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Contrasting income shocks with asset shocks: livestock sales in northern Kenya

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The literature on risk management in agrarian economies has predominantly focused on the use of assets to buffer consumption against income shocks. However, households in certain low-income, high-risk environments confront asset as well as income shocks. This study investigates livestock sales behavior in an environment where both income and asset shocks occur. The nature of each type of shock is analyzed, and their respective impact on sales behavior is identified. Results indicate income and asset shocks are positively correlated, but influence sales in an offsetting fashion. This provides a possible explanation for the limited empirical support found by previous studies investigating the role of livestock sales in buffering consumption. Marketing and savings institutions that reduce vulnerability to asset shocks in addition to income shocks offer the potential to reduce household risk exposure.

1. Introduction

Is risk management in low-income, high-risk environments only a matter of managing transitory income shocks? The majority of the risk management literature applied to such settings implies this is so, as studies have focused almost exclusively on income risk. While focusing exclusively on income shocks may be reasonable in some cases, it is not applicable to all contexts. Exogenous shocks such as droughts, floods, fires, disease, theft, or warfare threaten household well being not only through a transitory food availability crisis, but also through the prospect that assets accumulated over many years will be suddenly swept away by such events.[1] Of particular concern in this study, the loss of assets critical to income production can have a negative impact on future income production that may only be reversible over a long time horizon, if at all.

It is well established in the economics literature that asset risk influences capital accumulation patterns (Phelps, 1962; Levhari and Srinivasan, 1969; Sandmo, 1969). In addition, it has long been understood that income risk and asset risk can have

[1] In the context of this study, we focus on how households manage assets when exogenous shocks to income lead to transitory food availability declines and shocks to assets lead to longer term food availability declines. A topic for further analysis is the analysis of income and asset shocks using Sen's entitlement approach (1981).

different implication for savings behavior (Sandmo, 1970). However, previous studies on risk management in agrarian economies have focused on household modification of asset levels to buffer against transitory income shocks (Jacoby and Skoufias, 1998; Lim and Townsend, 1998; Rosenzweig and Wolpin, 1993; Paxson, 1992). Of particular relevance to the current study, livestock have been identified as a key asset households in low-income, high-risk production settings use to buffer consumption against income shocks (Dercon, 1998; Fafchamps, 1998; Fafchamps *et al.*, 1998; Kinsey *et al.*, 1998; Bromley and Chavas, 1989; Binswanger and Rosenzweig, 1986). These 'buffer stock' models hypothesize that livestock purchased as a store of wealth in unexpectedly high income years are sold to buffer consumption in unexpectedly low income years.

Empirical studies do not provide clear support of the hypothesis that livestock are used as a buffer stock. Rosenzweig and Wolpin find that in an area of semi-arid India where bullocks are used as traction animals, bullock marketing is used as a form of self-insurance. Lim and Townsend use the same data set to dispute this finding, arguing '... livestock and other real capital assets play little if any role in the smoothing of idiosyncratic or intertemporal shocks. Livestock and other assets are, if anything, bought in bad years and sold in good years' (p. 110). Udry (1995) presents evidence from northern Nigeria indicating that household level livestock savings levels do not respond significantly to income shocks. In an agro-pastoral context in semi-arid West Africa, Fafchamps *et al.* find no evidence that cattle holdings are liquidated to compensate for crop shortfalls, and only weak evidence that goats are sold in such circumstances.

This study focuses on livestock sales decisions made by pastoral nomads in northern Kenya. We use longitudinal household level data to illustrate how both asset shocks and income shocks influence household well being and asset management decisions. We build on classical precedents in the literature to illustrate how the sales response to an asset shock differs from the response to an income shock. We propose that the impact of asset shocks on household decisions may at least partially explain the lack of empirical support for the buffer stock hypothesis. In the specific example of nomadic pastoralism considered in this study a rainfall deficit not only temporarily lowers milk production but also lowers expected future milk production through herd loss. This study provides a possible explanation for the limited empirical support for the buffer stock hypothesis found in previous studies by explicitly considering the impact of asset shocks. While the extremely arid pastoral setting of this study places the issue of asset risk in stark relief, the results of this study suggest economic research on risk management in other low-income, high-risk settings may benefit by considering whether asset shocks as well as income shocks the impact household decision making and well being.

The paper is organized in the following way. The next section presents a series of simple dynamic models to contrast the impact of income shocks and asset shocks on sales behavior. Following this, a model that will serve as the basis for the empirical estimation work is developed. A description of the data set is provided in Section 3. The fourth section describes the production system of the study area and presents econometric analysis of both milk production and herd growth. The influence of rainfall shocks on both variables is highlighted. The fifth section presents estimation of longitudinal data on household sales decisions that identifies how income shocks and asset shocks influence livestock sales behavior. Section 6 presents simulation of these estimation results and a discussion of the findings. Section 7 concludes, noting how the policies designed to help manage asset shocks differ from those designed for income shocks.

2. Dynamic models of offtake behavior

To illustrate the difference between income shocks and asset shocks, consider the following simple models. First, assume that household i at time t has a herd size of $k_i(t)$. This herd produces a good consumable at time t defined by $f(k_i(t))$, where the production function of the consumable good is continuous, strictly increasing, concave in herd size, and equal to zero when herd size is zero. To reflect our pastoral setting, consider this to be the milk production function. The household consumes milk produced according to this function together with offtake from the herd at time t, $ot_i(t)$ according to the consumption function $c_i(t) = f(k_i(t)) + ot_i(t)$. Assume for the moment that all livestock taken from the herd are sold at a constant price p=1, and that proceeds from this sale are used to purchase a consumable good of equal value in consumption as milk.[2] Define a utility function that obeys the Inada conditions so that the utility of consumption is $U(f(k_i(t)) + ot_i(t))$.

Herd growth proceeds according to the Markov equation $k_i(t+1) = k_i(t) + g(k_i(t)) - ot_i(t)$, where $g(k_i(t))$ obeys the same functional conditions as defined above for the milk production function. The household discounts the future at a constant rate β. The household's Bellman equation can then be stated as follows

$$V[k_i(t)] = \underset{ot_i(t)}{Max}\ U\big(f(k_i(t)) + ot_i(t)\big) + \beta \cdot V\big[k_i(t) + g(k(t)) - ot_i(t)\big] \qquad (1)$$

First, consider the addition of an income shock to eq. (1). Define the shock to be $s(t) \in [s_b, s_g]$ with mean s_a, where b, g, and a stand for bad, good, and average respectively. Assume shocks are uncorrelated over time. Modify the production function of the consumption good to be $f(k_i(t), s(t))$, with $\partial f / \partial s > 0$. This means good shocks increase milk production and bad shocks decrease it. The modified Bellman's equation in this setting is the following.

$$\begin{aligned} V[k_i(t), s(t)] = \underset{ot_i(t)}{Max}\, & U\big(f(k_i(t), s(t)) + ot_i(t)\big) \\ & + \beta \cdot E_t\big[V\big[k_i(t) + g(k(t)) - ot_i(t), s(t+1)\big]\big] \end{aligned} \qquad (2)$$

[2] There is ambiguity as to what is meant by equivalent value in consumption in the setting of this study where animals and animal products are both home consumed and marketed. In the following section, we will approximate the equivalence of animals and animal products across these different uses by assigning cash values to all home produced and consumed goods.

The first order condition of eq. (2) is the following

$$\partial U(c_i(t))/\partial c_i(t) = \beta \cdot E_t[\partial V/\partial k_i(t+1)] \quad (3)$$

Assuming concavity of both the utility and the value function in consumption and herd size respectively, eq. (3) illustrates that a shock decreasing milk production will increase the marginal utility of income all else equal. As this value is equated to the discounted shadow value of capital, which is not influenced by the shock at time t, the offtake level selected when a bad shock occurs will be greater than that for an average shock. This is the livestock as a buffer stock result: $(\partial ot/\partial s) < 0$.

Next, consider the impact of an asset shock if there is no income shock. Define a proportionate survival function as $(1 - \theta_i(t))$, with $\theta \in [0,1]$. Define survival to be a function of the shock, $\theta_i(s(t))$. Assume $(\partial\theta/\partial s) < 0$, and assume that shocks impact starting period capital stock. The realization of a bad shock increases θ, which leads to a decrease in the proportion of the capital stock that survives.

The shock also influences the growth function of the herd. Define $g(k_i(t),s(t))$ as the modified growth function, with $(\partial g/\partial s) > 0$. The Bellman equation in this specification is as follows

$$\begin{aligned} V[k_i(t), s(t)] = {} & \underset{ot_i(t)}{Max}\, U\big(f(k_i(t)) + ot_i(t)\big) \\ & + \beta \cdot V\big[(1 - \theta_i(s(t))) \cdot k_i(t) + g(k_i(t), s(t)) - ot_i(t), s(t+1)\big] \end{aligned} \quad (4)$$

Equation (3) represents the first order condition of this version of the model as well, although contrasting eq. (2) with eq. (4) illustrates how the arguments of the utility and value functions differ across specifications.

Again assuming concavity of the utility and value functions in their respective arguments, this version of the model illustrates that a negative shock to the asset stock increases the expected shadow value of capital. As current period milk production is not influenced by this shock, changing the offtake level modifies the marginal utility of consumption. In this specification of the model, $(\partial ot/\partial s) > 0$.

While these models are extremely simple, they do serve to illustrate that the definition of the shock experienced by the household is critical to model predictions. A negative income shock will increase offtake levels, and a negative asset shock will decrease offtake levels. We now develop a model that combines these two types of shocks, and incorporates important realities of the study area that will be elaborated upon below.

First, define $s(t)$ to be the realized climate conditions at time t. Climate conditions influence the milk production function, the proportionate survival function, and the herd growth function. Second, allow the price of livestock to vary over time and denote selling price by $p(t)$.[3] Selling price is assumed to follow a known stochastic process.[4] An additional variable recording food aid at time t, $fa(t)$, is introduced to the model. Food aid is frequently distributed to herders in the study area, and is distributed to all households equally regardless of household need (McPeak and Barrett, 2001). The value of food aid in consumption is defined by δ. Fourth, we allow for an idiosyncratic element to enter the proportionate survival function, defined by $\tau_i(t)$. Finally, we specify both decision processes and production functions as conditional upon household specific variables $hh_i(t)$.

Modifying the notation of the various models developed above, the following model can be defined

$$
\begin{aligned}
V\big[k_i(t), s(t), p(t) : hh_i(t)\big] = \underset{ot_i(t)}{Max}\, U\big(f(k_i(t), s(t) : hh_i(t)) + p(t) \cdot ot_i(t) + \delta \cdot fa(t)\big) \\
+ \beta \cdot E_t[V[(1 - \theta_i(s(t), \tau_i(t))) \cdot k_i(t) \\
+ g(k_i(t), s(t) : hh_i(t)) - ot_i(t), s(t+1), p(t+1)]]
\end{aligned} \tag{5}
$$

This model provides the following first order condition

$$
\begin{aligned}
&\big(\partial U\big(f(k_i(t), s(t) : hh_i(t)) + p(t) \cdot ot_i(t) + \delta \cdot fa(t)\big)/\partial c_i(t)\big) \cdot p(t) \\
&\quad = \beta \cdot E_t\big[\partial V\big[(1 - \theta_i(s(t), \tau_i(t))) \cdot k_i(t) + g(k_i(t), s(t) : hh_i(t)) \\
&\quad - ot_i(t), s(t+1), p(t+1)\big]/\partial k_i(t+1)\big]
\end{aligned} \tag{6}
$$

No unambiguous prediction about the impact of a shock on sales is possible when both asset and income shocks are included in the model. However, the basic insights of the previous models do carry through to eq. (6). A shock that impacts milk production positively will decrease the offtake level. A shock that impacts herd growth positively will increase the offtake level. As it is quite likely that milk production and herd growth respond in a similar fashion to rainfall shocks, we will need to do distinguish between them to understand the impact of unexpected rainfall shocks on offtake behavior. After a brief discussion of the data set in the following section, we turn in Section 4 to empirical methods to clarify how milk production and herd growth are influenced by climate shocks. We then use estimation methods to identify the relative impact of these different variables on livestock sales behavior in Section 5. The estimation of sales behavior includes variables representing arguments included in eq. (6) to identify how changes to household level and exogenous variables influence household sales behavior. In particular,

[3] Price shocks have been cited in previous studies as a source of cycles in livestock populations (Rosen *et al.*, 1994; Rosen, 1987; Jarvis, 1974). These studies identify how price signals interact with breeding stock inventory decisions to endogenously generate population fluctuation. The production context of the current study differs from that considered by these earlier studies as the vast majority of change in livestock population comes about due to sudden herd die-off and ensuing herd rebuilding (see Fig. 1).

[4] Information on determinants of livestock marketing prices in this area can be found in Barrett *et al.* (2003).

variables recording herd size, livestock selling price, food aid production, and household characteristics are included. Although the impacts of these variables on sales behavior are interesting in and of themselves, the main purpose of including them is to allow focused attention on how changes in milk production and herd growth impact household sales behavior.

3. Description of the data

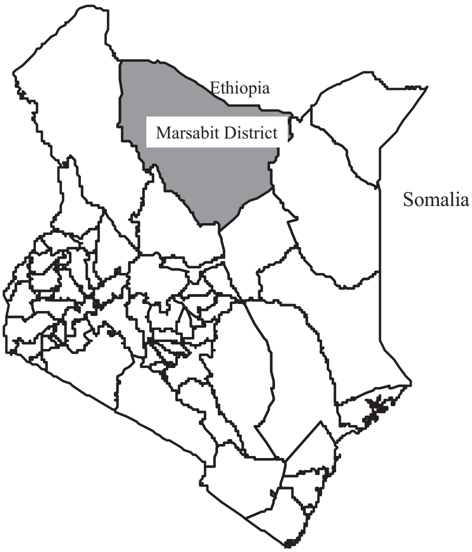
This study uses longitudinal data gathered in two areas of Marsabit District, Kenya (see Map 1). Gabra pastoralists are a Cushitic speaking group with a population in Kenya of around 35,000 according to the 1989 Kenyan census. A sample of 39 households was drawn in the Chalbi area of Gabra land, and a sample of 49 households was drawn from the Dukana area. The sampling method chosen was based on the idea of a transect, as no list of pastoral households existed for this area. Enumerators moved between the main towns of the study area (Kalacha and North Horr in Chalbi and Sabarei and Dukana in the Dukana area) interviewing herders they encountered at nomadic camps along the way (see Map 2).[5] The questionnaire was retrospective in nature, recording information for four time periods per year for each of the years 1993–97. Survey work began in mid-1997 and ended in early 1998. The beginning period of the recall period was defined as the 1992 drought that led to widespread herd losses in the study area, and ended with the period in which the respondent was interviewed.[6]

Within a year, the four time periods were defined to correspond to the bimodal rainfall pattern of the area: the long rains, the dry season following these rains, the short rains, and the dry season following these rains. Each period corresponds to a season that is roughly three months in length.

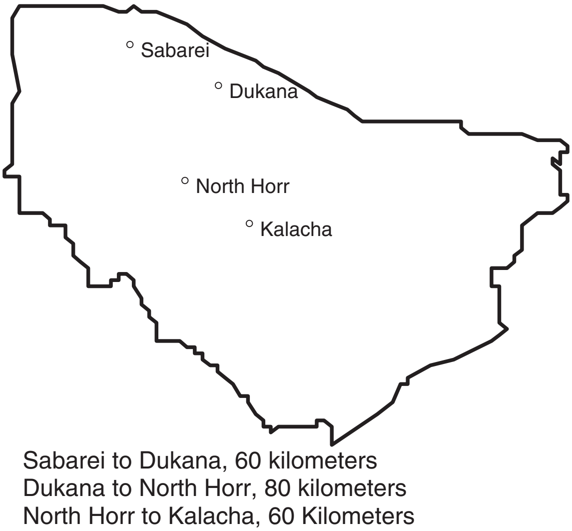
Respondents were asked to report the following variables for each time period: ages of household members; household size; household herd size and species composition; sales from the household herd, characteristics and price per animal

[5] The definition of this sample did not include former herders who have moved to the small towns of the study area, either in search of economic opportunities or due to the loss of their herd. Issues of selection bias are possible if herders who lost their animals between 1992 and 1997 were systematically overlooked due to the sampling method based on the outcome of herders still residing in the grazing areas. However, discussion with both nomads and town residents indicated this was not likely to be a major issue, as there was not a significant population flow from the rangelands into the towns during this time period, and very few households were forced out of pastoralism due to the herd losses experienced in 1996.

[6] Respondents appeared to have little difficulty in recalling season-specific information over the four year time period covered in this study. This was likely aided by the fact that widespread herd losses in 1992 served as a notable starting period. In addition, herd genealogies were constructed for camels and cattle to record livestock production information, and served as the foundation for other questions (for a discussion of this methodology, see Grandin, 1983). In a society where records are not written, information contained in herders' memories serves a critical function in herd management decisions. Knowledge of complicated genealogy structures and historical events is critical for both Gabra society and for herd management decisions (Tablino, 1999; Robinson, 1985; Torry, 1973). While repeated observations would be preferable for construction of a longitudinal data set, the recall data in this study is internally consistent, and is in our judgment reliable enough to analyze empirically.



Map 1. Kenya, noting Marsabit District



Map 2. Marsabit District, noting main towns in study area

sold; slaughters from the household herd, and characteristics of animals slaughtered; transfers into and out of the herd and characteristics of animals transferred; average milk production from the herd per day[7] and total milk sales per period; and other sources of household income. Stocks are reported for the beginning of

[7] This is the milk produced for human consumption. Traditionally, half the udder of a milking animal is taken for human consumption and the other half is left for young stock to suckle.

Table 1 Means and standard deviations of variables used in this study

	Mean	Standard deviation
Milk in liters per day	4.44	3.58
Herd growth in TLU	0.53	4.68
Sales level in TLU	0.24	0.42
Herd size in TLU	29.06	25.27
Large stock TLU/ small stock TLU	2.00	1.96
Age of oldest male	50.62	13.38
Age of oldest female	36.57	11.48
Household size in adult equivalents	4.51	1.66
Rainfall over six month period in mm.	56.82	38.27
Fraction of rainfall in current period	0.52	0.45
Long rains dummy	0.26	0.44
Short rains dummy	0.26	0.44
Price of male goat in shillings	869.58	237.25
Food aid deliveries in tons per period	71.32	88.09

the season and flows are recorded for totals during the period. Household size is converted into an adult equivalent scale following the method outlined by Martin (1985).[8] Variables recording herd size are converted to total livestock units (TLU), following the method of Schwartz *et al.* (1991).[9]

Variables exogenous to the household are also recorded in the data set. The average price received for male goats per period is constructed as the age and site corrected average of all sales recorded in the data set. As will be noted below, male goats are the type of animal sold more frequently than any other type, making this the key price series to include in the analysis. Four variables are used to record rainfall characteristics of a given time period; one measures total rainfall in the current three-month period plus the last three-month period, a second measures the percent of this total that fell in the current three month period, and the final two are dummy variables that record whether the period in question is a rainy season. A variable records the tons of food aid delivered to the towns of the study area in a given time period.[10] Table 1 presents summary statistics of variables used in later regressions.

[8] The adult equivalent weighting scheme used in this study assigns a value of one to individuals of both sexes older than 15, a value of .6 to individuals 6–14 years old, a value of 0.3 to children ages 2–5, a value of 0.1 for children under 2.

[9] One livestock unit = 10 sheep or goats = 1 head of cattle = 0.7 camels. This differs slightly from the scheme in Schwartz *et al.* as they weigh 11 goats equal to one TLU. As the total number of sheep and goats is the variable recorded in the data set, the composite measure of smallstock is assigned a weight of one animal = 0.1 TLU.

[10] The rainfall and food aid records were provided by the Catholic mission in North Horr and the AIC mission in Kalacha.

4. Pastoral production and stochastic shocks in Gabra rangelands

Pastoral households depend primarily on livestock to produce income and meet their consumption needs. Pastoral herders tend to reside in arid and semi-arid environments that are characterized by a high degree of production risk (Scoones, 1995). One aspect of this production risk involves transitory income shocks such as a decline in livestock milk production when rainfall is unexpectedly low. In addition, production risk involves the prospect of a sudden dramatic decrease in household assets due to rainfall deficits, livestock disease, or theft of animals. Asset losses during droughts of up to half of a household's herd over a period of months are reported from a variety of studies in east Africa (Coppock, 1994; McCabe, 1987; Sobania, 1979). In a pastoral context, livestock losses may be so severe that households are unable to maintain a pastoral lifestyle, finding instead that they have become snared in permanent poverty since few alternatives to livestock raising are possible in arid and semi-arid environments (Schlee, 1991; Legesse, 1989; O'Leary, 1987).

Gabra rangelands, located in northern Kenya and southern Ethiopia, are the most arid in all of east Africa (FAO, 1971). Mean annual rainfall is below 300 millimeters for the vast majority of Gabra rangelands, making rain-fed cultivation impossible (Schwartz *et al.*). Robinson (1985) describes the environment as '. . . one of rugged desolation; searing winds and unrelenting sun' (p.43). His examination of Gabra oral history suggests sudden herd losses are frequent in this area, as they figure prominently and repeatedly as far back as the mid 1800's. In the post-independence era, widespread herd losses are recorded for Gabra herders in 1965, 1970–1, 1975–6, 1980, 1983, 1991–2, and 1996 (Tablino, 1999; O'Leary, 1987).

Gabra live in portable houses and practice nomadic pastoralism with their herds of camels, cattle, sheep and goats in order to survive in this harsh environment. Gabra rely almost entirely on their herds to generate income, and milk produced by the household herd is the major component of household consumption. Assigning market values to home consumed goods reveals that on average, 72% of household income over a three-month period is accounted for by milk produced by the household herd;[11] 15% is obtained by the sale of animals; 10% is obtained by home consumption of slaughtered animals, and 1% is obtained by skin and hide sales, gifts, and remittances respectively.[12] It is important to note that although milk is the main component of the diet on average, milk production exhibits significant variation over time. The average of the household level coefficient of

[11] Not all of this milk is consumed directly by the household. On average, 12% is sold. Milk marketing is an activity women undertake in this area, while men make decisions over livestock marketing and herd management. For a discussion of intrahousehold contestation over milk marketing, see McPeak and Doss (2002). We abstract from these issues in the current study.

[12] On average, 19% of this income measure is cash income. The remainder is derived by assigning market values to home produced and consumed goods.

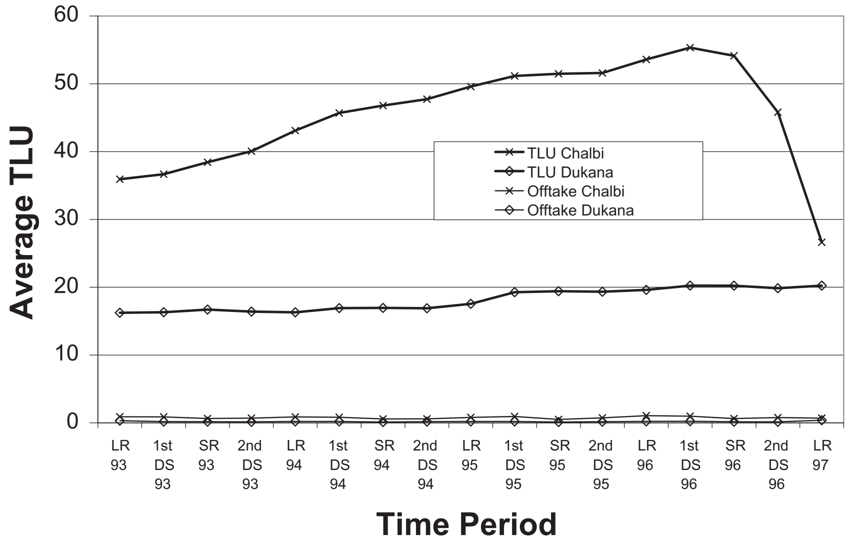


Fig. 1. Average herd size and offtake by site, early 1993–early 1997

variation for milk production over time is 43 for the Chalbi households and 55 for the Dukana sample.

A certain amount of the variation in milk production may result from changing rainfall conditions. Pasture growth in this area is entirely dependent on rainfall and rainfall is highly variable. The coefficient of variation for annual rainfall in North Horr for the period 1986–97 is 58, and within year rainfall is bi-modally distributed.

Further variation in milk production may be due to changes in household herd size.[13] Total household milk production will obviously be adversely impacted if milk-producing animals die. The majority of herders in the study area were in a rebuilding phase following the losses of 1991–2. The data set begins after these losses and follows herders through a period of rebuilding until a second period of widespread herd loss in Chalbi in 1996, although no such loss occurred in Dukana. Figure 1 presents the average herd size over time for each site recorded in the data set, and also includes average offtake levels (the total of sales and slaughters per period) to confirm that mortality is the predominant regulator of herd size in this area.

[13] Sex composition of the herd may also be important for milk production. While sex composition information was not gathered for smallstock (goats and sheep), analysis of the herd genealogy information indicates that for all time periods considered, female camels accounted for 60% of household camel herds, and female cattle accounted for 61% of household cattle herds. The ratio of household level female camels and cattle to total household camels and cattle exhibits low variability ($\sigma^2=0.01$) across households and the variation that exists is not explainable by household characteristics ($R^2=0.01$ for a regression of this ratio on household size and age of head in 1993). The mean results are similar to earlier studies that found female composition for camels 62% (O'Leary) and 60% (Torry), and for cattle 72% (O'Leary).

Table 2 LSDV estimation of milk production and herd growth (heteroskedastic consistent standard errors in parentheses)

	Milk production	Herd growth
Herd size in TLU	0.1236‡	−0.0954‡
	(0.0109)	(0.0250)
Herd size^2 in TLU ($\times 10^{-3}$)	−0.1795‡	0.0146
	(0.0372)	(0.0855)
Large stock TLU/ Small stock TLU	−0.0832*	0.3998‡
	(0.0444)	(0.1022)
Rainfall in six month period	0.0199‡	0.0539‡
	(0.0042)	(0.0097)
Rainfall^2 in six month period ($\times 10^{-3}$)	−0.1094‡	−0.2127‡
	(0.0268)	(0.0618)
Fraction of six month rain in current period	0.6757‡	4.6338‡
	(0.2555)	(0.5879)
Long rains dummy	1.5560‡	−2.6644‡
	(0.2548)	(0.5864)
Short rains dummy	0.5106†	−3.7113‡
	(0.2281)	(0.5249)
Age of oldest male	−0.1123	−1.5801‡
	(0.2170)	(0.4992)
Age^2 of oldest male ($\times 10^{-3}$)	1.8905	6.8522*
	(1.6808)	(3.8677)
Age of oldest female	−0.4918‡	0.5824
	(0.1901)	(0.4375)
Age^2 of oldest female ($\times 10^{-3}$)	4.7773†	−7.7146*
	(1.8817)	(4.3299)
Household size in adult equivalents	-0.2990	−1.2604‡
	(0.1971)	(0.4535)
Wald test for herd size significance ($\chi^2_{(2)}$)	247.8‡	58.8‡
Wald test for rainfall significance ($\chi^2_{(2)}$)	22.7‡	45.8‡
Wald test for male age significance ($\chi^2_{(2)}$)	3.6	23.0‡
Wald test for female age significance ($\chi^2_{(2)}$)	6.6†	9.2†
Wald test for FE significance ($\chi^2_{(88)}$)	1263.4‡	299.8‡
R^2	0.75	0.22

Notes: ‡ denotes significant at the 1% level, † denotes significant at the 5% level, * denotes significant at the 10% level.

In the modeling section, the component of the consumption equation defined as a milk production function was specified $f(k_i(t), s(t) : hh_i(t))$. In this section, we develop an empirical analog to this equation. We use this specification to conduct fixed effects Least Squares Dummy Variable (LSDV) estimation of the milk production data. The main objective of this exercise is to identify the degree to which fluctuation in milk production is due to rainfall variation. As we are arguing that climate shocks lead to unforeseen change in milk production levels, we are attempting to identify the direction and magnitude of this influence.

Regressors included in this specification include a quadratic representation of total rainfall over a six-month period, a variable recording the fraction of this total rainfall that fell in the current three-month period, and seasonal dummy variables that record whether the time period in question is usually a rainy season. The Range Management Handbook for this area suggests seasonal pasture growth periods last between three and six months (Schwartz *et al.*, 1991). To account for the fact that overall current period feed availability is a function of past rainfall as well as current period rainfall, the six month total is used. The fraction of the total that falls within a given three month season controls for the timing of rainfall within a rainy season—dry season pair. The dummy variables are included to account for the fact that there is a seasonality to herd reproduction, as animals tend to give birth in rainy seasons due to both species specific gestation periods and breeding seasons.

Herd size as measured in TLU and its square is also included in the regression, as is the herd composition measure described in the previous section. Variables recording household characteristics are included to see whether there are household specific factors that influence milk production and herd size change. These include quadratic representations of the age of the oldest male and the age of the oldest female in the household, the household size in adult equivalents, and a household specific dummy. Results are listed in table two.

The results confirm that changing rainfall conditions significantly influence milk production. Milk production is positively influenced by increased rainfall over the past six months (up to 91 mm, which is just under one standard deviation above the six month mean of 57 mm), and increases significantly the larger the fraction of total rain that has fallen in the past three months and when the period in question is a rainy season. The seasonality result reflects seasonality in livestock births, as livestock in this area tend to conceive during rainy seasons and give birth either one rainy season (sheep and goats) or two rainy seasons (cattle and camels) hence. Rainfall levels and temporal distribution significantly influence milk production, leading Gabra herders to face uncertainty about the production level of the main component of their diet. Also of note is the result that herd size significantly influences milk production. As described above, households are exposed to the risk of sudden and dramatic losses to their herds. These sudden herd loss leads to a decrease in milk production that will persist over time until herds rebuild.

The next objective is to investigate the herd growth process. What conditions influence the sudden herd losses and ensuing rebuilding process described above? In the modeling exercise, the state equation for asset accumulation was described as $k_i(t+1) = (1-\theta_i(t)) \cdot k_i(t) + g(k_i(t), s(t) : hh_i(t)) - ot_i(t)$. For ease of exposition, offtake was described in the model as representing sales. However, the data indicate changes in the herd size also occur due to slaughters and transfers between herders. This allows calculation of herd growth according to the formula $-\theta_i(t) \cdot k_i(t) + g(k_i(t), s(t) : hh_i(t)) = k_i(t+1) + ot_i(t) - k_i(t)$, where offtake is the composite of sales, slaughters, and net transfers. This results in a measure of herd growth that records the net effect of births, deaths, and livestock raiding,[14] which is

[14] During the study period, the Gabra were more often raided than raiders. While historically they have been raiders as much as raided, in the mid-90s they were being 'paid-back' by the neighboring Rendille for Gabra raids in the early 90s and were subject to major raids from the neighboring Dassenetch.

used in the estimation procedure. Herd growth in Dukana averages 0.5 TLU per period with a standard deviation of 1.8, while in Chalbi the mean is 0.6 TLU per period and the standard deviation is 7.0. The data reveal that there is a significant idiosyncratic element of herd growth. In neither site is it the case that for a given period, all households experienced herd growth of the same sign.

Herd growth as represented in the model by $-\theta_i(t) \cdot k_i(t) + g(k_i(t), s(t))$ is a mixture of both stochastic herd loss and herd births. Given data limitations, it is not possible to directly estimate each influence separately. We therefore investigate the net impact of these two factors. Again, we utilize a fixed effects (LSDV) approach to identify how different variables influence herd growth. The same set of regressors used in the estimation of milk production is utilized in this estimation.

The data reveal that milk production and herd growth tend to move together contemporaneously—the correlation between milk production and herd growth in Chalbi is 0.25 and in Dukana it is 0.26. Beyond the obvious biological linkage between herd growth and milk production, this correlation could also reflect correlated responses to a given climate shock. The estimation results support this conjecture, as the impact of rainfall on herd growth and milk production is qualitatively similar. Rainfall over the past six months has a positive effect on herd growth (up to 120 mm), as does the fraction of this total that fell in the current period. However, in contrast to the milk production results, the seasonal dummies are negative and significant. Possible explanations for this result are that births tend to occur during seasons when rains are expected due to gestation lags and we are holding rainfall levels constant, and raids tend to take place during rainy seasons. We also find that herd size has a negative and significant influence on herd growth. This could be due to larger herds either growing more slowly or losing animals at a higher rate than do smaller herds.

In this section, evidence has been presented on the nature of income shocks and asset shocks in northern Kenya.[15] We have noted that the milk production and the herd growth measure are positively correlated. We have also found from the estimation results that both milk production and herd growth respond to rainfall conditions, and that they respond in a qualitatively similar fashion. Finally, our modeling effort suggests income shocks and asset shocks will have countervailing influences on sales behavior. In the following section, we use estimation methods to distinguish the effect of income shocks from that of asset shocks on livestock sales. We also illustrate how a failure to include both types of shocks can lead analysis astray.

[15] As production externalities may exist in common property settings, milk production and herd size change estimations were conducted including a variable recording the average herd size per period of other herders in the area following the methodology of Lybbert *et al.* (2002). No evidence of a negative externality was found. The herd size of other herders does not significantly decrease milk production, herd growth, or increase herd loss.

5. Estimation of sales behavior

Chalbi herders sold an average of 0.4 TLU per three-month period. For 20% of observations no sales occurred. No purchases of animals were recorded. Goats and sheep account for over 99% of recorded sales, the majority of which were goats (71%). Male animals account for 61% of observed sales.

In Dukana, herders sold an average of 0.1 TLU per period. For 53% of observations, no sales occurred. No purchases of animals were recorded. Goats and sheep account for 97% of sales (goats account for 63%), and cattle for 3%. Male animals account for 72% of observed sales.

As there are many observations of zero sales in a given period, a tobit estimation procedure is adopted. The dependent variable used in the estimation is defined as the sales level in TLUs per period.

Regressors used in the estimation correspond to those previously described, and are selected based on the specification of eq. (6) in Section 2. The matrix of exogenous variables includes a measure of the average livestock selling price in the period, a measure of the food aid delivery to the area in the current period, household demographic variables, and measures of the rainfall conditions in the current period. All but the final set of rainfall variables directly reflect the specification in of eq. (6) presented in the modeling section. The rainfall variables are included in estimating the sales equation to rule out the possibility that there is a direct impact of rainfall conditions on livestock sales that was not included in the modeling exercise. Such a response could occur in reaction to issues such as a rainfall induced transport constraint or rainfall induced pasture conditions. We wish to control for any such direct impact as the main regressors of interest in the sales estimation are the dependent variables of the previous section; milk production and herd growth. Since the goal of the analysis is to illustrate how rainfall shocks influence livestock sales though milk production and herd growth, we wish to rule out the possibility that these indirect results are in fact reflecting a direct impact of rainfall on sales.

Special steps need to be taken in the estimation to address concerns about the potential endogeneity of the milk production and herd growth variables. Following the methodology outlined by Smith and Blundell (1986), estimates of milk production and herd growth, $\hat{m}$ and $\hat{g}$, are obtained in a first stage regression.[16] These are used to calculate estimates of their respective error terms, $\hat{v}_m$ and $\hat{v}_g$. The coefficients of these estimates in the second stage tobit regression provides the basis for a test of weak exogeneity.

In addition, steps are taken in the estimation procedure to recognize the longitudinal nature of the data set. First, household specific dummies are defined for

[16] To assist in identification, regressors in the first stage estimation differ from those described in table two. In the first stage estimation, quadratic representations of the numbers of camels, cattle, and smallstock, are used instead of the TLU and herd composition variables. We also use quadratic representations of rainfall at the three month and six month intervals. The overall fit and results of these models are similar to those reported in Table 2. Results are available upon request from the author.

each of the 88 households. Denote the matrix of household specific dummies V, and the household specific coefficients $\omega_i, i = 1, \ldots, 88$. Second, the variance of the unobserved term is allowed to vary according to household specific characteristics. Structural heteroskedasticity is defined as a function of household specific means for the herd size, household size, age of the household head, herd composition over the course of the study period, and a dummy variable recording whether the household is in Chalbi or Dukana. Denote the matrix of household specific means as $\overline{hh}_i$, and the respective coefficients for variables in this matrix by the vector γ.

We begin by estimating the following model

$$\begin{aligned}
&y_{it}^* = \beta X_{it} + \omega_i V_{it} + \alpha_m \cdot \hat{v}_m + \alpha_g \cdot \hat{v}_g + u_{it} \\
&y_{it} = \begin{cases} y_{it}^* & if \quad y_{it}^* > 0 \\ 0 & if \quad y_{it}^* \leqslant 0 \end{cases} \\
&u_{it} \sim N(0, (\sigma \cdot \exp(\gamma \cdot \overline{hh}_i))^2) \\
&\hat{v}_m = m - \hat{m} \\
&\hat{v}_g = g - \hat{g}
\end{aligned} \tag{7}$$

The joint test for weak exogeniety of the milk and herd growth variables ($\alpha_m = 0$, $\alpha_g = 0$) results in a Wald statistic $\chi^2_{(2)}$ of 3.64. We then test in turn for exogeneity of the milk production and herd growth variables, first eliminating $\hat{v}_g$ and then eliminating $\hat{v}_m$. In neither case is weak exogeneity of the remaining regressor rejected ($t = 0.696$ and 1.465 respectively). The results indicate there is no simultaneity bias introduced in this specification by including milk production and herd growth as regressors. As such, the model is estimated excluding estimates of the first stage residuals, and these results are presented in Table 3. Also presented in Table 3 are estimation results when the growth variable is omitted. This specification is provided to illustrate how a failure to consider asset shocks can explain a rejection of the buffer stock hypothesis.

The coefficients for household specific dummies and the structural heteroskedasticity term are not reported, although the table does include χ^2 test statistics for their respective joint significance. Household specific variables and household specific fixed effects have a significant influence on sales behavior. In addition, the joint significance of the household specific averages does not reject the hypothesis of structural heteroskedasticity. These findings indicate there are household specific influences on both average sales behavior and the size of the variance of the unobserved term.

The exogenous variables recording rainfall conditions directly do not have a significant impact on sales behavior except for the case of one of the dummy variables recording seasonality. The selling price of male goats does not significantly influence sales behavior, suggesting livestock sales are not particularly price responsive in this area. The food aid result is counterintuitive, as it shows that

Table 3 LSDV estimation of sales level

	Sales level	Sales level (omitting growth)
Milk production	−0.0103*	−0.0051
	(0.0061)	(0.0061)
Herd growth	0.0101‡	
	(0.0028)	
Herd size in TLU	0.0089	0.0066
	(0.0054)	(0.0054)
(Herd size in TLU)^2 ($\times 10^{-3}$)	−0.0127	−0.0143
	(0.0655)	(0.0658)
Rainfall in six month period	−0.0009	−0.0006
	(0.0010)	(0.0010)
Rainfall^2 in six month period ($\times 10^{-3}$)	0.0102	0.0081
	(0.0066)	(0.0067)
Fraction of rainfall in current period	0.0284	0.0441
	(0.0508)	(0.0517)
Long rains dummy	0.0102	−0.0077
	(0.0514)	(0.0521)
Short rains dummy	−0.1301‡	−0.1473†
	(0.0429)	(0.0438)
Male goat price ($\times 10^{-2}$)	−0.0206	−0.0147
	(0.0161)	(0.0160)
Food aid deliveries ($\times 10^{-3}$)	0.0552†	0.0480†
	(0.0218)	(0.0218)
Age of oldest male	−0.0189	−0.0310
	(0.0508)	(0.0509)
Age^2 of oldest male ($\times 10^{-3}$)	0.2948	0.3626
	(0.3638)	(0.3652)
Age of oldest female	0.0004	0.0023
	(0.0420)	(0.0419)
Age^2 of oldest female ($\times 10^{-3}$)	0.3830	0.3375
	(0.4138)	(0.4134)
Household size in adult equivalents	−0.0385	−0.0503
	(0.0399)	(0.0390)
Sigma	0.3511‡	0.3501‡
	(0.0307)	(0.0300)
Herd size significance $\chi^2_{(2)}$	10.6‡	5.5*
Rain past six months significance $\chi^2_{(2)}$	4.2	3.9
Male age significance ($\chi^2_{(2)}$)	1.8	1.7
Female age significance ($\chi^2_{(2)}$)	58.0‡	52.7‡
Heteroskedasticity $\chi^2_{(4)}$	277.0‡	370.0‡
Household dummy variables $\chi^2_{(88)}$	254.1‡	249.4‡

‡ denotes significant at the 1% level, † denotes significant at the 5% level, * denotes significant at the 10% level.

sales and food aid are positively related holding all else constant. As eq. (6) implies increased food aid should lead to decreased offtake, this result suggests the interaction between livestock sales and food aid is more complicated than presented in the modeling section. We leave this as a topic for future research.

Estimation results support the contention of the income shock model that offtake responds to income variability. Decreased milk production is associated with higher sales. Note that when we omit the herd growth variable in specification two, the coefficient for milk production becomes non-significant. This provides a possible explanation for the ambiguous results found in previous studies of the buffer stock hypothesis. Results also support the contention of the asset shock model that a decrease in herd growth is associated with lower sales levels. With regard to longer-term changes in household asset levels, it is found that increases in household herd size are positively associated with increased sales.

Overall, estimation results confirm the model prediction that negative changes in income will increase offtake, while negative changes in assets will decrease offtake. Lower milk production leads to higher sales and lower herd growth leads to lower sales. To investigate the relative magnitude of these various effects, estimation results are simulated in the following section.

6. Simulation of estimation results

As predicted by the simple model of income shocks in Section 2, the sales level increases to compensate for the decreases in consumption brought about by decreased milk production. As predicted by the simple model of asset shocks in Section 2, sales decrease as the expected marginal value of capital increases due to negative herd growth. Both changes in income and assets influence household sales decisions. In this section we use simulation methods to identify the relative magnitude of income and asset shocks on sales behavior.

Our interest is in revealing the impact on sales of unexpected shocks to these variables. We therefore need to distinguish between predictable and unpredictable changes in these variables to focus attention on shocks to income and assets. We begin by identifying predictable seasonal patterns in milk production and herd growth. We define baseline intra-annual patterns of milk production and herd growth based on the assumption that all rain for a given period falls within the designated rainy season, 100 mm of rain falls during the long rains and 50 mm of rains for the short rains (Schwartz *et al.*, 1991). We use the same set of assumptions and the predicted values for milk production and herd growth per season in a normal year to then estimate a baseline seasonal pattern of sales.

We then predict milk production, herd growth, and the sales level in a drought year. The lowest rainfall level recorded for a six month period in the data set (1 mm over six months recorded in mid-1995) is used to predict milk production and herd growth for each of the four seasons within a year. These predicted drought levels are then substituted into the sales estimation to provide an estimate of drought period sales level for each of the four seasons.[17]

[17] When simulating the impact of the drought, the direct impact of a decline in rainfall over the six month period on sales is not included. There are two reasons for this. First, we wish to focus attention on changes in milk production and herd growth. Second, the rainfall level parameters in the sales estimation are not jointly significant.

The results indicate that while sales behavior is clearly influenced by predictable seasonal patterns,[18] unpredictable deviations from these seasonal patterns also influence sales behavior. If both milk production and herd growth are impacted by the drought as described in Table 4, seasonal sales levels decline from the normal year predictions by: 2.9%, 3.0%, 1.7%, and 1.8%. If we consider the impact of the drought on milk production alone, the seasonal sales level increase by: 1.8%, 1.9%, 2.2%, and 1.6%. Finally, if we consider the impact of the drought on herd growth alone, seasonal sales level decreases compared to the normal year by: 4.6%, 4.8%, 3.8%, and 3.4 %. Income shocks and asset shocks that are driven by rainfall deviations lead to offsetting impacts on sales behavior, though the net effect is dominated by the response to the asset shock.

Alternatively, we can focus on the crisis period experienced in late 1996. Both average household milk production and average herd growth reached their respective minimums for all time periods covered in the study in late 1996 of 2.5 liters per day and −5.9 TLU. The simulated impact of the decline in milk production of this magnitude from its mean leads to a 6.6% increase in the predicted sales level. The simulated impact of the herd growth decline of this magnitude from its mean leads to a 19.1% decline in the predicted sales level. If both declines are included in the simulation, the predicted sales level decreases by 13.3%.

Finally, if we consider the impact of herd size on sales, we can find that the maximum mean herd size of 35 TLU reached in early 1996 leads to a predicted sales level 45.3% greater than the sales level implied by the mean herd size of 21 TLU in early 1997, and 19.5% greater than the sales level implied by the mean herd size for all periods of 29 TLU. Household sales behavior is influenced by both within period asset shocks and longer term changes to asset stocks over time.

In summary, milk production and herd growth shocks are positively correlated, but have countervailing influences on sales behavior. Asset shocks have a larger impact on sales level than income shocks, so that the net effect of an exogenous event such as the failure of a rainy season is more reflective of the response to the asset shock than to the income shock. Finally, we find that the household herd size has an important influence on sales behavior, and that household herd size varies significantly over time. Overall, we find that explicit consideration of asset shocks is critical for understanding household behavior and propose that a failure to consider asset shocks may explain the mixed empirical findings on the role of livestock as a buffer stock in the arid and semi-arid tropics.

7. Conclusion

There is increasing recognition that vulnerability to shocks is one of the defining characteristics of poverty (World Bank, 2000). In addition, there is growing recognition of the influence household asset endowments have on poverty dynamics

[18] Predicted seasonal sales levels are: long rains, 0.23 TLU; first dry season 0.20 TLU; short rains, 0.14 TLU; second rainy season, 0.20 TLU.

(Zimmerman and Carter, 2003; Carter and May, 2001; Dreze and Sen, 1989). This study combines these insights by explicitly recognizing household vulnerability to asset loss.

The majority of studies on risk management in low-income, high-risk environments have focused on how households adjust asset stocks to compensate for fluctuations in income. While such 'buffer stock' models have provided many insights into household behavior, this study suggests they may overlook the issue of asset risk.

The data used in this study was gathered in an area where assets play a role in income production and are subject to stochastic loss. The findings indicate there will be limited use of assets to buffer consumption in the face of an exogenous shock to income if the exogenous shock also threatens assets. This is because liquidation of assets to compensate for a current income deficit comes at the cost of reduced expected future income. This study finds that both income shocks and asset shocks influence livestock sales.

Policies that help households cope with asset shocks are not conceptually different from those that reduce vulnerability to income shocks. In both cases policies should be targeted at strengthening market and savings institutions. However, the type of markets and savings institutions that will help households cope with income shocks are different from those that address asset shocks.

Consider first the income shocks described in this study. Households could smooth consumption when confronted by fluctuations in milk production by marketing excess milk during a good period, saving the money until a deficit period, and using the savings during the deficit period to buy consumption goods. In contrast, consider the asset shocks described in this study. Households could smooth consumption in the face of asset fluctuation by selling animals during a good period, saving the money until after a crisis period has passed, and then purchasing replacement livestock. Improved output markets help households confront both types of shocks, but in one case milk is marketed and in another livestock is marketed. And while addressing both types of shocks involves deployment of savings, the time when withdrawals from savings will occur differs. For an income shock, it is during the crisis. For an asset shock, it is after the crisis has passed. Finally, the input market required differs both in terms of timing and commodity type. To address income shocks, the required good is a consumption good, and it should be made available during a crisis. In the case of asset shocks, the input market needs to provide replacement livestock after the crisis has passed. The structure of policies designed to help households cope with income shocks differs significantly from those designed to respond to asset shocks.

This study finds that recognition of asset vulnerability allows new insights into household level risk management. The development economics literature has placed a great deal of emphasis on how households self-insure through asset accumulation as a means to confront income shocks. Less attention has been paid to the possibility that these assets themselves may be subject to risk. While the arid pastoral setting of this study provides an extreme example of asset vulnerability, the basic concepts may be applicable in other low-income, high-risk settings. Household in many parts of the world confront the possibility that their assets will disappear suddenly due to natural or man-made disasters. Policies designed to reduce household vulnerability to shocks needs to consider the possibility that not only is household income subject to shocks, but household assets may be as well.

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