, received as gifts, lost to drought, disease, and predators, lost to theft, sold alive, and slaughtered for sale; and the value of live sales (descriptive statistics in Tables 1, 2). Region, enumeration-area type, household size, weights, remittance receipt, distance to the nearest all-season road, housing materials, reported shocks and responses, and the household head's sex, age, and literacy and members' work were merged by household identifier (all analytic records and households matched). Poverty status came from the survey's consumption aggregate, whose household identifiers do not follow the numbering of the other files (household size agreed for the same identifier in only 11% of households). Households were therefore linked on the information both files record (region, enumeration-area type, displacement status, household size, and the poverty-analysis weight, then spending on food eaten away from home, rent, and non-food items), without imputation: of 7,212 households, 7,050 were linked to a single household, 76 to several partners with the same poverty status, 26 could not be resolved, and 60 were outside the poverty analysis. The first three groups total 7,152, the

1 https://microdata.nbs.gov.so/index.php/catalog/59/get-microdata

TABLE 1 Descriptive statistics for animal-type records (panel A) and continuous household characteristics (panel B).

Variable	Mean or %	SD	Median	Min	Max	% Zero
A. Animal-type records (N = 7,008)						
Live sales (animals sold)	1.71	8.84	0	0	650	61.09%
Closing stock	13.88	21.05	7	1	550	0.00%
Opening stock	18.31	31.93	8	0	763	5.85%
Births	3.25	5.30	2	0	100	32.89%
Theft losses	0.22	1.38	0	0	45	92.49%
Lost to drought, disease, and predators	5.68	16.45	1	0	300	48.70%
Slaughtered for sale	0.43	8.71	0	0	720	86.39%
Purchased	0.35	3.17	0	0	210	89.00%
Received as gifts	0.08	0.81	0	0	50	96.82%
Household size (persons)	6.58	2.58	6	1	23	0.00%
B. Households (N = 2,521)						
Household size (persons)	6.57	2.63	6	1	23	0.00%
Animal types held	2.78	1.73	2	1	9	0.00%
Closing stock, all types (TLU)	7.98	13.42	3.10	0.01	313.10	0.00%
Opening stock, all types (TLU)	9.81	15.43	3.90	0.00	313.20	3.41%
Live sales, all types (TLU)	0.70	1.86	0.20	0.00	67.50	42.92%
Head's age, years (n = 2,406)	42.71	13.15	42	17	65	0.00%
Distance to all-season road, km (n = 2,226)	6.94	92.05	0	0	2,000	79.38%
Housing-quality index, 0–3 (n = 2,226)	1.15	1.15	1	0	3	38.54%

Opening stock = closing stock + sold + slaughtered for sale + lost to drought, disease, and predators + stolen − born − purchased − received as gifts; 77 negative values were set to zero. Panel A: animal-type records were mostly she goats (28.5%) and billy goats (17.3%), and settlement type was mostly nomadic (43.7%) and rural (39.1%); 70.1% of the 6,855 records with a poverty status were classified as poor. Panel B: stocks and live sales are summed over animal types in Tropical Livestock Units (TLU; camel 1.0, cattle 0.7, sheep and goats 0.1, donkey 0.5, chicken 0.01; Jahnke, 1982), with the opening stock as in the household-level model; n, households with the item recorded. The head's age is top-coded at 65 in the public file. Distance is recorded as 0 when the road is less than 1 km away (SNBS, 2022); 13 households report more than 100 km (up to 2,000 km).

number on which the SNBS poverty report bases its consumption deciles (SNBS, 2023b). Of the 2,474 analytic households with a poverty status, 67.9% were classified as poor (Table 2), close to the roughly 65% obtained by applying the published area headcounts (nomadic 78.4%, rural 65.5%, urban 46.1%; SNBS, 2023b) to these households' settlement composition; because the headcounts refer to persons, the comparison is approximate. Food consumption data not used in the linkage agreed with the food spending of linked households (correlation of log values 0.81–0.88) but not with that of households merged by identifier (0.04). Variable definitions follow the SIHBS documentation (SNBS, 2022).

Study population and unit of analysis

The population comprises livestock-owning households. Of the 7,212 households interviewed, 2,523 (35.0%) reported owning or raising livestock or chickens, or having bought or sold any, in the past 12 months, and one record was made for each listed animal type they owned at interview (SNBS, 2022). The unit of analysis is the household-animal-type record, so households with several animal types contribute several records. Two of the 13 listed types (improved chickens and other livestock) had too few records and were excluded. The 11 retained types combine species with sex and age classes: camels; male sheep, ewes, male lambs, and female lambs; billy goats and she goats; indigenous cattle and oxen; indigenous chickens; and donkeys. Because classes of one species enter as separate records, the main results were also re-estimated at the household-species and household levels. In record-level models, stock, births, theft, and sales all refer to the same animal type; holdings of different types are aggregated, in Tropical Livestock Units (TLU), only in household-level models. The 7,008 analytic records came from 2,521 households (mean 2.78, median 2 records; interquartile range 1–4; range 1–9); 724 households (28.7%) contributed one record (Supplementary Table S7).

Variables and operational definitions

The outcome is the number of animals sold alive in the 12 months before the survey; animals slaughtered for sale are recorded separately and excluded. The focal variables are herd size, the stock of the animal type held at interview (a closing stock, which already reflects the period's sales and other flows);

TABLE 2 Categorical household characteristics (N = 2,521 households; percentage of households).

Characteristic	%	Characteristic	%
Rural	40.5%	Holds donkeys	23.0%
Urban	24.7%	Holds chickens	11.5%
Nomadic	34.8%	Any live sale	57.1%
Classified poor (n = 2,474)	67.9%	Any births	83.9%
Female head	46.9%	Any theft	14.0%
Head can read (n = 2,442)	35.7%	Any losses to drought, disease, and predators	65.3%
Received remittances, past 12 months	18.8%	Any main shock, past 24 months	89.4%
Member in paid or non-farm work, past week (n = 2,509)	42.0%	Shock: drought or severe water shortage	71.7%
Holds camels	23.1%	Shock: large rise in food prices	51.2%
Holds cattle	21.8%	Shock: death of livestock	36.7%
Holds sheep	37.6%	Shock: livestock theft	1.7%
Holds goats	79.8%	Shock: conflict or robbery	2.1%

n, households with the item recorded, where fewer than 2,521. Shocks are those named among the household's three most significant shocks of the past 24 months. Poverty status comes from the linkage described in Materials and Methods.

births, the number born into the herd (the survey does not specify whether young are recorded against the class of the dam or of the offspring); and theft, the number lost to theft, a loss to human removal distinct from mortality due to disease, drought, or predation. Losses to drought, disease, and predators are recorded as a single item.

Because a closing stock already reflects the sales being explained, the models use the opening stock reconstructed from the stock-flow identity: closing stock + sold alive + slaughtered for sale + lost to drought, disease, and predators + stolen − born − purchased − received as gifts. The 77 negative values (1.10% of records), where recorded inflows exceeded the closing stock plus recorded outflows, were set to zero. Slaughter for household consumption, animals given away, other losses, and movements between classes are not recorded (SNBS, 2022); omitted outflows would make the reconstruction understate the opening stock, whereas movements between classes cancel when records are summed to the household-species level. An approximate opening stock from four flows (closing stock + sold + stolen − born) and other stock definitions are examined in the robustness analyses. Opening stock and births entered as log(1 + x), so that the stock coefficient approximates an elasticity, and theft as an indicator of any theft, because 92.49% of records reported none; the number stolen and rates per animal held were used in sensitivity analyses.

Controls were animal type (11 categories; she goats as reference), settlement type (rural as reference), household size, and region (17 pre-war regions surveyed; Awdal as reference). Poverty status was used only in a sensitivity analysis, because livestock sales help to finance consumption and poverty may be endogenous to the outcome; it is available for 6,855 of the 7,008 records, and the other 153 are retained in all other models. Further controls were added in sensitivity analyses: losses to drought, disease, and predators (log(1 + x)); remittance receipt in the past 12 months; household shocks (indicators that drought or severe water shortage, livestock death, a large rise in food prices, or insecurity [conflict, or robbery, burglary, or assault] was among the three most significant shocks of the past 24 months); the head's sex, age (top-coded at 65, per 10 years), and literacy; distance to the nearest all-season road (log(1 + km)), a proxy for market access; and a housing-quality index (0–3) counting finished floor (cement or tiles), wall (stone, cement bricks, or baked bricks), and roof (iron sheets, tiles, or concrete) materials, a wealth proxy not derived from consumption. Distance and housing data were missing for 295 households (1,029 records; 211 nomadic households), leaving 5,979 records; head data were missing for 115 households (342 records), leaving 6,666; and models with all further controls use the 5,684 records with complete data.

Coefficients are reported as odds ratios (ORs) for the participation equation and incidence rate ratios (IRRs) for the quantity equation (the multiplicative change in the expected number sold among records with a sale). For opening stock and births, a ratio refers to a one-unit increase in log(1 + x), that is, multiplying (1 + x) by about 2.7; a quantity coefficient of 0.83 for the stock, for example, implies that a 10% larger opening stock is associated with about 8% more animals sold among records with a sale. For theft, a ratio compares records with and without any theft.

Analytical approach

Analyses used R 4.3.3 with haven (2.5.4), dplyr (1.1.4), MASS (7.3–60.0.1), pscl (1.5.9), AER (1.2–12), car (3.1–2), sandwich (3.1–0), lmtest (0.9–40), numDeriv (2016.8–1.1), and survival (3.5–8). NB2 models used glm.nb (MASS), and zero-inflated and hurdle models zeroinfl and hurdle (pscl), with logit zero-inflation and participation equations, log-link count equations, and a relative convergence tolerance of 10^{-14}. Household-clustered covariance matrices (vcovCL, sandwich; HC1 adjustment) and z tests with 95% Wald confidence intervals (coeftest, lmtest) were used throughout. Poisson, negative binomial (NB; variance a quadratic function of the mean, NB2), zero-inflated Poisson and NB (ZINB),

TABLE 3 Comparison of count-model families on the fully adjusted specification (N = 7,008).

Model	k	Log-likelihood	AIC	BIC	Zeros (%)	CV
Poisson	33	−12,289.66	24,645.31	24,871.52	48.70	−1.86
Negative binomial (NB2)	34	−9,265.52	18,599.03	18,832.10	58.11	−1.33
Zero-inflated Poisson	66	−9,855.40	19,842.79	20,295.21	61.25	−1.51
Zero-inflated NB	67	−8,770.49	17,674.99	18,134.26	61.23	−1.27
Hurdle Poisson	66	−9,881.89	19,895.78	20,348.19	61.09	−1.51
Hurdle NB (primary)	67	−8,794.38	17,722.75	18,182.02	61.09	−1.27

All models include log(1 + opening stock), log(1 + births), any theft, animal-type fixed effects, settlement type, household size, and region fixed effects; in zero-inflated and hurdle models the same covariates enter both equations. k, number of estimated parameters; Zeros, mean predicted probability of a zero (observed 61.09%); CV, mean out-of-sample log-likelihood per record from 10-fold cross-validation with folds assigned by household (higher is better). The comparison on the reduced specification is in Supplementary Table S6.

TABLE 4 Odds ratios (OR) and incidence rate ratios (IRR) for the focal predictors and principal controls from the final hurdle negative binomial model (Model 3).

Term	Participation: OR [95% CI]	p	Quantity: IRR [95% CI]	p
log(1 + opening stock)	2.28 [2.11, 2.47]	<0.001	2.29 [2.10, 2.49]	<0.001
log(1 + births)	1.52 [1.40, 1.66]	<0.001	1.03 [0.98, 1.08]	0.281
Any theft (vs. none)	1.35 [1.05, 1.73]	0.018	0.76 [0.67, 0.86]	<0.001
Urban (vs. rural)	1.20 [0.96, 1.50]	0.118	1.00 [0.89, 1.14]	0.953
Nomadic (vs. rural)	1.09 [0.92, 1.29]	0.309	0.91 [0.82, 1.01]	0.069
Household size (per person)	0.95 [0.93, 0.98]	0.002	1.01 [0.99, 1.02]	0.475

N = 7,008 records (2,521 households). Participation: logit for any live sale; quantity: zero-truncated NB2 for the number sold among records with a sale (θ = 3.61). 95% confidence intervals are from household-clustered standard errors. Animal-type and region fixed effects (16 indicators; Awdal as reference) are included but not shown: animal-type ORs, ranged from 3.37 (billy goats) to 0.12 (donkeys) and IRRs from 1.85 (indigenous chickens) to 0.15 (donkeys), relative to she goats. Complete estimates and Models 1 and 2 are in Supplementary Table S1.

and hurdle Poisson and NB models were compared on the fully adjusted specification (all covariates in both equations of two-part models) by the Akaike and Bayesian information criteria (AIC and BIC), predicted zeros, observed and expected count frequencies, and the mean out-of-sample log-likelihood from 10-fold cross-validation with folds assigned by household (Table 3). The Vuong test was not used because it is not valid for testing zero-inflation against a non-inflated counterpart (Wilson, 2015).

The primary model is a hurdle NB model (Mullahy, 1986): a logit equation for whether any animals of a type were sold (participation) and a zero-truncated NB2 equation for how many were sold when sales occurred (quantity). Tobit and Heckman selection models, used in some studies of livestock market participation (Belay et al., 2021; Lutta et al., 2020), were not used for the primary analysis. At the record level, converting the outcome to TLU would only rescale a count of one animal type, leaving its discreteness and concentration at zero; Tobit assumes a single latent index for whether and how much a household sells, a restriction the hurdle model relaxes; and a selection model needs a variable that affects the decision to sell but not the number sold, which these data lack. TLU weights also reflect body weight rather than market value (Jahnke, 1982), so TLU are used only in household-level models. The Tobit restriction was nevertheless tested on the value of live sales (US dollars, recorded only for sales), entered as log(1 + value): a Tobit model left-censored at zero (Tobin, 1958) was compared by a likelihood-ratio test with the double-hurdle model that nests it (Cragg, 1971), which combines a probit equation for any sale with a truncated normal regression for the value of sales. The 17 records with a sale but a value of zero were excluded, and a sensitivity analysis also excluded 35 records whose value per animal sold was below one-tenth or above ten times the median for their animal type.

Multicollinearity was screened with generalised variance inflation factors (GVIFs). Three staged hurdle NB models were estimated: Model 1 with the three focal predictors only; Model 2 adding animal-type fixed effects; and Model 3 (Table 4) adding settlement type, household size, and region fixed effects. Standard errors were clustered by household (heteroskedasticity-robust in household-level models). Primary models are unweighted. Significance was assessed at $\alpha = 0.05$, with 95% confidence intervals for all ORs and IRRs. Robustness was assessed by varying the theft and births measures, stock definition, controls, sample, model family, and unit of analysis (Tables 5, 6). Records were summed to the household-species level (camels; cattle, combining indigenous cattle and oxen; sheep; goats; donkeys; chickens) with species fixed effects, and re-estimated separately for small ruminants (goats and sheep) and for camels and cattle. At the household level, holdings were converted to TLU (camel 1.0, cattle 0.7, sheep and goats 0.1, donkey 0.5, chicken 0.01; Jahnke, 1982), any sale was modelled by logit, and TLU sold by selling households by Poisson quasi-maximum likelihood.

To hold fixed all conditions shared by a household's records, including those the data capture only partly (enumeration area, local

TABLE 5 Robustness of the births and theft associations in pooled record-level models: alternative measures, samples, model families, and controls.

Specification	N	Participation (OR)		Quantity (IRR)	
		Births	Any theft	Births	Any theft
A. Alternative measures of stock, births, and theft (hurdle NB; records)					
Primary model (Table 4)	7,008	1.52***	1.35*	1.03	0.76***
Theft as log(1 + animals stolen)	7,008	1.53***	1.04	1.02	0.83***
Births and theft as rates per animal held	7,008	1.18***	1.34	1.23***	0.48*
Stock: opening stock plus births	7,008	1.22***	1.37*	0.88***	0.76***
Stock: opening stock net of theft	7,008	1.52***	1.58***	1.03	0.82**
Stock: approximate opening stock (closing + sold + stolen − born)	7,008	1.51***	1.34*	1.02	0.77***
Stock: log closing stock	7,008	1.37***	1.85***	0.96	0.87
B. Alternative samples (hurdle NB; records)					
Excluding the record with 650 sold from 90 head	7,007	1.52***	1.35*	1.02	0.77***
Excluding records with a negative implied opening stock	6,931	1.49***	1.33*	1.01	0.74***
Excluding records with number sold > closing stock	6,850	1.59***	1.31*	1.08**	0.72***
Excluding households that named conflict or robbery among their main shocks	6,869	1.51***	1.37*	1.03	0.77***
Including the record with 999 animals lost to drought, disease, and predators	7,009	1.52***	1.35*	1.03	0.76***
C. Alternative model families (records)					
ZINB, covariates in both equations	7,008	1.57***	2.01**	1.05	0.75***
NB2, single equation, opening stock	7,008	—	—	1.25***	0.88
NB2, single equation, log closing stock	7,008	—	—	1.15**	1.15
D. Controls (hurdle NB; records)					
Region fixed effects excluded	7,008	1.40***	1.59***	1.01	0.75***
Poverty status added (records with a poverty status)	6,855	1.51***	1.33*	1.03	0.75***
Primary model, households with data for all further controls	5,684	1.51***	1.38*	1.02	0.75***
All further controls added (same households)	5,684	1.53***	1.36*	1.00	0.75***

Values are ORs (participation) and IRRs (quantity) from hurdle NB models with the Model 3 covariates, including region fixed effects, unless stated otherwise. *p < .05; **p < .01; ***p < .001; unmarked values are not significant at p < .05 (household-clustered inference). The stock measure was positively associated with both margins in every specification (p < .001). Rates: births or animals stolen divided by (opening stock +1). ZINB: participation values are from the zero-inflation equation with the sign reversed. NB2: single-equation IRRs, for the number sold, zeros included. Panel D: further controls are listed in Materials and Methods; the 5,684-record rows compare the primary model with the model adding all further controls on the same records. Rows for each control added separately, with the matching primary model on the same records, and estimates with standard errors are in Supplementary Table S3.

security, and drought), participation was also estimated with household fixed effects, comparing animal types within households: by exact conditional logit (Chamberlain, 1980) with animal-type fixed effects, log(1 + opening stock), and log(1 + births), and by a linear probability model; the number sold, zeros included, was modelled by Poisson quasi-maximum likelihood. Households with one record do not contribute, the conditional logit uses only households with records both with and without a sale, and conditions that differ between a household's herds are not held fixed. Whether the theft association differed between and within households was tested in a correlated random-effects linear probability model with region fixed effects that adds household means of the record-level covariates (Mundlak, 1978); the coefficient on the household mean of theft is the between- minus the within-household association.

Whether the theft association differed by region, remittance receipt, regional insecurity, or non-livestock work was tested by adding to both equations of the primary model an interaction of theft with one of: an indicator of the northern regions (Awdal, Bari, Nugaal, Sanaag, Sool, Togdheer, and Waqooyi Galbeed); indicators of the eight regions with at least 20 theft records (the other nine sharing one term; joint Wald test); remittance receipt; the survey-weighted regional share of households naming conflict or robbery, burglary, or assault among their three most significant shocks (per 10 percentage points); or paid or non-farm work by a household member aged 15 or older in the previous week, a proxy for non-livestock income. Recorded theft was also compared with the shocks households ranked among their three most significant and their reported responses, which include selling livestock or poultry. The influence of extreme records was assessed by re-estimating the

TABLE 6 Robustness of the births and theft associations by unit of analysis, within households, and with survey weights.

Specification	N	Participation (OR)		Quantity (IRR)	
		Births	Any theft	Births	Any theft
A. Alternative units of analysis					
Household-species level (6 species)	4,963	1.58***	1.38*	1.03	0.91
Goats and sheep only (household-species)	2,960	1.53***	1.60**	1.01	0.93
Camels and cattle only (household-species)	1,129	1.87***	0.43*	1.01	0.77
Household level (TLU)	2,521	1.62***	2.07***	1.18**	1.00
B. Within-household comparisons (household fixed effects; records)					
Conditional logit, opening stock (primary within-household model)	3,631	1.37***	1.34	—	—
Conditional logit, opening stock as a natural spline	3,631	1.39***	1.24	—	—
Conditional logit, closing stock	3,631	1.17*	1.69*	—	—
Poisson, number sold (zeros included)	4,337	—	—	1.14*	0.82
C. Survey weights (SIHBS household weights; design-based inference)					
Primary model, weighted	7,008	1.55***	1.40*	1.09**	0.82*
Household-species level, weighted	4,963	1.66***	1.67**	1.07*	0.95
Household level (TLU), weighted	2,521	1.79***	2.42***	1.29***	0.93
Primary model, poverty-analysis weight	6,899	1.55***	1.38*	1.09**	0.81*

Symbols and models as in Table 5. Panel A: household-species rows use species and region fixed effects (in the camel and cattle row, the three units in Banadir, none of which sold, are omitted because the region effect is not identified); household (TLU) row: stock, births, and sales in TLU (Jahnke, 1982), any theft in any species, logit for any sale, and Poisson quasi-maximum likelihood for TLU sold by selling households. Panel B: household fixed-effects models comparing animal types within households, with animal-type fixed effects, log(1 + births), and log(1 + opening stock) unless stated otherwise (settlement type, household size, and region are absorbed); conditional logit (exact conditional likelihood) for any sale and Poisson quasi-maximum likelihood for the number sold, zeros included; N is the number of records in the households that contribute to the estimate (896 households for the conditional logit and 1,160 for the Poisson model). Panel C: weighted pseudo-maximum-likelihood estimates with the SIHBS, household weight or the weight adjusted for the poverty analysis (N = 6,899 records), with significance from design-based standard errors (strata: region × enumeration-area type; primary sampling units: households). Standard errors are in Supplementary Table S3 (panel A), Supplementary Table S8 (panel B), and Supplementary Table S9 (panel C). * $p < 0.05$, ** $p < 0.01$ and *** $p < 0.001$. Values without a significance marker are not statistically significant at $p < 0.05$.

TABLE 7 Predicted live sales at representative opening-stock, birth, and theft levels (primary hurdle model).

Predictor	Evaluation level	P(sale)	E(sold | sale)	E(sold)	Change in E(sold)
Reference	Medians (8 head; 2 births), no theft	0.30	2.16	0.66	—
Opening stock	25th percentile (3 head)	0.19	1.56	0.29	−55.3%
	75th percentile (21 head)	0.46	3.65	1.69	+157.3%
	90th percentile (45 head)	0.60	6.22	3.74	+469.3%
Births	25th percentile (0 births)	0.22	2.13	0.47	−28.6%
	75th percentile (4 births)	0.35	2.18	0.76	+15.3%
Theft	Any theft (vs. none)	0.37	1.85	0.68	+3.3%

Reference record: she goats, rural, opening stock and births at their sample medians (8 and 2), no theft, and household size at its mean (6.58); predictions are averaged over the 17 regions, weighted by each region's share of records. Percentiles are those of the analytic sample (N = 7,008). P(sale), predicted probability of any sale; E(sold), expected number sold; E(sold | sale) = E(sold)/P(sale), expected number sold by records with a sale. Change is relative to E(sold) for the reference record. Because the opening stock contains the reported sales, the stock gradient is probably overstated (see Limitations).

primary model without each record with the largest closing herd, number sold, number slaughtered for sale, opening stock, and fitted value.

The primary, household-species, and household-level models were also re-estimated with the SIHBS household weights by weighted pseudo-maximum likelihood, and with the poverty-analysis weight as a sensitivity check. The public files identify neither enumeration areas nor design strata. The sample was allocated in clusters of 12 households within the 49 combinations of region and enumeration-area type (all 49 cell sizes are multiples of 12 and together give the 601 enumeration areas), so design-based (Taylor linearisation) standard errors treated these combinations as

strata and households as primary sampling units; ignoring clustering within enumeration areas, they are likely to be somewhat too small. Predicted probabilities of selling and expected numbers sold were computed at the 25th and 75th percentiles of opening stock and births, at the 90th percentile of opening stock, and with and without theft, with the other covariates at the reference values in the note to Table 7, averaged over regions.

Ethics statement

This study is a secondary analysis of de-identified microdata from the SIHBS 2022, collected and distributed by the Somalia National Bureau of Statistics under its own ethical and data-protection protocols. No new primary data were collected from human or animal subjects by the authors, and the data were accessed through the Somali National Data Archive under its standard registered-user terms of use.

Results

Sample and data cleaning

The raw data comprised 7,020 records from 2,523 households, with no missing values in the primary-model variables; poverty status was unavailable for 153 of the 7,008 analytic records. In 158 records (2.25%), the number sold exceeded the closing herd; this is not logically impossible, because the closing stock is recorded after the year's sales, and these records were retained (their influence is assessed in Table 5). Two animal types with fewer than 10 records each and no variation in the outcome (improved chickens, n = 9; other livestock, n = 2) were excluded to avoid quasi-complete separation, leaving 7,009 records of 11 types from 2,522 households. One further record, the only one of its household, was excluded: it reported 999 animals lost to drought, disease, and predators although the household held one she goat and reported no births, purchases, gifts, sales, slaughter, or theft, and as a count it would give an opening stock of 1,000 head, the largest in the sample. The analytic sample therefore comprised 7,008 records from 2,521 households; including that record left the focal estimates unchanged to two decimal places (Table 5), and excluding the 77 records with a negative reconstructed opening stock left them essentially unchanged. The reconstruction leaves 47 records (0.67%) in which the number sold exceeds the opening stock, against 158 for the closing stock.

Descriptive statistics

Tables 1 and 2 summarise the records and the 2,521 analytic households. Any sale was reported in 38.91% of records and any theft in 7.51% (39.79% and 7.53% weighted; Supplementary Table S9), and 51.30% reported losses to drought, disease, and predators. At household level, theft (14.0% of households) was much less common than such losses (65.3%) and accounted for 3.7% of the animals lost to the two causes (4.4% in TLU). The median household held two animal types and 3.1 TLU, and 57.1% sold at least one animal. Most households (89.4%) named at least one main shock in the past 24 months, most often drought or severe water shortage (71.7%), whereas livestock theft (1.7%) and conflict or robbery (2.1%) were rarely named (Table 2; Supplementary Table S11).

Model selection and key diagnostics

The outcome was strongly overdispersed (variance/mean ≈46), and 61.09% of records were zeros. A likelihood-ratio test of Poisson against NB2 was decisive ($\chi^2(1) = 19{,}716.06$, $p < 0.001$); a one-sided Cameron–Trivedi test on the baseline Poisson model (three focal predictors, closing herd size entered linearly) was only marginal ($z = 1.49$, $p = 0.068$) because one implausibly large fitted value dominates it, and gave $z = 5.24$, $p < 0.001$ without the two extreme records (Supplementary Table S6). On the fully adjusted specification (Table 3), the hurdle and zero-inflated NB models fitted far better than NB2 (AIC 17,723 for hurdle NB and 17,675 for ZINB vs. 18,599), reproduced the observed share of zeros (61.09% observed; 61.09% hurdle NB, 61.23% ZINB, 58.11% NB2), and had higher cross-validated log-likelihoods; their Poisson counterparts fitted much worse (AIC above 19,500). ZINB had the lowest AIC and BIC, but its advantage over hurdle NB was small ($\Delta AIC = 48$), and the cross-validated log-likelihood was identical to two decimals (−1.27 per record).

The hurdle NB model was retained as primary for three reasons. First, the ZINB advantage was small compared with that of both models over NB2 ($\Delta AIC = 876$ for hurdle NB), and their expected count frequencies were nearly identical (Supplementary Table S4). Second, the hurdle model separates the decision to sell from the number sold, the margins on which this study's questions turn and which households have been found to decide sequentially (Bellemare and Barrett, 2006), whereas in ZINB zeros arise from both a latent class of non-sellers and the count process, so its inflation equation does not describe the decision to sell. Third, the hurdle model requires no assumption about which households are non-participants by design rather than by chance, which the data cannot establish. ZINB was retained as a robustness check (Supplementary Table S2; Table 5).

All GVIFs were below 2.7 ($GVIF[1/(2\cdot df)] < 1.32$), and the truncated NB quantity equation had $\theta = 3.61$. With closing herd size entered linearly, two records were extreme: one with 650 animals sold from a 90-head herd, and one with a 550-head herd and an implausible fitted value (≈6.62 million), which reflects functional-form misspecification under a log link rather than an outlier to be removed. In the primary model, excluding the 550-head record (fitted value 23.8; 2 sold) changed no focal ratio by more than 1%. The largest fitted value in the primary model, 77.8 animals, was for the record with 650 she goats sold, which reported a sale value of 0 although the household's other sales were valued at US$1,600 for 2 camels and US$325 for 5 billy goats. This inconsistency may reflect a recording error, which could not be verified against the completed questionnaire; the record was retained, and excluding it changed the quantity-equation stock ratio by 4% and the focal births and theft ratios by less than 2% (Table 5; Supplementary Table S10). Excluding the largest opening stock (763 head; 720 she goats slaughtered for sale from a closing herd of 15, valued at US$180) changed no focal ratio by more than 1%.

Main statistical findings

Table 4 reports the focal estimates from the fully adjusted hurdle model (Model 3); Models 1 and 2 and all fixed effects are in

Supplementary Table S1. Opening stock was strongly associated with both margins (participation OR = 2.28, 95% confidence interval [2.11, 2.47]; quantity IRR = 2.29 [2.10, 2.49], per unit of log(1 + stock)), but its quantity coefficient, 0.83 (standard error 0.04), was below the elasticity of 1 implied by a constant sales rate among sellers ($z = -3.98$, $p < 0.001$). Births were associated with a higher probability of selling (OR = 1.52 [1.40, 1.66], $p < 0.001$) but not with the number sold (IRR = 1.03 [0.98, 1.08], $p = 0.281$). Any theft was associated with a higher probability of selling (OR = 1.35 [1.05, 1.73], $p = 0.018$) and with fewer animals sold among records with sales (IRR = 0.76 [0.67, 0.86], $p < 0.001$). Region effects were jointly significant in both equations (participation $\chi^2(16) = 235.8$; quantity $\chi^2(16) = 78.3$; both $p < 0.001$), and with region controlled, settlement type was not significantly associated with either margin. Larger households were slightly less likely to sell (OR = 0.95 per person [0.93, 0.98], $p = 0.002$). Without region effects (Models 1 and 2), the theft OR was larger (1.51 and 1.65) and the births OR smaller (1.41 in both).

Robustness of the pooled estimates

The births participation association was significant in every pooled specification (Table 5), including when births were also counted in the stock (OR = 1.22, $p < 0.001$). The theft OR exceeded 1 and was significant under every alternative stock definition, with each further control added, after excluding the 650-animal record, the 77 records with a negative implied opening stock, or the 158 records in which the number sold exceeded the closing herd, in the ZINB inflation equation, at the household-species level (OR = 1.38), and at the household level in TLU (OR = 2.07); without region effects it was larger (OR = 1.59, $p < 0.001$). It was not significant when theft was measured as log(1 + animals stolen) (OR = 1.04, $p = 0.681$) or as a rate per animal held (OR = 1.34, $p = 0.465$), suggesting that the association is with the occurrence of theft rather than the number of animals stolen, and it differed in direction by species group: OR = 1.60 ($p = 0.009$) among goats and sheep but 0.43 ($p = 0.031$) among camels and cattle (Table 6). The quantity association of theft (IRR below 1) held in the other record-level hurdle and ZINB specifications but not with the closing stock (IRR = 0.87, $p = 0.106$) or at the household-species (IRR = 0.91, $p = 0.172$) and household levels ($p = 0.996$). In single-equation NB2 models, theft was not significantly associated with the number sold with either the opening stock (IRR = 0.88, $p = 0.069$) or the closing stock (IRR = 1.15, $p = 0.113$); with closing herd size entered linearly and no region effects, it was associated with more animals sold (Supplementary Table S6).

Adding poverty status (6,855 records) or further controls left the focal estimates essentially unchanged (Table 5, panel D; Supplementary Table S3): the participation OR ranged from 1.32 to 1.38 for theft and from 1.50 to 1.53 for births, and the quantity IRR for theft from 0.75 to 0.76. Losses to drought, disease, and predators were associated with a lower probability of selling (OR = 0.86 [0.79, 0.94] per log unit, $p < 0.001$) and fewer animals sold (IRR = 0.87 [0.83, 0.91], $p < 0.001$). A large rise in food prices was associated with a higher probability of selling (OR = 1.43 [1.22, 1.67], $p < 0.001$), and households headed by women were more likely (OR = 1.24 [1.05, 1.46], $p = 0.010$) and those with a literate head less likely to sell (OR = 0.78 [0.66, 0.92], $p = 0.003$). Remittances, road distance, the head's age, and insecurity were not significantly associated with selling, nor was housing quality except in the model with all further controls (OR = 1.15 [1.03, 1.28], $p = 0.016$); estimates for all added controls are in Supplementary Table S10.

Heterogeneity of the theft association

The theft association did not differ detectably between regions, by remittance receipt, with regional insecurity, or by non-livestock work (Supplementary Table S10). The participation OR was 1.32 [0.84, 2.07] in the northern regions and 1.36 [1.01, 1.83] in the southern and central regions (interaction $p = 0.913$). Among the eight regions with at least 20 theft records, ORs ranged from 0.79 (Gedo) to 3.78 (Bakool), but a joint test did not reject equal associations ($\chi^2(8) = 12.98$, $p = 0.112$). The OR was 1.64 [0.97, 2.80] with remittances and 1.30 [0.98, 1.72] without (interaction $p = 0.444$), and the quantity interactions were also non-significant ($p = 0.485$ and $p = 0.124$; across regions $p = 0.914$). Across the range of regional insecurity (conflict or robbery named by 0.2% of households in Togdheer and 12.6% in Bari), the theft OR was 1.44 [1.05, 1.99] and 1.06 [0.52, 2.15] (interaction $p = 0.483$; quantity $p = 0.357$), and excluding the 139 records of the 54 households that named conflict or robbery left it at 1.37 (Table 5, panel B). The OR was 1.62 [1.18, 2.22] in households with no member in paid or non-farm work in the past week and 0.97 [0.65, 1.45] in those with one, a difference that was not statistically significant (ratio 0.60 [0.36, 1.00], $p = 0.051$; quantity $p = 0.603$).

Livestock theft was rarely among the main shocks households reported, and few reported selling livestock in response to it (Supplementary Table S11). Of the 354 households with recorded theft, 32 named livestock theft among their three most significant shocks of the past 24 months, as did 10 without recorded theft. Of these 42 theft shocks, 32 had affected only the reporting household and 4 all households in the community (60.0% of drought shocks had affected all households), and 29 started in May 2021 or later. Responses were most often prayer (23 shocks) and spending cash savings (5); selling livestock or poultry was reported for 4. Of the 273 households that recorded both theft and a live sale, 25 named livestock theft among their main shocks and 3 reported selling livestock or poultry in response. Selling livestock or poultry in response to any main shock was reported by 10.2% of households with recorded theft and 9.0% of those without.

Within-household comparisons and survey weights

Within households, the theft association with selling was similar in size to the pooled estimate but imprecise (Table 6, panel B): the conditional-logit OR was 2.02 [1.39, 2.92] with animal-type fixed effects only and 1.34 [0.88, 2.04] ($p = 0.176$) with opening stock and births added, and the linear probability model gave a difference of 3.2 percentage points [−1.5, 7.9]. Only 896 households had records both with and without a sale, and 181 of them also had records both with and without theft. The OR was 1.24 [0.82, 1.87] with the opening stock as a natural spline and 1.69 [1.12, 2.54] with the closing stock. With region fixed effects,

the between-household theft association did not differ significantly from the within-household association (difference 3.4 percentage points [−4.4, 11.2], p = 0.394), and theft in the household's other animal types was not associated with selling (OR = 0.98 [0.80, 1.21], p = 0.866); without region effects, the between-household association exceeded the within-household association by 9.6 percentage points [1.7, 17.6] (p = 0.018; OR for theft in other animal types 1.19 [0.98, 1.44], p = 0.086; Supplementary Table S8). Births remained associated with selling within households (OR = 1.37 [1.18, 1.61], p < 0.001) and, with zeros included, with more animals sold (IRR = 1.14 [1.03, 1.27], p = 0.011), whereas theft was not significantly associated with the number sold (IRR = 0.82 [0.64, 1.04], p = 0.108). The within-household theft association was not significant in any species group, including goats and sheep (OR = 1.38 [0.86, 2.21]; Supplementary Table S8).

Weighting left the participation estimates essentially unchanged (Table 6, panel C; Supplementary Table S9). In the weighted primary model, theft was associated with a higher probability of selling (OR = 1.40 [1.05, 1.87], p = 0.021) and fewer animals sold among records with sales (IRR = 0.82 [0.69, 0.96]), and births with a higher probability of selling (OR = 1.55 [1.38, 1.74]). Unlike in the unweighted model, births were also associated with more animals sold (IRR = 1.09 [1.02, 1.15], p = 0.007; unweighted 1.03, p = 0.281), as in the unweighted household-level model (IRR = 1.18). The household-level theft OR was 2.42 weighted (2.07 unweighted), the weighted within-household difference for theft was 2.7 percentage points [−3.7, 9.0], and estimates with the poverty-analysis weight were similar. Design-based standard errors were within 3% of the household-clustered ones.

Value of live sales and predicted sales

Models of the value of live sales gave the same pattern (Supplementary Table S12); they exclude the 17 records that reported a sale but a value of 0, including the 650-animal record (6,991 records from 2,517 households). In the double-hurdle model, theft was associated with a higher probability of selling (probit coefficient 0.18, p = 0.013) and a lower value of sales among records with sales (−0.21 on the log scale, about 19% lower, p < 0.001), and births with a higher probability of selling (0.25, p < 0.001) and, unlike the number sold, a higher value of sales (0.10, p < 0.001); value rose less than proportionally with opening stock (0.44). The Tobit model, which forces both margins to share one coefficient, showed no association with theft (0.22, p = 0.290), and its restriction was rejected ($\chi^2(33)$ = 6,379.8, p < 0.001). At household level, the double-hurdle theft coefficients were 0.40 (p < 0.001) and −0.22 (p = 0.003), the Tobit theft coefficient was positive (0.71, p < 0.001), and the restriction was again rejected ($\chi^2(23)$ = 2,882.6, p < 0.001). Excluding the 35 records with implausible values per animal left these conclusions unchanged.

Table 7 translates the primary model into predicted probabilities of selling and expected numbers sold for a reference record (she goats, rural, median opening stock of 8 head and median births of 2, no theft), averaged over regions. Moving opening stock from the 25th to the 75th percentile (3–21 head) raised the probability of selling from 0.19 to 0.46 and the expected number sold from 0.29 to 1.69 animals; at these percentiles, the median, and the 90th percentile (45 head), the expected number sold was 8%–10% of the opening stock. Moving births from the 25th to the 75th percentile (0–4) raised the probability of selling from 0.22 to 0.35, with little change in the number sold by sellers (2.13 vs. 2.18). Any theft raised the probability of selling from 0.30 to 0.37 and lowered the expected number sold by sellers from 2.16 to 1.85, so the expected number sold across all records rose only from 0.66 to 0.68.

Discussion

Herd size

Herd size was the most stable focal predictor and was associated with both whether and how much a household sold (Table 4). Among records with sales, the number sold rose less than proportionally with the opening stock (coefficient 0.83), but because larger holdings were also much more likely to sell, the expected number sold across all records rose roughly in proportion to the stock (8%–10%; Table 7), as a fixed sales rate would also produce. These figures use the opening stock, which contains the reported sales, and are probably upper-end values (Limitations). The data therefore do not settle whether the association reflects wealth and risk-bearing capacity or a fixed sales rate; they show that it combines a strong participation margin with a less-than-proportional quantity margin. Nor does it show that acquiring a larger herd causes greater market engagement, because herd size, births, and sales are components of one annual herd-accounting identity from which the opening stock is reconstructed. Measuring the stock after the sales, as the closing herd does, lowered the stock coefficients (participation 0.52 vs. 0.82; quantity 0.57 vs. 0.83; Supplementary Table S3), and entering the closing herd linearly produced implausible predictions for the largest herds. The result is best read as confirming, in a large nationally collected Somali sample, a herd-size–participation association already well established (Belay et al., 2021; Lutta et al., 2020), not as new causal evidence.

Theft losses

Theft was associated with a higher probability of selling in the pooled models (OR = 1.35), net of herd size, an association more directly interpretable in behavioural terms than the herd-size result because theft and sales are separate flows out of the herd. It was larger without region effects (OR = 1.59) and held under the pooled checks of stock definition, sample, model family, and controls (Table 5), but it was not significant for the number of animals stolen, was confined to goats and sheep, and was reversed among camels and cattle. Within households, which also holds fixed the local security and drought conditions shared by a household's herds, the theft OR was similar (1.34) but imprecise, and with region controlled the between- and within-household associations did not differ significantly. The data therefore cannot show whether the association operates through the animal type stolen or the household as a whole.

Among records with sales, theft was associated with fewer animals sold (IRR = 0.76), which persisted when the stock was defined net of stolen animals and for the value of sales (Supplementary Table S12) but was absent at the household-species and household levels; it should therefore not be read as a behavioural response. Nor should the positive association with the

number sold that appeared with the closing herd entered linearly and no region effects (Supplementary Table S6), or the within-household OR with the closing stock (1.69): because theft lowers the closing herd for a given opening stock, a model conditioned on the closing herd attributes part of the larger opening herd of theft-affected records to theft. The surviving finding is therefore narrower: records with theft were more likely to report a sale. Even this direction runs against the evidence on asset shocks (Fafchamps et al., 1998; McPeak, 2004), since theft removes animals directly and would be expected, other things equal, to reduce sales, and losses to drought, disease, and predators were associated here with a lower probability of selling and fewer animals sold.

Several mechanisms could produce a positive association between theft and the decision to sell, and the data cannot distinguish among them. First, a defensive or distress-liquidation response to an unanticipated asset shock: theft may leave households short of the income or food the stolen animals provided, prompting sales of other animals. Destocking is reported as a response to drought in the Borana zone (Sintayehu et al., 2025), although drought, unlike theft, also lowers the condition and value of the remaining animals. Second, households may sell pre-emptively to reduce exposure to further theft. Third, reverse causality: greater market activity may increase exposure to theft, for example, when animals are moved to and from markets. Fourth, local insecurity and drought may raise both theft and sales without a causal link; in north-western Kenya, raiding has been linked to drought and hunger and has contributed to insecurity and market closure (Schilling et al., 2012), and the recall period coincided with the 2021–2022 drought. Region fixed effects, the herd's own losses to drought, disease, and predators, and households' reports of drought and insecurity shocks hold part of these conditions fixed, but incompletely, because insecurity and drought vary within regions and shocks were recorded only when among a household's three most significant. Fifth, household characteristics other than the head's sex, age, and literacy may raise both theft exposure and sales.

Each mechanism can operate at household level, where it is absorbed by household fixed effects together with local security and drought conditions; because the within-household estimate was similar to the pooled one but imprecise, the comparison neither supports nor rules out versions that act through the animal type stolen, such as theft of animals taken to market. The concentration of the association in goats and sheep, the most liquid species in a mixed pastoral portfolio (Wanyoike et al., 2023), is compatible with each. The association did not differ detectably by region, regional insecurity, or remittance receipt (an alternative source of cash after a shock), and was larger, though not significantly so, in households without non-livestock work, as a need for cash after theft would predict; these tests had limited power, and nine regions had fewer than 20 theft records each. The shock data give little direct support for distress selling: only 3 of the 273 households that recorded both theft and a live sale reported selling livestock or poultry in response, and households with theft were hardly more likely than others to report selling in response to any main shock (10.2% vs. 9.0%). This check is incomplete, because coping responses were recorded only for the three most significant shocks of the past 24 months and theft was not among them for 322 of the 354 households with theft. Because the data do not show whether theft preceded or followed sales, distress selling is best treated as one hypothesis among several, not a finding.

The results also qualify practical implications. Routine, class-targeted sales, such as sales of calves and steers associated with business profitability among 405 smallholder cattle farmers without insurance cover in Namwala District, Zambia (Siankwilimba, 2024), differ from the shock-associated sales hypothesised here. If the distress-sale interpretation were confirmed, the theft association would bear on herd-security interventions for theft-affected households, although such interventions would address a small part of herd losses: theft was recorded by 14.0% of households and accounted for 3.7% of the animals lost to theft or to drought, disease, and predators. Nor do the results support a recommendation on livestock insurance, which this study does not examine: index-based insurance, as studied in northern Kenya, covers covariate, largely drought-related losses rather than idiosyncratic losses such as theft (32 of the 42 livestock theft shocks in the SIHBS had affected only the reporting household; Supplementary Table S11), and demand for it is shaped by basis risk (Jensen et al., 2018) and prior climate-loss exposure (Oduniyi et al., 2020).

Births

Births were associated with a higher probability of selling (OR = 1.52) but not with the number sold. The participation association held in every pooled specification, at the household-species and household levels, among both small ruminants and camels and cattle, and within households (OR = 1.37; Tables 5 and 6), and was weaker but present when births were counted in the stock (OR = 1.22), so it is not explained entirely by births enlarging the stock available for sale. The association with the amount sold was less clear: absent in the primary model, it was present in the weighted models, the unweighted household-level model (Table 6; Supplementary Table S9), and the value of sales (Supplementary Table S12). Interpretation is also limited at the household-animal-type level: births and sales of related classes (for example, she goats and billy goats, or ewes and lambs) fall in different records, the survey does not specify whether young are recorded against the class of the dam or of the offspring, and births were reported for most records of male classes (68% of billy-goat records; Supplementary Table S5), so how respondents assigned births to classes is unknown. The association therefore cannot be taken as evidence of the restocking-and-surplus-sale dynamic described for pastoralists in Tana River County, Kenya, whose herds were replenished mainly through births and whose market participation depended on attaining and maintaining sufficiently large herds (Lutta et al., 2020). Births may also act as both an asset shock and an income shock: more young animals make it easier to sell without depleting the herd, whereas additional milk can reduce the need to sell, and asset and income shocks can affect livestock sales in opposite directions (McPeak, 2004). The positive participation association is consistent with the asset effect dominating on that margin, but the data cannot separate the two. Because pastoral households take several years to rebuild herds after a shock (Mauerman et al., 2023), any link between births and sales more likely operates through slow, cumulative recruitment than as an immediate

market trigger. The finding is suggestive rather than established, and programmatic inferences about herd fertility and market engagement should be drawn cautiously.

Species and settlement heterogeneity

The gradient in live sales across animal types, from billy goats (highest) to donkeys (lowest), partly reflects the classification itself: male animals are commonly the sale class (see, for cattle, Siankwilimba, 2024), so the high rate for billy goats is captured, not explained, by the animal-type fixed effects. It is also consistent with species occupying distinct roles in a mixed pastoral portfolio: small ruminants as comparatively liquid, faster-turnover commodities, and camels, cattle, and draught animals as longer-horizon stores of wealth and production capacity that may be sold less often (Wanyoike et al., 2023). The species groups differed in the direction of the pooled theft association (positive for goats and sheep, negative for camels and cattle), whereas births were associated with a higher probability of selling in both (OR = 1.53 and 1.87; Table 6). With region controlled, settlement type was not significantly associated with either margin (Table 4). Without region effects, urban records were more likely than rural records to report a sale (OR = 1.36, p = 0.005), and the higher sales among nomadic households with closing herd size entered linearly (IRR = 1.28) were no longer significant once herd size entered in logarithms (IRR = 1.16, p = 0.131; Supplementary Table S6), so they reflected functional form rather than a difference between settlement types. The remaining controls were not the focus of this study, and their associations (Table 4; Supplementary Table S10) are not treated as established results.

Contribution to livestock production research

These results show, with count models suited to the outcome and nationally collected survey data, that theft and births are each associated with the decision to sell live animals, net of herd size, but, in the primary model, births were not associated with the number sold, and theft was associated with fewer animals sold among sellers in the record-level models but not at the household-species or household level. The raiding literature documents the motives and effects of livestock theft on livelihoods, mobility, and markets (Bollig, 1990; 2006; Fleisher, 2000; McCabe, 2004; Schilling et al., 2012); these results add a quantitative association between theft and household live sales in nationally collected survey data. Pastoral market-participation research rarely makes this decomposition, typically treating herd size as the main stock-based correlate. Methodologically, the specification of the stock matters: with the herd measured after the sales and entered linearly, theft appeared to raise the number of animals sold, whereas with the reconstructed opening stock it was associated with fewer animals sold among records with sales. Region effects and within-household comparisons also changed the reading of the theft association: without region effects, it appeared to operate between rather than within households. For livestock production practice, the results suggest that herd demographic composition, not simply herd size, is worth tracking alongside conventional offtake statistics: holdings with births were more likely to sell than holdings of the same opening size without births, as were holdings with theft compared with similar holdings in the same region without theft, and extension or market-monitoring systems built only around herd-size thresholds may miss this distinction.

Limitations

Several limitations qualify these conclusions. The cross-sectional design precludes causal inference for all reported associations, and the herd-size association is further complicated by the accounting identity linking herd size, births, and sales. The opening-stock reconstruction set 77 negative values to zero and omits unrecorded flows such as slaughter for home consumption and animals given away, and some recorded flows are implausible, although excluding the most extreme records changed estimates little. The questionnaire accepts a sale value of zero alongside a positive number sold and does not compare sales with the herd held (SNBS, 2022), and the extreme records could not be checked against completed questionnaires. Because the survey accepts only positive counts of animals owned at interview (SNBS, 2022), animal types that a household sold or lost entirely during the period are not observed. Because the reconstructed opening stock contains the reported sales, errors in reported sales enter both the outcome and the stock and would tend to inflate the stock coefficients, whereas the closing stock, being net of sales, biases them downward; the quantity coefficients with the two measures (0.83 and 0.57; Supplementary Table S3) may therefore bracket the elasticity, and both are below 1. This is an informal comparison of two stock definitions, not a formal bound, because the unrecorded flows have no observed values from which to bound the opening stock.

Reverse causality cannot be excluded for theft, and its association with the number sold depended on the stock definition and level of aggregation. Theft and birth counts are self-reported over a 12-month recall window without formal assessment of recall error; theft is rare at the record level (92.49% of records report none), limiting precision; and the excess of reported sales of exactly 5 and 10 animals (263 and 108 records, against about 185 and 48 expected under the primary model) suggests some rounding. The household-animal-type unit treats sex and age classes of a species as separate herds, although aggregation left the participation associations unchanged. Design-based standard errors ignore clustering within enumeration areas, which the public files do not identify, and are likely to be somewhat too small. The poverty linkage rests on information shared by the files rather than a common identifier and has not been confirmed by SNBS; poverty status is unknown for 153 records and enters only a sensitivity analysis. Region fixed effects do not capture conditions varying within regions, and the household fixed-effects models, which do, rest for theft on 181 households and are imprecise. The housing-quality index is a coarse wealth proxy missing for 295 households, most of them nomadic; shock indicators cover the three most significant shocks of the past 24 months, a longer period than the livestock recall; and the head's age is top-coded at 65. Middle Juba was not surveyed because of insecurity (SNBS, 2023a), so conditions there are not represented. ZINB fitted slightly better than the hurdle NB model retained as primary, although the focal associations had the same direction under both. Finally, the analysis omits price variables, measures insecurity only through ranked shocks and their regional prevalence, uses road distance as a proxy for market access, and cannot show whether theft preceded or followed sales for most theft-affected households, because the survey records its timing only for those that ranked it among their main shocks.

Future research

Future research should prioritise four directions. First, panel data on the same households would allow herd size, births, theft, and sales to be sequenced, addressing the stock-flow circularity of this cross-sectional design. Second, recording the circumstances and timing of theft relative to sales would help distinguish distress liquidation from a reverse pathway in which market activity increases exposure to theft, and from common exposure to insecurity and drought. Third, adding price, market-distance, and security indicators, recording losses to drought, disease, and predation separately, and recording coping responses to every theft rather than only to a household's most significant shocks would show which asset shocks accompany sales and whether theft-affected households sell livestock in response. Finally, applying the same stock-flow decomposition outside Somalia would show whether the concentration of the births and theft associations on the decision to sell, and the contrast in the theft association between small ruminants and camels and cattle, hold beyond this population.

Conclusion

This study asked whether live sales among Somali pastoral households are associated mainly with herd size or also with the composition of herd change (growth through births versus loss through theft). Both stock and flow variables were associated with live sales, mainly with the decision to sell rather than the number sold. Opening stock showed the most stable association, on both margins, although among records with sales the number sold rose less than proportionally with the stock. Births and theft were each associated with a higher probability of selling; in the primary model births were not associated with the number sold, and theft was associated with fewer animals sold among sellers, a result not found at the household-species or household level. The births association held within households, although its interpretation depends on how births are recorded across animal classes. The theft association held in the pooled models across stock definitions, controls, samples, model families, and levels of aggregation, but it was smaller once region was controlled, not significant for the number of animals stolen, confined to goats and sheep, and imprecise within households. It is compatible with distress selling after an unanticipated shock, but equally with pre-emptive selling, greater theft exposure among households that sell more often, or local insecurity and drought that raise both theft and sales, and the shock data offered little direct evidence of selling in response to theft. The results suggest that herd stock, recruitment, and shock-related depletion may be behaviourally distinct components of sales that operate chiefly on market participation; confirming this requires information on the timing of theft relative to sales and on local insecurity.

Data availability statement

The data used in this study are drawn from the 2022 Somalia Integrated Household Budget Survey (SIHBS), collected and distributed by the Somalia National Bureau of Statistics (SNBS; Reference ID: DDI-SOM-SNBS-SIHBS-2022-v02), and accessible via the Somali National Data Archive (SoNADA) subject to free registration.

Author contributions

AAO: Data curation, Writing – original draft, Writing – review and editing. NMA: Conceptualization, Methodology, Formal analysis.

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Conflict of interest

The author(s) declared that this work 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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The author(s) declared that generative AI was used in the creation of this manuscript. An AI language tool (ChatGPT) was utilized strictly for language refinement, grammar correction, and copyediting during the preparation of the final draft. The tool was not used for study design, data collection, statistical analysis, or drawing conceptual conclusions.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/past.2026.17831/full#supplementary-material

SUPPLEMENTARY TABLE S1
Hurdle negative binomial Models 1–3: participation and quantity equations (N = 7,008 records, 2,521 households).

SUPPLEMENTARY TABLE S2
Zero-inflated negative binomial model with all covariates in both equations, and single-equation NB2 model (covariates of the primary model; N = 7,008).

SUPPLEMENTARY TABLE S3
Robustness of the focal associations: coefficients, standard errors, and ratios (full version of Table 5 and Table 6, panel A).

SUPPLEMENTARY TABLE S4
Observed and expected frequencies of the number of animals sold, and generalised variance inflation factors (fully adjusted specification).

SUPPLEMENTARY TABLE S5
Records, births, sales, and theft by animal type (analytic sample, N = 7,008).

SUPPLEMENTARY TABLE S6
Results for the specification with closing herd size entered linearly (N = 7,008 records, the primary analytic sample, unless stated).

SUPPLEMENTARY TABLE S7
Records per household (analytic sample: 7,008 records, 2,521 households).

SUPPLEMENTARY TABLE S8
Household fixed-effects models: within-household estimates, between- and within-household comparison, and estimates by species group.

SUPPLEMENTARY TABLE S9
Survey-weighted estimates: design information, weighted and unweighted focal estimates, the weighted primary model, weighted descriptive statistics, and the weighted within-household comparison.

SUPPLEMENTARY TABLE S10
Further controls, heterogeneity of the theft association, and extreme records.

SUPPLEMENTARY TABLE S11
Household shocks, coping responses, and household controls.

SUPPLEMENTARY TABLE S12
Value of live sales: Tobit and double-hurdle models.

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