Income Shocks and Poverty Traps: Asset Smoothing in Rural Ethiopia

Douglas Scott*

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Evidence is found of two distinct patterns of response to the onset of the recent drought in rural Ethiopia. Agricultural Households with pre-shock cattle holdings of three or more animals effectively used these assets as a buffer against the fall in agricultural income. In contrast, households with smaller herds preserved their current herd size, at the expense of reduced consumption. These results are consistent with the existence of poverty trap in household cattle holdings, and highlight the stark choices faced by some groups during this period, to either reduce consumption today or potentially undermine productivity in the future.

Key words: *poverty traps, Ethiopia, drought, asset smoothing*

JEL Classifications: O12, D31, D15, O55

* *Correspondence Address*: Douglas Scott, University of Nottingham, School of Economics, Sir Clive Granger building, University Park, Nottingham, UK, NG72RD. *E-mail*: douglas.scott@nottingham.ac.uk

1 Introduction

The dynamics of poverty in developing countries has attracted increased attention in recent years. A small, but growing, literature has sought to identify mechanisms which serve to trap specific groups in a state of persistent deprivation, while others transition to a higher standard of living. The notion of a dynamic system separating those who will move out of poverty, given time, from those who are trapped indefinitely, is of clear interest from a policy perspective. For example, identifying such a process *ex-ante* would allow for tailored insurance instruments or safety nets to be targeted directly towards those most at risk, while also making it possible to identify where a relatively small intervention would be capable of pushing borderline individuals onto a higher trajectory.

This paper employs an innovative approach to detecting such poverty traps, through heterogeneity in the coping strategies used by households in response to an income shock. Applying this methodology to a nationally representative dataset of rural households in Ethiopia, evidence is found of two distinct patterns of response to the onset of a period of severe drought. Households with initial cattle holdings of three or more animals effectively used these assets to insulate consumption expenditure against the drought-induced fall in income. In contrast, those households with smaller herds often elected to preserve their cattle stocks, at the expense of lower levels of consumption. These findings are consistent with the hypothesis of an asset-based poverty trap, defined by the pre-shock level of household cattle holdings.

1.1 Asset-based Poverty Traps

The theoretical literature has suggested a wide variety of economic relationships which have the potential to generate some form of poverty trap.[1] However, the specific focus of this study is a bifurcation in the accumulation of asset wealth, whereby a household's convergence to either a high or low equilibrium is determined by initial asset holdings. It is suggested that such a pattern of growth could be expected to exhibit an 'S-shaped' relationship, consisting of three equilibria (Lybbert et al., 2004; Carter and Barrett, 2006; Adato et al., 2006).

[1] Some notable examples include, Eswaran and Kotwal (1986) on poverty traps generated by credit market imperfections and land efficiency, Dasgupta and Ray (1986) on the links between nutrition, wages and productivity, and Mookherjee, Napel and Ray (2010) on poverty traps induced by a complementarity between aspirations and educational attainment.

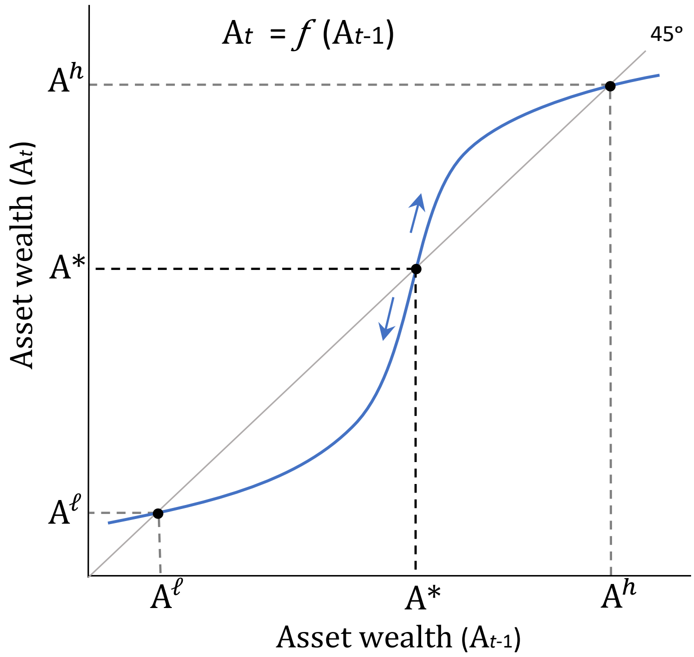


Figure 1: Hypothetical asset dynamics with multiple equilibria

The stylised representation of an asset-based poverty trap in Figure 1, indicates the current level of asset wealth available A_t, given assets in the previous period. The equilibrium level A^* represents an unstable asset threshold, at which growth bifurcates towards a high or low, stable equilibrium. As $\delta A_t/\delta A_{t-1} < 1$ between A^* and A^ℓ, any household with initial asset wealth below this threshold will converge to the low-level equilibrium A^ℓ (without exogenous influence). Conversely, as $\delta A_t/\delta A_{t-1} > 1$ above the threshold, initial period asset holdings above A^* will set a household on the convergence path to the higher equilibrium A^h.

The type of separation shown in Figure 1 could potentially occur through a variety of channels. These could include a correlation between wealth and attitudes to risk, differential access to credit, or even selective exclusion from informal risk-sharing and lending networks.[2] Indeed, the theoretical literature has suggested a number of mechanisms which have the potential to generate such a growth path (Azariadis and Drazen, 1990; Banerjee and Newman, 1994; Dercon, 1998). In spite of this, however, the empirical evidence in support of the poverty trap hypothesis is often restricted to very specific populations or groups of assets. In addition, the

[2]Examples of these particular types of reinforcing patterns of wealth accumulation can be found in Banerjee (2004); Eswaran and Kotwal (1986); Carter (1988) and Santos and Barrett (2011).

most appropriate strategy for identifying such mechanisms also remains unclear.

This paper will proceed as follows. Section 1.2 presents a review of the current literature on asset-based poverty traps, with a particular focus on those studies relating to Ethiopia. Section 2 discusses the predominant theory of consumption smoothing through asset stocks and demonstrates how shock-responses may be influenced by the presence of a poverty trap threshold. An overview of the data used in this analysis can be found in Section 3. Section 4 discusses the empirical strategy and considerations for obtaining valid inference. The main results of the analysis can be found in Section 5, alongside estimations suggesting a possible explanation for these findings. A brief summary and concluding remarks are presented in Section 6.

1.2 The Analysis of Poverty Traps

Until recently, studies which have set out to identify asset-based poverty traps have focused on modelling the dynamic relationship between current and lagged asset holdings, over time (Carter and May, 2001; Lybbert et al., 2004; Adato et al., 2006; Barrett et al., 2006). Due to the need to model a potentially complex growth path, containing multiple equilibria, estimating this relationship often relies on non-parametric techniques. Lybbert et al. (2004) employ such an approach in studying a small group of pastoralist households living on the Borana Plateau in southern Ethiopia. The authors find that, where a household's herd size exceeds 15 cattle in any given period, the future growth path of this asset will tend towards a stable, high equilibrium of 75. In contrast, those households falling below this threshold herd size (either in the initial period or as a result of a shock to their livestock holdings) will instead converge to a low-level equilibrium of only a single head of cattle. Following a similar methodology, Barrett et al. (2006) find comparable results among a group of pastoralist households in northern Kenya, although a lower threshold of 5-6 cattle was found in the Kenyan sample.

By focusing on small, pastoralist groups whose income, consumption and asset holdings can be defined in terms of cattle ownership, both of the papers mentioned above can confidently represent a household's wealth through a single asset. However, in restricting their analysis to such specific groups, it is unclear whether these findings would have value to those concerned with a more general population. A study of households in KwaZulu-Natal, South Africa, conducted by Adato, Carter and May (2006), avoids the need to focus attention on one specific asset by constructing a livelihood-weighted asset index, based on the value of assets required to attain a level of consumption equal to the national poverty line. The study concludes that households with sufficient initial assets to generate a consumption level of approximately twice the poverty line would converge to a higher level of wealth over time, while those below this threshold would instead collapse to a lower long-run equilibrium.

Although the type of non-parametric approach used in these studies provides the necessary degree of flexibility to estimate a complex, non-linear growth path, it relies on the assumption that a population's asset dynamics can be accurately represented using only a bivariate relationship (between current and lagged assets). Within such models all heterogeneity in the units of analysis is necessarily disregarded, as are additional covariates potentially influencing changes in herd size. This brings into question the value of conclusions based solely on this approach. Nevertheless, to enable comparison with the main results of the paper, the Ethiopian data, employed in this study, is analysed using a similar non-parametric method to Lybbert et al. (2004) in the preliminary results section of this paper.

Following the work of Jalan and Ravallion (2004) and Lokshin and Ravallion (2004), recent contributions to the literature have employed more parametric methods to identify multiple equilibria in the evolution of asset stocks. These studies have the advantage, over the papers mentioned previously, in that they permit the inclusion of covariates within the analysis. In the most commonly applied method the current level of the asset stock is regressed on its lagged value, using polynomials to allow for both a concave and convex relationship over the range of asset wealth (see Figure 1). Quisumbing and Baulch (2009) use this approach, alongside the non-parametric methods previously discussed, in their large-scale study of rural households in Bangladesh. Within this sample, they identify only a single low-level equilibrium in both the parametric and non-parametric estimations. The authors suggest the presence of relatively well-functioning factor markets as the reason for the contrasting results to the African studies. However, using a similar methodology, Giesbert and Schindler (2012) find evidence of only a single low-level equilibrium, using a nationally representative panel of households in rural Mozambique. The presence of only a single equilibrium in these studies mirrors the results obtained by applying the lagged polynomial approach to the Ethiopian data used in this analysis (see Section 5.1).

Two important contributions to the literature, from the perspective of this paper, come from Van Campenhout and Dercon (2012) and Naschold (2013). Both studies analyse the asset accumulation path in a sample drawn from 15 Ethiopian villages, between 1993 and 2004. Unlike the previous papers mentioned, Van Campenhout and Dercon (2012) employ a piecewise linear specification in an attempt to identify a poverty trap in tropical livestock units. They find evidence of a discontinuity at approximately 7 units (around 7-10 cattle). However, when applying a number of non-parametric and lagged polynomial approaches to the same dataset, Naschold (2013) finds no evidence of the multiple equilibria growth path, suggested in the first paper. Contradictory findings, such as these, highlight the degree to which parametric results may be highly dependent on the functional form assumptions imposed upon the data. In addition, accurately estimating a continuous asset growth path using a parametric model requires a sample containing observations at every level of the asset. This is of particular concern, as the dynamic system implied by a poverty trap would see all households converge to one of two extremes. The data must, therefore, contain sufficient exogenous shocks to ensure that the area around the threshold remains populated. This final comment suggests an alternative approach to identifying a point at which asset growth paths bifurcate.

In an environment where households have limited access to credit, Deaton (1991, 1992a) demonstrates that households can effectively protect vital consumption, from all but the worst shocks to income, through the sale and accumulation of asset stocks. His seminal buffer stock model is particularly applicable to low-income, rural communities, who have little or no access to formal credit or savings. There exists a well-established literature testing the implications of the buffer stock theory (see Rosenzweig and Wolpin (1993), Fafchamps et al. (1998), Kinsey et al. (1998). However, it is often observed that it is the rich, rather than the poor, who employ such strategies to smooth consumption.

Evidence of heterogeneity in the use of asset sales to protect consumption is present in Kazianga and Udry (2006), who study the impact of a period of extreme drought on a panel of households from rural Burkina Faso. The authors find that lower income households elected to deliberately reduce consumption, rather than sell the small amount of livestock they had available. Verpoorten (2009) uncovers similar evidence of both consumption smoothing and asset protection strategies, using data on livestock holdings during the civil war in Rwanda. In the context of Ethiopia, a study by Carter et al. (2007) identifies two distinct asset recovery paths, following a period of severe drought in the agriculture-dependent South Wollo region. A potential explanations for such heterogeneity can be found in Hoddinott (2006), whose research on resettled household in rural Zimbabwe found that consumption smoothing through cattle stocks was more likely amongst households with a minimum of three cattle. In an attempt to explain this result, Hoddinott speculates that, in electing to sell some of their herd, households with a higher number of cattle would still be left with sufficient animals to plough their fields in the following season. If this hypothesis were accurate, such a relationship between herd size and agricultural productivity could plausibly generate the type of poverty trap described in the previous section.

Observable changes in behaviour in response to an income shock open-up the possibility of identifying a poverty trap threshold indirectly, through changes in the shock-responses of households close to this level of assets (A^* in Figure 1). This concept is closely related to the work of Carter and Lybbert (2012), who use a threshold estimator to identify two separate consumption smoothing regimes in the same Burkina Faso data used by Kazianga and Udry (2006). While the original paper found only weak evidence in support of the conventional buffer stock theory, Carter and Lybbert's analysis concluded that the behaviour of households above the threshold conformed closely to the predictions of the model. Those with smaller herd sizes however, did not appear to smooth consumption in this manner, in spite of having sufficient animals to do so.[3]

This study makes two key contributions to the literature. Firstly, the discovery of heterogeneity in the evolution of livestock holdings, in different Ethiopian populations and time-periods (see Lybbert et al. 2004; Carter et al. 2007, and Van Campenhout and Dercon 2012), provides sufficient motivation for a larger, more representative analysis of rural livestock dynamics in Ethiopia. This paper provides such an analysis. The second contribution is methodological. As discussed, the majority of previous attempts to detect multiple equilibria in asset growth, either fail to control for the influence of external variables, or are overly dependent on the initial assumptions regarding functional form. Carter and Lybbert's finding, that a desire to protect assets may override consumption smoothing motives in the vicinity of a poverty trap threshold, suggests an alternative. This paper seeks to build on this result, by using systematic differences in income shock responses as an indirect approach to detecting the presence of an asset-based poverty trap.

[3]The value of livestock sales was sufficient to offset between 80-90% of the shock to income in households above the threshold. Below this threshold however, only 25-30% of the income shock was smoothed using this strategy (Carter and Lybbert, 2012).

2 Theoretical Framework

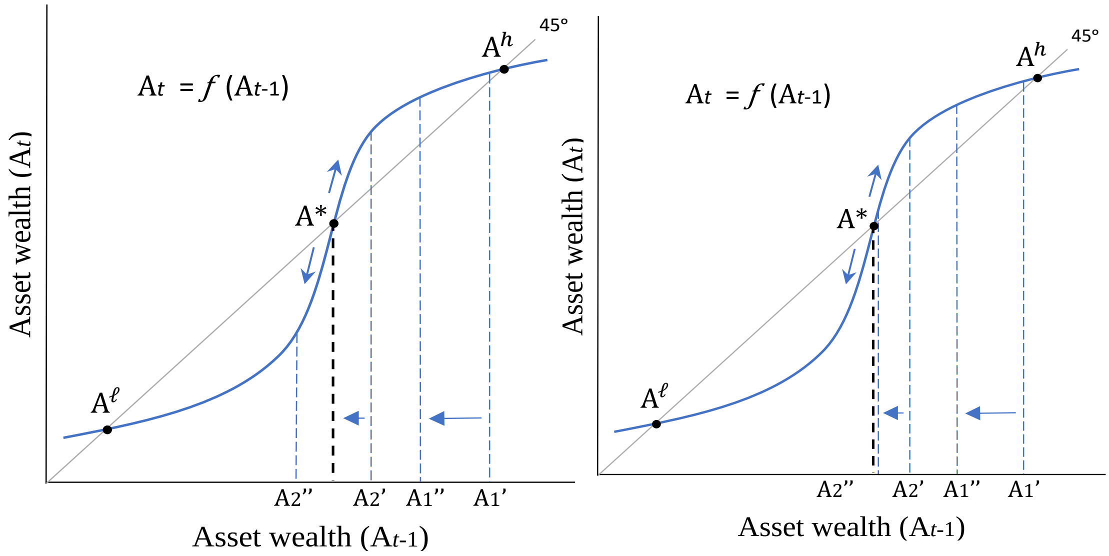
Angus Deaton's (1991, 1992a) seminal buffer stock model is the most widely applied theory of household consumption smoothing through asset stock adjustment. The model shares many characteristics with Friedman's (1957) Permanent Income Hypothesis (PIH), while diverging from the standard intertemporal choice model in the underlying assumptions regarding access to credit. Deaton's theory considers risk-averse households, who seek to smooth consumption, given a stochastic stream of income. However, in contrast to the PIH, agents are not presented with an unlimited capacity to borrow and save. Instead, the model considers the case where households have no access to credit, but are able to insulate consumption from negative income shocks through the sale and accumulation of a 'buffer' stock of assets. At each point in time, households will attempt to bring their consumption paths as close to the PIH benchmark as the borrowing constraint permits. However, where a household experiences a negative income shock, with insufficient assets to fully offset the shortfall, all current income and the value of any available buffer assets will be consumed, with nothing carried forward to the next period.

If there exists a threshold level of asset wealth (see Figure 1), the use of assets to fully offset the impact of a negative income shock, could have potentially serious implications for households whose pre-shock asset wealth lies close to this threshold. To illustrate, consider the original growth path described in Figure 1, under the assumption that households fully offset any negative shock to income through the sale of assets.[4]

Figure 2a shows the initial asset position of a relatively wealthy household at $A_1{}'$, well in excess of the threshold A^*. At this point the household would lie on the convergence path towards the high equilibrium. In the event of a negative shock to income, requiring a reduction it assets from $A_1{}'$ to $A_1{}''$ (to avoid a reduction in consumption), the household would remain on the higher convergence path. Therefore, fully offsetting the effect of the income shock will have no impact on this household's long-run level of asset wealth. In contrast, the consequences of fully smoothing consumption change dramatically if a household's initial asset wealth lies only 'just' above the threshold A^*. Consider a second household, with initial assets at $A_2{}'$ in Figure 2a. This level of assets implies that (given sufficient time) this household will also converge to the high-level equilibrium. Unlike the

[4]The standard S-shaped growth-path is not a pre-requisite for the following discussion. A piecewise linear representation of poverty trap dynamics would generate similar behaviour.

first case however, fully offsetting the impact of the same shock will push this household below the threshold to A_2'', moving it onto the lower convergence path, where successive periods will, instead, see asset wealth decline to the low-level equilibrium A^ℓ.



(a) Consumption smoothing

(b) Asset smoothing

Figure 2: Heterogeneity in coping strategies

As noted in Carter and Zimmerman (2003), if a negative shock is substantial enough that fully smoothing consumption would require a household to reduce its asset stock to a level below the threshold, the drastic consequences of such an action may instead lead households to consider allowing consumption to fall in the short-run (at least to some degree), in order to protect a level of asset wealth above A^*. If the capacity exists to withstand a fall in consumption, higher long-run levels of asset wealth suggest that this strategy of *asset* smoothing will represent the optimal shock response.[5] Figure 2b illustrates how a smaller reduction in asset wealth by the second household (afforded at the expense of a fall in consumption) generates heterogeneity in the extent to which the two households use assets sales

[5]It is important to recognise however, that if consumption levels also lie close to the type of nutritional threshold suggested in Dasgupta and Ray (1986), or reducing consumption leaves vulnerable members at risk of the long-run consequences of malnutrition (Alderman et al., 2006; Dercon and Porter, 2014), a household may simply be side-stepping one poverty trap, only to fall into another.

to protect consumption. Figure 2b implies that the extent to which a household favours a strategy of consumption smoothing, over asset protection, will depend on how close its initial asset wealth lies to the threshold.

The choices shown in Figure 2a and 2b could relate to a typical small-holder farmer, whose tangible asset wealth is largely comprised of land and livestock. As well as providing an important input in the generation of agricultural income, livestock may also serve as a buffer stock against transient income shocks (see Rosenzweig and Wolpin, 1993; Fafchamps et al., 1998; Dercon, 1998). In the event of a shock, however, if the choice to reduce livestock holdings pushes this asset below a minimum level, required to effectively use land to generate income, it could risk leaving the household unable to meet basic subsistence needs in the future (Hoddinott, 2006). Without exogenous influence, a requirement to first reduce livestock, and then land holdings, to support consumption, would see the household move towards a state of chronic poverty, where it would posses insufficient asset wealth to generate the income required to escape the low-level equilibrium.

It is possible to simulate this form of heterogeneity in shock responses using an adaptation of the duel-technology model proposed by Carter and Lybbert (2012). In model (1), risk-averse households seek to maximise expected utility, over an infinite horizon, through choosing how to allocate current resources between consumption c and accumulation of a productive asset A.

$$\max_{c\ A} \quad E_0\left[\sum_{t=0}^{\infty} \beta^t u(c_t)\right] \tag{1}$$

Subject to:

$$\begin{aligned} f(A_t\theta_t) &= max\ [f^\ell(A_t\theta_t), f^h(A_t\theta_t)] \\ x_t(A_t\theta_t) &= f(A_t\theta_t) + (1-\delta)A_t \\ A_{t+1} &= x_t - c_t \\ c_t &\leq x_t \qquad \forall t \\ A_t &\geq 0 \qquad \forall t \end{aligned}$$

The first constraint defines income as dependent on a household's choice of a low or high technology $f^\ell(A_t\theta_t)$ or $f^h(A_t\theta_t)$, where the realised income from either choice depends on the current level of assets A_t and the realisation of a stochastic variable θ. Expected marginal returns are greater under the high technology at all levels of the asset stock, but adoption entails an initial fixed cost. The term x_t, in the second constraint, refers to 'cash-on-hand', a measure of the total resources available to the household in the current period (Deaton, 1991, 1992). This is comprised of current income and the value of any assets held, subject to a depreciation rate δ. The equation for the evolution of the asset stock, simply imposes the condition that assets in the following period equate to current period cash-on-hand, less current consumption. The condition $c_t \leq x_t$ indicates that cash-on-hand places an upper limit on consumption, under the assumption of no access to credit, while the final constraint implies that the value of the asset stock is non-negative in all periods. A set of optimal choices, for different initial asset stocks, can be obtained through expressing model (1) in Bellman equation form and solving numerically through value function iteration.[6] The functional form and parameter assumptions required can be found in Appendix 1.

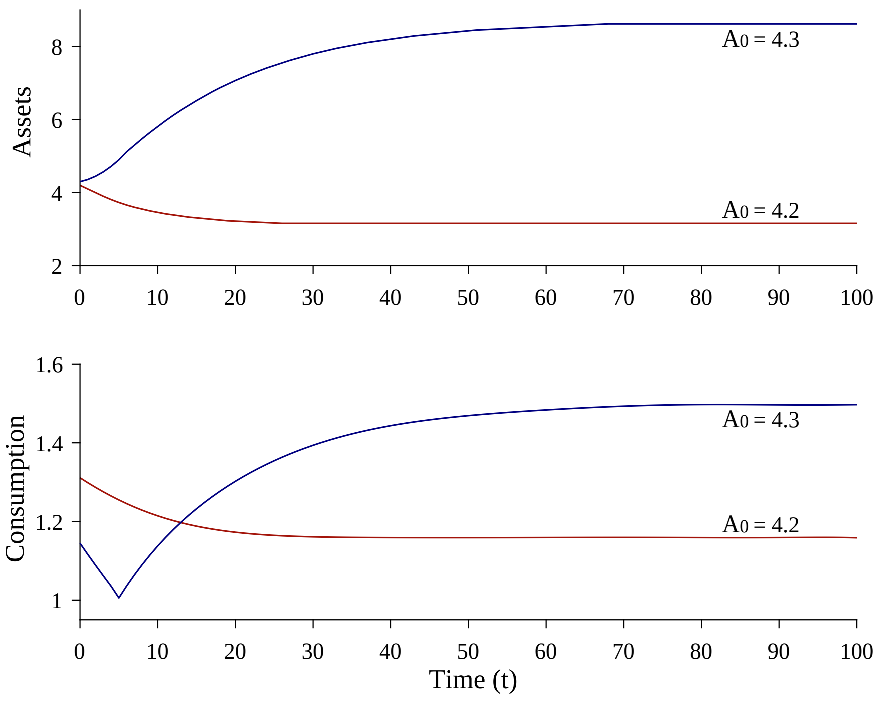


Figure 3: Time-paths of assets and consumption

Model (1) generates the type of bifurcation in asset growth described in section 1.2. The uppermost panel of Figure 3 illustrates the movement towards a high

[6]The Bellman equation relating to model (1) is $V(A_t) = \max_{c \leq x} [u(c_t) + \beta \int V(x_t - c_t) d\Omega\theta]$, where $\Omega =$ the cdf of $[\theta]$.

and low asset equilibrium, for households with initial asset stocks immediately above and below a separating threshold of $A^* \approx 4.22$. While $A_0 = 4.3$ implies adoption of the high return technology, $A_0 = 4.2$ does not. In the example shown, however, $A_0 = 4.3$ is still not sufficient to allow immediate adoption of the high technology. Instead, it comes at the initial cost of foregone consumption in the early time periods, shown in the lower panel of Figure 3.

The presence of the bifurcating threshold A^* in model (1) also generates heterogeneity in income shock responses. The clearest illustration of this comes through analysing optimising behaviour, based on the first-order condition from the Bellman equation. This condition implies that households should consume available resources until the marginal utility of consumption equals the (discounted) expectation of the value of carrying assets forward into the next period, $u'(c_t) = \beta E(V')$. Following Carter and Lybbert (2012), Figure 4 provides a graphical representation of this relationship, as a function A_{t+1}.

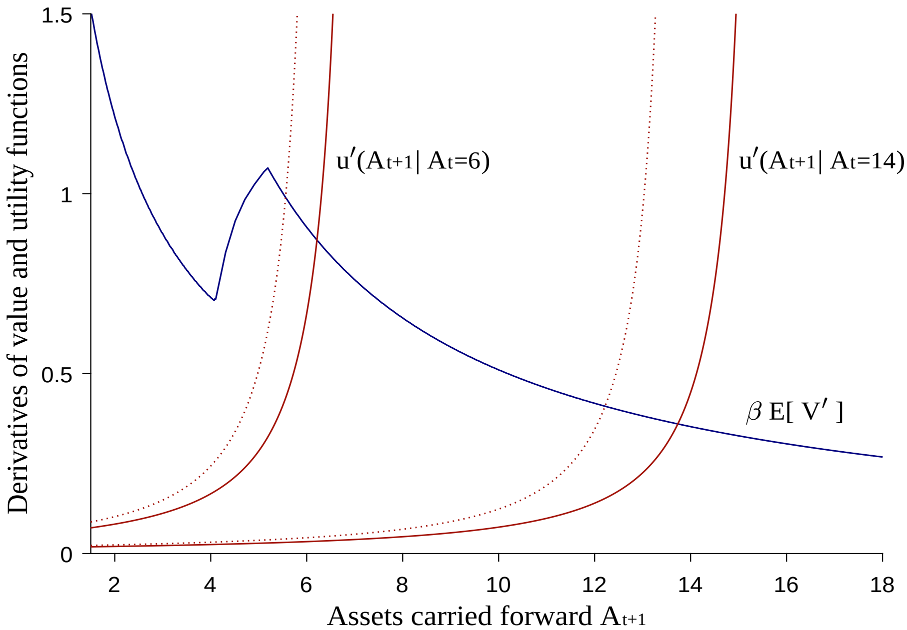


Figure 4: The response of assets and consumption to an income shock

The key feature of Figure 4 is that the marginal value curve $\beta E(V')$ is not strictly decreasing in assets. Between the threshold $A^* \approx 4.22$ and the level of assets required to adopt the high technology (≈ 5.08) the value of holding additional assets increases rapidly. Over this range, households will be willing to sacrifice consumption to accumulate sufficient assets to optimally choose the high return technology (see Figure 3). Having achieved this minimum asset level, however, households at risk of having to return to the low technology, in the event of an unexpected shock to income, will also be willing to sacrifice higher level of consumption to ensure they remain in this position (relative to those at higher levels of the asset distribution).

To illustrate this final point, the marginal utility curves for two representative levels of the initial asset stocks ($A_t = 6$ and $A_t = 14$), are indicated by the solid u' curves in Figure 4. The optimal choice of assets carried forward in each case is found at the intersection with the marginal value curve $\beta E(V')$. The dashed lines represent the marginal utility of consumption, for the same initial asset levels, after a severe, unexpected shock to income (introduced via a 40% downward shift in the entire distribution of the stochastic term θ in model (1)). The two new points of intersection with $\beta E(V')$ imply that a higher proportion of the shock will be absorbed through a reduction in assets by the household with $A_t = 14$. while, the household closer to the high technology adoption level (and closer to A^*) will respond with a relatively larger reduction in consumption.[7]

If an asset threshold A^* does exists, it should be possible to define an initial level of assets, henceforth denoted γ, as the point at which proximity to the threshold induces households to switch from a strategy which prioritises smoothing consumption to a strategy which prioritises asset protection. The level $\gamma > A^*$ would serve to separate households into two distinct shock response regimes.

Proposition 1: For those households who's pre-shock assets exceed γ, a marginal decrease in transient income should induce a smaller reduction in consumption, relative to those below γ. Instead, asset wealth should be drawn down as a buffer against the shock.

Proposition 2: For those households below γ, an income shock will induce an avoidance response and any asset reduction will be of a smaller magnitude than that observed for households in the higher asset regime. As a consequence, consumption in the low asset group will be permitted to fall to a relatively greater degree.

[7]This can be seen in the relative increases in the marginal utility of consumption (the vertical change between the pre-shock and post-shock points of intersection).

3 Data and descriptive statistics

The data used in this analysis comes from two waves of the Ethiopian Socioeconomic Survey (ESS), representing the periods 2013-14 and 2015-16. The initial sample was selected to be representative of all households in rural Ethiopia. Following the literature, the natural choice for the asset stock variable (over which the sample splitting point γ is defined) is household livestock holdings (Lybbert et al., 2004; Carter et al., 2007; Van Campenhout and Dercon, 2012; Naschold, 2013). Furthermore, as the sale of cattle was found to be the most common coping response in the severe drought periods of 1984-85 and 1990-92 (Webb et al., 1992), this paper focuses specifically on cattle as the potential buffer stock asset.[8]

The two sample waves employed come from an earlier ESS survey of 3466 rural households conducted in 2011.[9] Attrition between this initial data collection and the first panel wave is minimal (approximately 4%), leaving a potential sample of 3323 households in the 2013-14 survey. Although the majority of rural households in Ethiopia are involved in both crop and livestock agriculture, a relatively small proportion are not involved in one or other of these activities. As the population of interest is small-scale agriculturalists, households who owned no cattle in any of the three waves of the ESS survey (including the initial 2011 wave) are omitted, as are households with no cultivated land in any period. In addition, to avoid the inclusion of large-scale, commercial agriculture, households with more than 30 cattle or 5 hectares of cultivated land, in any survey wave, are also dropped from the analysis.[10] The level of attrition between the 2013-14 and 2015-16 wave is, again, minimal (approximately 1.9%). However, it is not possible to generate key variables for all observations in the selected sample. In particular, measurement of land areas and harvest quantities are commonly reported in local units, for a small number of which there exists no plausible method of conversion.[11] Subsequently, the usable sample of observations falls to 2561 in 2013-14 and 2495 in 2015-16.

The specific years considered in this analysis cover the onset of a period of extreme drought in Ethiopia. Weak or failed rains were reported in some regions

[8]Livestock is by far the most important asset in rural Ethiopia (Dercon, 2004), and cattle are present in more than 90% of livestock owning households (Van Campenhout and Dercon, 2012).

[9]Substantial differences within the agricultural survey instruments, required to generate income measures, prevent the use of the 2011 wave in this analysis.

[10]The sensitivity of key finding to alternative cut-off levels is considered in Section 5.5.

[11]This particular source of attrition appears largely random, however. A comparison of mean household characteristics between observations included in the sample and those with missing values (including attrition between waves) can be found in Appendix table A1.

as early as mid-2014 and throughout the following year the situation became progressively worse (FAO, 2015). Driven by the unpredictable El Niño weather patterns, the country experienced the initial failure of the early *belg* rains in 2015, followed by low or eratic rainfall in the main *meher* season.[12] The resultant poor harvests, particularly in the North and East of the country, prompted the need for emergency food assistance to be distributed to an estimated 10.2 million people, in addition to the 7.9 million already protected by the government's Productive Safety Net Programme (HRD, 2015). Although the drought was considered to be the worst the country has experienced in recent decades, improvements in Ethiopia's capacity to respond to such events prevented the type of widespread famine experienced in the 1970s and 80s. Nonetheless, the loss of agricultural income suffered by small-scale farmers during the period was extremely high, with the fall in grain output ranging from between 10 and 30%, in the Tigray, Somalie and Gambela region, to between 45 and 66% in Afar and Dire Dawa (CSA, 2016).

3.1 Variable summary

Table 1 summarises the key variables used in the following analysis. The section on *Demographics and education* indicates that households are composed of 5-6 members, on average, with a household head who is most likely to be illiterate and aged between 45 and 50 years old. The remarkably poor levels of education in rural Ethiopia are reflected by the proportion of working age household members within the sample, who have received no formal schooling.

Total farm income reports farm revenue, minus farm expenditure, for the previous 12 months, where the measure of revenue is comprised of income from land rental and the rental of agricultural tools, combined with the (imputed) value of all crops produced. Deducted from this is a measure of expenditure, comprising of the cost of hired factors of production (land and labour), as well as the imputed value of crops paid to these factors as non-financial reimbursement. The nominal value of farm income is deflated spatially and temporally, following Deaton and Zaidi (2002), and reported in table 1 in (1000) Ethiopian Birr, per adult-equivalent.[13]

[12]Ethiopia typically experiences two rainy seasons, the relatively smaller *belg* rains, between March and May, before the main *meher* rains, between June and September. 90% of cereal production is derived from the larger *meher* season (Taffesse et al., 2012).

[13]Adult-equivalency scales are reported in Appendix table A2.

Table 1: Data summary

	Sample		Wave 1 (2013-14)		Wave 2 (2015-16)	
	mean	sd	mean	sd	mean	sd
Demographics and education						
Household size	5.54	2.16	5.53	2.13	5.54	2.18
Age of head	46.61	14.40	45.76	14.33	47.48	14.43
Head is literate	0.40	0.49	0.38	0.49	0.41	0.49
% of members ($15 \leq$ age ≤ 60) with no education	65.37	33.99	64.89	33.89	65.86	34.08
Income and consumption (000)†						
Total farm income	4.88	11.88	5.92	12.94	3.81	10.58
Permanent income	4.88	7.74	4.90	7.80	4.86	7.67
Transient income	0.00	4.50	1.02	4.22	-1.04	4.54
Total consumption	4.84	7.29	5.35	7.84	4.31	6.63
Food consumption	3.95	7.07	4.41	7.59	3.48	6.45
Agriculture and rainfall						
Number of cattle	4.09	4.16	4.40	4.23	3.77	4.06
Land cultivated (ha)	0.98	0.92	1.04	0.93	0.92	0.91
Land irrigated (ha)	0.13	0.46	0.14	0.46	0.12	0.45
Land rented (ha)	0.13	0.40	0.17	0.45	0.08	0.32
Plot TWI‡	12.73	1.58	12.76	1.61	12.70	1.55
Rainfall deviation (mm)	-69.37	323.17	36.33	282.77	-177.87	326.13
Location and social protection						
Distance to bank (km)	17.50	12.01	18.36	12.84	16.62	11.03
Distance to MFI‡ (km)	13.01	11.98	12.98	12.02	13.04	11.95
Distance to market (km)	23.87	5.36	23.71	5.32	24.04	5.39
PSNP‡ in kebele††	0.41	0.49	0.40	0.49	0.42	0.49
Observations	5056		2561		2495	

MFI = Micro-finance Institute, PSNP = Productive Safety Net Programme

† All income and consumption figures reported in 1000 Ethiopian Birr, per adult equivalent

‡ TWI = Topographical Wetness Index. MFI = Micro-finance Institute.
PSNP = Productive Safety Net Programme.

†† A *kebele* is the smallest administrative area in Ethiopia (e.g. a group of villages)

The decomposition of farm income into Permanent and Transient (shock) components is described in Section 4.1, while a more detailed summary of these variables is provided in table 3. It is of interest to note that the measure of transient income is positive in the first survey wave, implying that 2013 was a relatively successful year for the sample households. In the 2015-16 wave however, the drought reduced agricultural incomes, by almost 1040 Birr (approximately 21%), on average, relative to the permanent income level. The measure of permanent income is positively correlated with both the transient income shock ($\rho = 0.1925$) and the number of cattle owned ($\rho = 0.03474$).

The measure of total consumption in table 1 is the value of household food and non-food consumption over the previous 12 months. Food consumption is comprised of purchased, gifted and own-produced food items, from a list of 26 commonly consumed foodstuffs.[14] Non-food consumption includes everyday items, such as candles, soap, fuel and transportation, but also expenses such as clothing, education and informal funeral insurance (IDDIRs). Expenditures on taxes and levies are excluded, as are ceremonial expenses (such as weddings and funerals), which would represent one-off purchases, rather than the general pattern of household expenditure. Expenditure on durable asset purchases is also omitted. Nominal consumption values are again deflated spatially and temporally, and expressed in 1000 Ethiopian Birr, per adult equivalent.

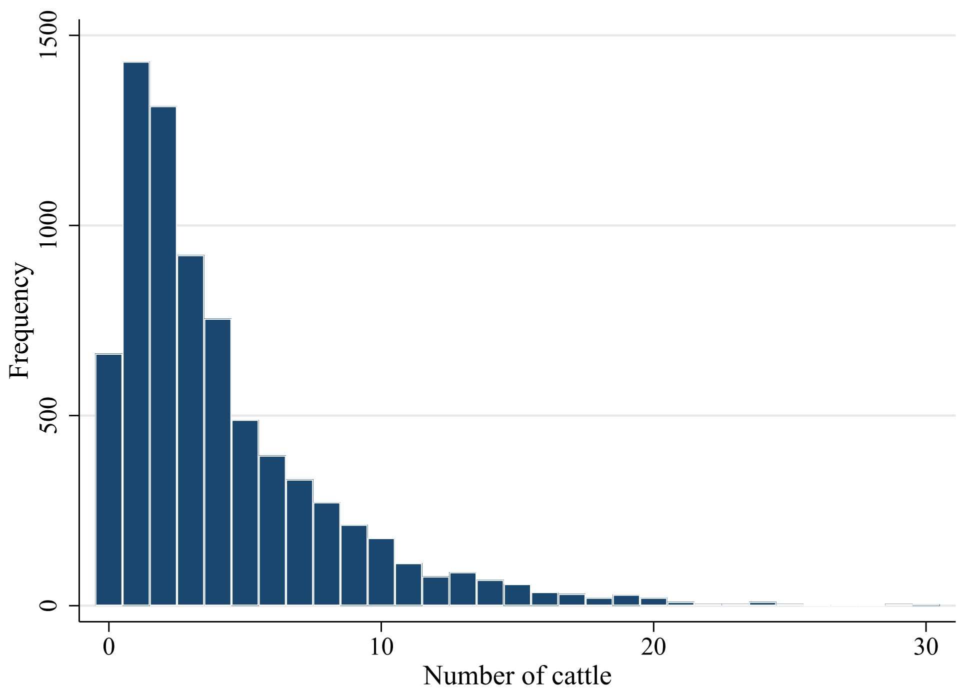


Figure 5: Distribution of herd size from all observations

[14]See CSA (2017) for the full list of food and non-food items included in the value of total consumption.

The average number of cattle reported in table 1 is seen to decline from a mean herd size of 4.4 animals in the 2013-14 wave, to 3.77 at the height of the drought in 2015. Although some of this decline may capture direct livestock mortality (FAO, 2015), it will also reflect the use of cattle sales as a buffer against the subsequent income shock. Figure 5 provides a frequency distribution of the herd size from all available observations.[15] As would be expected in this sample of small-scale, agricultural households, this distribution is heavily weighted towards cattle holdings of less than 5 animals.

The remainder of the *Agriculture and rainfall* section of table 1 reports the characteristics of cultivated land, such as the area which is irrigated or rented by the sample households. In addition, the topographical wetness index (TWI), provides a measure of the soil saturation and the topographical control of hydrological processes (Sörensen et al., 2006). The rainfall deviation variable records one-year deviations from the average annual rainfall between 2001 and 2015. The effects of the drought are clearly visible in the second wave of the survey, where the sample households experienced an average rainfall deficit of approximately 178mm, relative to the expected long-run level.

The final set of variables reported in table 1 indicate the relative location of the households and their access to the Productive Safety Net Programme (PSNP). The distance to a bank and micro-finance organisation (MFI) are intended to control for variation in access to formal savings and credit facilities, which could provide an alternative to the use of asset sales as a potential coping strategy. Proximity to a large weekly market is a measure of remoteness, which would be a characteristic of both differential access to asset markets, and a strong indication of household poverty status (World Bank, 2016). As a further control, the PSNP variable indicates whether or not the safety net programme was operating in the local area during the period in which the survey took place.

[15]The distribution does not appear obviously bimodal, as perhaps could be expected, under the assumption of a high and low equilibrium in general asset wealth. However, this may simply reflect the influence of shocks to asset holdings disrupting movement towards either extreme.

4 Empirical Strategy

4.1 Measuring shocks

In order to recover an exogenous measure of shocks to income this paper employs a widely used instrumental variable approach, based on annual deviations from long-run rainfall (Paxson, 1992; Jacoby and Skoufias, 1998; Fafchamps et al., 1998). These rainfall deviations are also interacted with cultivated land characteristics, to provide additional valid instruments, given the condition that the allocation of land to specific crops (or uses) occurs before rainfall levels are realised (Kazianga and Udry, 2006). Agricultural income is decomposed into a permanent and a transient component, as well as a measure of unexplained income, representing the residual from the following estimation.

$$y_{it} = \beta_1 F_{it} + \beta'(F_{it}T_{it}) + \phi' D_{it} + \tau_t + \psi_i + \epsilon_{it} \tag{2}$$

In equation (2) the dependent variable y_{it} represents agricultural income (per adult equivalent), for household i, at time t. The deviation from long-run average rainfall is denoted F_{it}, while the term in brackets $F_{it}T_{it}$ represents a vector of interactions between rainfall deviations and land characteristics. T_{it} contains variables measuring areas of cultivate land grouped according to topographical wetness index (high, medium, low), irrigation (yes/no) and rental status (yes/no). The vector D_{it} contains household demographic and education variables, consisting of the household size, the age of the household head, the age of the head squared and the proportion of household members (15 to 60 years or age) with no formal education. τ_t and ψ_i represent a common time effect and household fixed-effect, respectively, while ϵ_{it} represents the error term.

Table 2 shows the results of estimating the income model (2), on the sample of Ethiopian households. The dependent variable is agricultural income per adult-equivalent, as defined in section 3. The first column reports the ability of the rainfall variable to predict income, without covariates. As would be expected, the coefficient on rainfall deviation implies a strong positive relationship. Column 2 reports estimates of the model, omitting the interaction of rainfall and land characteristics ($F_{it}T_{it}$) from model (2). In column 3, where the estimation includes these interaction, an F-test of the additional coefficients indicates that these variables are also important determinants of income (p-value $= 0.0000$).

Table 2: Defining Permanent and Transient Income

	(1)	(2)	(3)
Rainfall deviation	12.1647***	12.1438***	9.9020***
	(0.6720)	(0.7962)	(1.0917)
Household size		-493.3396***	-525.1025***
		(136.0913)	(135.9875)
Age of head		187.3476	254.1190**
		(118.9250)	(121.6753)
Age of head squared		-2.3290*	-2.9560**
		(1.2349)	(1.2562)
% No education		-22.8911***	-23.9665***
		(6.9259)	(6.8468)
Rain dev x Area irrigated			4.6013**
			(2.1243)
Rain dev x Area rented			-2.2156
			(1.4300)
Rain dev x Area low TWI †			-3.7535***
			(0.9990)
Rain dev x Area high TWI			10.5631***
			(2.3233)
2015-16 wave		553.7899	506.8071
		(343.9195)	(363.0677)
Household fixed-effects	Yes	Yes	Yes
Observations	5056	5056	5056
R^2 *within*	0.1206	0.1279	0.1630
R^2 *between*	0.2949	0.2836	0.3269
R^2 *overall*	0.2124	0.2157	0.2578

Standard errors in parentheses * p<0.1, ** p<0.05, *** p<0.01

† TWI refers to Topographical Wetness Index

The results of equation (2) can be decomposed to obtain measures of permanent, transient and unexplained income, according to (3). A detailed summary of these variables is presented in table 3.

$$\begin{aligned} \text{Permanent income:} \quad & \hat{y}^P_{it} = \hat{\phi}' D_{it} + \hat{\psi}_i \\ \text{Transient income:} \quad & \hat{y}^T_{it} = \hat{\beta}_1 F_{it} + \hat{\beta}'(F_{it} T_{it}) + \hat{\tau}_t \\ \text{Unexplained income:} \quad & \hat{y}^U_{it} = \epsilon_{it} \end{aligned} \tag{3}$$

Following the decomposition of agricultural income into permanent, transient and unexplained components, the upper section of table 3 reports the means and standard deviations of these generated variables. The first two columns describe the predicted values for all observations within the sample, while the remaining columns show the same information for the first and second waves of the survey. Column 1, in the lower section of table 3, reports the mean fall in transient income among household/wave observations, where transient income was < 0 (a negative shock). The second column reports the mean increase in this variable, for observations where a non-negative shock occurred (transient income ≥ 0). The remaining four columns in table 3 indicate the mean values, for positive and negative shocks, experience by households in wave 1 and 2 of the survey.

Table 3: Summary of income components

	Sample		Wave 1 (2013-14)		Wave 2 (2015-16)	
	mean	sd	mean	sd	mean	sd
Total farm income	4.88	11.88	5.92	12.94	3.81	10.58
Permanent income	4.88	7.74	4.90	7.80	4.86	7.67
Transient income	0.00	4.50	1.02	4.22	-1.04	4.54
Unexplained income	0	6.90	0	6.86	0	6.95
Observations	5056		2561		2495	

	Sample		Wave 1 (2013-14)		Wave 2 (2015-16)	
Shock direction	< 0	≥ 0	< 0	≥ 0	< 0	≥ 0
	mean	mean	mean	mean	mean	mean
Transient income	-2.86	3.57	-2.24	3.30	-3.24	4.11
Observations	2805	2251	1055	1506	1750	745

All income figures reported in 1000 Ethiopian Birr, per adult equivalent

4.2 The consumption response to an income shock

The first prediction of the theory presented in Section 2 is that the consumption response to the drought-induced income shock will differ, dependent on the level of pre-shock cattle holdings, relative to γ (see Proposition 1). Versions of the following empirical model have been used extensively to test whether the relationship between income and consumption conforms with the Permanent Income Hypothesis (Bhalla, 1980; Wolpin, 1982 and Paxson, 1992). In this context however, the primary aim is only to establish the degree to which consumption is protected from transient income shocks in the high and low cattle regimes.

$$c_{it} = \theta_1 \hat{y}_{it}^P + \theta_2 \hat{y}_{it}^T + \theta_3 \hat{y}_{it}^U + \beta' H_{it} + \tau_t + \psi_i + \mu_{it} \tag{4}$$

Equation (4) uses the decomposed income variables in a household-level fixed-effects estimation. The dependent variable is the value of household consumption (per adult equivalent), for household i, at time t. The variables $\hat{y}_{it}^P$, $\hat{y}_{it}^T$ and $\hat{y}_{it}^U$ are based on the first-stage estimation (2) and constructed according to the income decomposition in (3). The term H_{it} represents a vector of characteristics, specific to the household, while τ_t and ψ_i represent a common time effect and household fixed-effect. μ_{it} denotes the error in this second-stage estimation. To permit valid inference, the presence of the generated income regressors $\hat{y}_{it}^P, \hat{y}_{it}^T$ and $\hat{y}_{it}^U$ in the second stage estimations (5) and (7) must be addressed. Treating these predicted measures as fixed values, rather than estimations, ignores sampling variation and the degree of uncertainty in their construction. Therefore, the standard errors in the two-stage estimations of the consumption and asset models will be obtained via a bootstrap procedure (see Mooney and Duval, 1993).

Although the ability to smooth consumption in the sample of households overall is clearly of interest, section 2 puts forward the hypothesis that consumption smoothing behaviour will be more pronounced amongst households above the asset level γ. This level of cattle holdings should mark the point at which proximity to a hypothesised poverty trap induces a switch from consumption smoothing to asset smoothing behaviour. Testing this prediction requires separating the sample into households with a pre-shock herd size $A_{it} > \gamma$ from those with cattle holdings $A_{it} \leq \gamma$.[16] This separation is illustrated in equation (5), which includes the h and ℓ terms on the income coefficients, to make clear the distinction in the effect of the income variables between the high and low cattle regimes.[17]

$$c_{it} = \begin{cases} \theta_1^h \hat{y}_{it}^P + \theta_2^h \hat{y}_{it}^T + \theta_3^h \hat{y}_{it}^U + \beta' H_{it} + \tau_t + \psi_i + \mu_{it}, \text{ if } A_{it} > \gamma \\ \theta_1^\ell \hat{y}_{it}^P + \theta_2^\ell \hat{y}_{it}^T + \theta_3^\ell \hat{y}_{it}^U + \beta' H_{it} + \tau_t + \psi_i + \mu_{it}, \text{ if } A_{it} \leq \gamma \end{cases} \tag{5}$$

[16]Due to the timing of different sections of the ESS survey, measures of the number of cattle owned were recorded prior to agricultural income measure in each wave. As a result, the appropriate pre-shock asset level of interest is recorded at time t, as opposed to $t-1$.

[17]To ease notation, no h or ℓ script is applied to the non-income terms in (5), although all coefficients are permitted to vary between the two regimes.

If the level of cattle holdings γ were known *a priori* estimation of equation (5) would be relatively straightforward. As this is not the case however, it is necessary to utilise the sample splitting approach devised by Hansen (1996, 1999). The method relies on minimising the residual sum of squares across a range of candidate values. Therefore, allowing the data itself to determine the most likely value of γ. A detailed description of this approach is provided in Appendix 3.

4.3 The cattle response to an income shock

If a poverty trap threshold does exist in asset wealth, Section 2 suggests that a household's proximity to this threshold will influence the extent to which asset sales are used to offset a negative shock to income. According to Proposition 2, behaviour above γ should broadly conform with the buffer stock theory, whereby cattle stocks will be drawn upon to achieve a marginal utility of consumption which is as close to smooth as the availability of the buffer stock permits. In contrast, those households below γ may employ a strategy of asset smoothing, when faced with a similar shock to income.

The estimation strategy for determining the effect of agricultural income shocks, on cattle holdings, is equivalent to the approach used to assess the extent of consumption smoothing in section 4.2. In equation (6), the dependent variable is replaced with the change in the number of cattle ΔA_{it}, while all income terms on the right-hand side of (6) represent the same variables found in (4). As only a single observation of the change in cattle stocks is available, the term ξ represents a region-level fixed-effect and the model is estimated using ordinary least squares. In addition, the variables indicating distance (kms) to i) a market ii) a bank iii) a microfinance organisation, and the presence of the PSNP in the local area, are added to the H vector of controls.

$$\Delta A_{it} = \alpha_1 \hat{y}^P_{it} + \alpha_2 \hat{y}^T_{it} + \alpha_3 \hat{y}^U_{it} + \beta' H_{it} + \xi_i + \upsilon_{it} \tag{6}$$

$$\Delta A_{it} = A^r_{it+1} - A_{it}, \qquad t = \text{Wave 1}$$

The precise definition of the dependent variable ΔA_{it} requires further clarification, however. Given that the survey is conducted with an interval of two years between waves, it would not be appropriate to use the change between waves as a measure of ΔA_{it}. Doing so, would disregard an interim harvest period (2014/15), where asset holdings could be lost or recovered, potentially masking the true impact of any shocks. Subsequently, the change in assets is constructed using a (one year) recalled variable, indicating the herd size in the interim year.[18] The term A^r_{it+1} in equation (6) represents this recalled herd size for 2014/15, recorded in the second wave of the survey. In principal, it is clearly possible to generate ΔA_{it} covering two time periods, 2013/14 to 2014/15 and 2014/15 to 2015/16. However, in the two recorded panel waves, livestock holdings are measured prior to the realisation of harvest incomes (owed to the different timings of the survey instruments), implying that no harvest measure is available during the period of the second change (2014/15 to 2015/16). Therefore, only the first change is used and ΔA_{it} measures changes in cattle holding between the period immediately preceding the main harvest in Wave 1 (2013/14) and the period before the (unrecorded) harvest in (2014/15).

The hypothesis of separate response regimes implies that all coefficients in model (6) can assume different values above and below γ. This separation is modelled below, where all terms in (7) have the same interpretation as in the pooled model (6) and the h and ℓ terms are, again, added to the income coefficients to denote the high and low regimes.

$$\Delta A_{it} = \begin{cases} \alpha_1^h \hat{y}_{it}^P + \alpha_2^h \hat{y}_{it}^T + \alpha_3^h \hat{y}_{it}^U + \beta' H_{it} + \tau_t + \xi_i + \upsilon_{it}, \text{ if } A_{it} > \gamma \\ \alpha_1^\ell \hat{y}_{it}^P + \alpha_2^\ell \hat{y}_{it}^T + \alpha_3^\ell \hat{y}_{it}^U + \beta' H_{it} + \tau_t + \xi_i + \upsilon_{it}, \text{ if } A_{it} \leq \gamma \end{cases} \tag{7}$$

In both the asset model (7) and the consumption model (5) the value of the sample splitting level of cattle γ will be replaced with an estimated value $\hat{\gamma}$, based on the herd size which minimises the residual sum of squares from a single-equation estimation of (5), as described in Appendix 3.

[18] The consequences of possible measurement error in the dependent variable, due to the use of this recalled information, is discussed in Section 5.5.4.

5 Results

5.1 Preliminary results

This section estimates the time-path of cattle stocks directly, using the more commonly applied methods discussed in section 1.2. Section 5.1.1 uses a similar non-parametric approach to Lybbert et al. (2004) and Adato et al. (2006), while section 5.1.2 employs the lagged polynomial method of Jalan and Ravallion (2004), Barrett et al. (2006) and Giesbert and Schindler (2012). In each case, the growth-path for the Ethiopian sample, is modelled using observations from the two panel waves 2013/14 and 2015/16, as well as the recalled herd size from 2014/15 (see Section 4.3).

Before comparing these preliminary results with the main findings of the paper, however, it is important to recognise that the methods used below do not necessarily provide answers to precisely the same questions. Directly modeling the evolution of asset stocks has the potential to identify a poverty trap which generates *measurable* changes in asset stocks. However, if agents engage in avoidance behaviour, through asset smoothing, multiple equilibria in the underlying growth path may not be detected. In contrast, it is the detection of precisely this type of avoidance behaviour which motivates the main results of this analysis.

5.1.1 Non-parametric estimation of the asset growth-path

Figure 6 maps the relationship between current and lagged cattle holdings using the Locally Weighted Scatter-plot Smoothing (LOWESS) method of Lybbert et al. (2004) and Adato et al. (2006), whereby local regressions are estimated for each of the n data-points within the sample. In generating Figure 6, each regression uses only those observations within a 5% bandwidth of the data-point in question. Unlike more parametric methods, this approach makes no assumptions regarding the functional form underlying the relationship $A_t = f(A_{t-1})$.

It is clear from Figure 6 that estimating the evolution of cattle stocks using this approach implies a relationship which does not conform with the S-shaped growth-path in Figure 1. Rather than generate multiple equilibria, Figure 6 indicates the presence of only a single (low-level) equilibrium. This can be found at approximately 3 cattle, and is indicative of a point of convergence, as opposed to bifurcation.

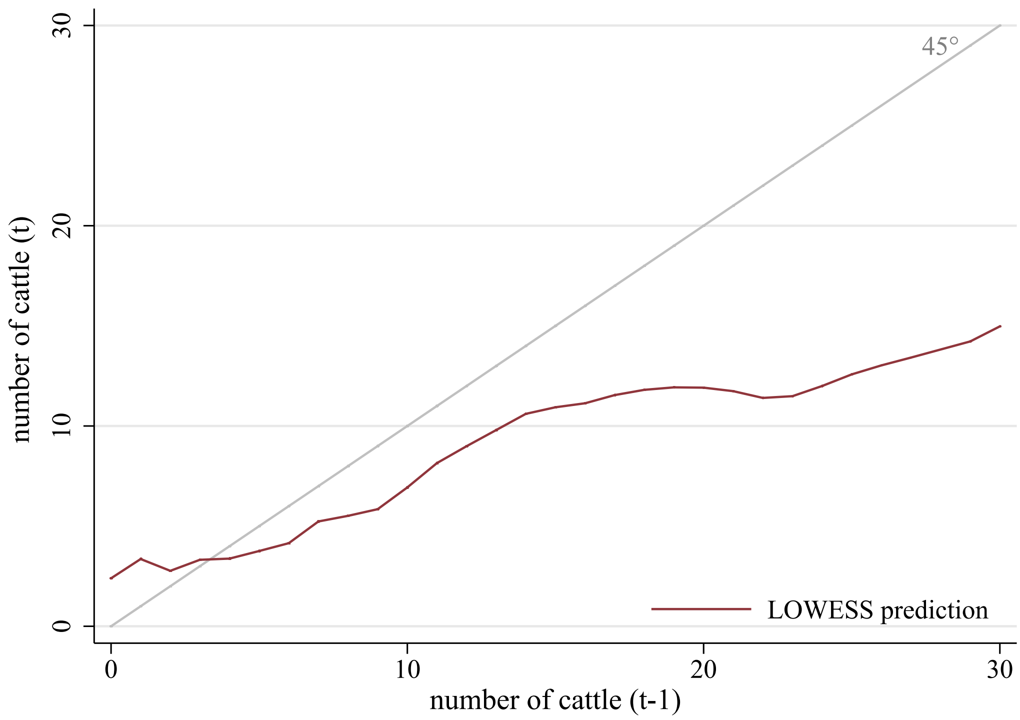


Figure 6: Non-parametric estimation of herd size dynamics

5.1.2 Parametric estimation of the asset growth-path

Turning now to the lagged polynomial approach of Jalan and Ravallion (2004), Barrett et al. (2006) and Giesbert and Schindler (2012). Figure 7 graphs the predicted values of current cattle holdings against lagged herd size, with the predicted value of A_t obtained from an estimation of model (8). This equation is similar to that employed by Barrett et al. (2006), whereby polynomials of the lagged herd size (up to the fourth-order) are included as regressors, allowing the relationship $A_t = f(A_{t-1})$ to generate the hypothesised non-linearities shown in Figure 1.

$$A_{it} = \sum_{p=0}^{4} \beta_p A_{it-1}^{p} + \beta' G_i + \tau_t + \xi_i + \varepsilon_{it} \quad (8)$$

The first term on the right-hand side of (8) represents the polynomials of lagged herd size (and a constant β_0). G is a vector of control variables, measured in the 2013/14 wave, including demographic and education characteristics, as well as the general location characteristics of the household. ξ_t and τ_t indicate region and time effects. The full regression results from a least squares estimation of model (8) are reported in Appendix table A3.

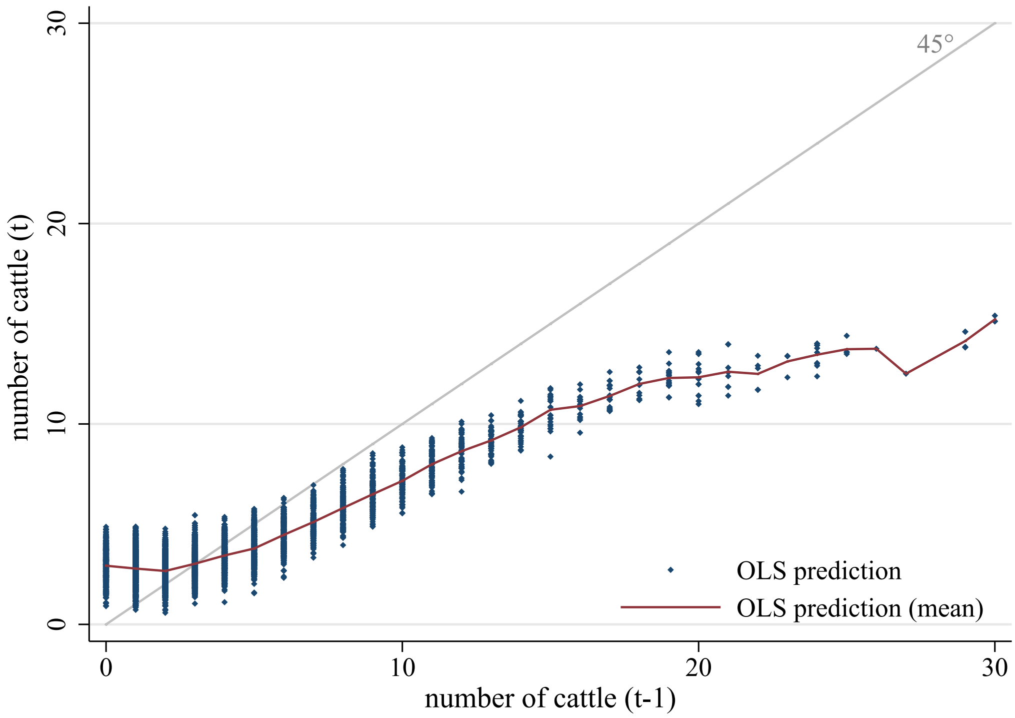


Figure 7: Parametric estimation of herd size dynamics

Figure 7 summarises the relationship between current and lagged herd size, estimated using the lagged polynomial approach described above. As the lagged herd size variable is discrete, each value on the x axis corresponds to a number of predictions at any given level of A_{t-1}. Figure 7 reports these predicted values, but also fits a line through the mean prediction at each level of lagged cattle holdings.[19] Although few observations make for an imprecise estimation of the time-path at larger herd sizes, the results of the parametric approach appear to mirror those of the non-parametric estimation. Again, the 45 degree line is intercepted only once, and from above, indicating a pattern of converge rather than bifurcation.

[19]If instead, the median predicted value at each lagged herd size is used, this does little to alter the relationship in Figure 7.

5.2 Estimation of γ

The main findings of this paper begin by reporting the results of the estimation used to determine the sample splitting value γ. Having found the herd size most likely to represent this value, sections 5.3 and 5.4 report the effect of the drought-induced income shock on consumption and cattle holdings for households above or below (equal to) this level.

Using the methodology described in Appendix 3, the most likely candidate value for γ is found through comparison of the residual sum of squares (RSS), from a single-equation estimation of model (5), across the range of A. If two distinct consumption smoothing regimes exist, this implies that households can be separated into either regime, dependent on whether their pre-shock cattle holdings lie above or below the predicted level. Figure 8 graphs the residual sum of squares obtained from splitting the sample at all potential values of γ, between $1 \geq A \geq 30$. The graph is minimised at a value of 2, indicating that this herd size is the level of cattle holdings, around which the coefficients in the model are most likely to assume different values.

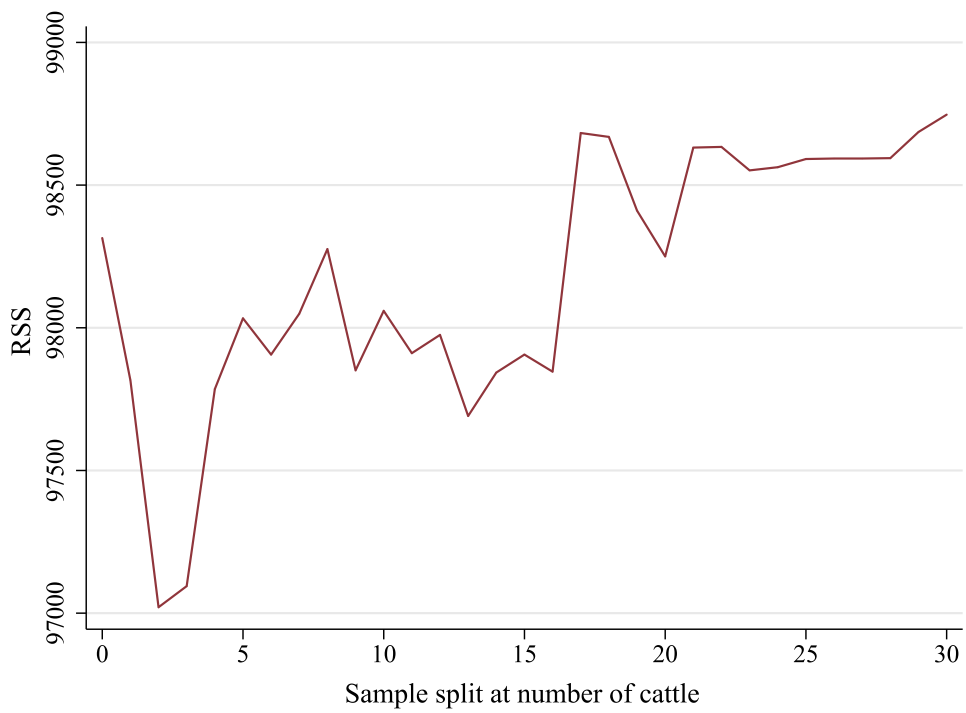


Figure 8: Residual sum of squares at potential levels of γ

Table 4: Significance of difference between regime coefficients

Threshold estimate	RSS	MSE	Bootstrap repetitions	p-value
$\hat{\gamma} = 2$	97021	19.60	1000	0.0060

Having estimated the most likely value, at which to split the sample, it is also necessary to determine whether being above or below $\hat{\gamma} = 2$ alters the impact of the income shock in a statistically significant manner. Based on Hansen's (1999) approach, the p-value of 0.006 in Table 4 provides strong evidence against the null hypothesis of no difference between coefficients in the two regimes. Therefore, as section 2 suggests, estimating the coefficients according to (5), and splitting the sample at $\hat{\gamma} = 2$, will allow a more accurate understanding of the sample household's behaviour, in response to the drought-induced income shock.

Table 5: Characteristics of households in high and low cattle regimes

	$A_{it} > 2$		$A_{it} \leq 2$		F-test 1	F-test 2
	mean	sd	mean	sd	p-value	p-value
Household size	5.74	2.13	5.31	2.16	0.0000	0.0000
Age of head	46.64	14.05	46.58	14.78	0.8830	0.9573
Head is female	0.16	0.37	0.20	0.40	0.0002	0.0005
Head is literate	0.40	0.49	0.39	0.49	0.4201	0.4424
Total farm income	5.00	11.40	4.75	12.36	0.4449	0.9925
Total consumption	5.44	8.49	4.19	5.66	0.0000	0.0000
Food consumption	4.53	8.26	3.34	5.45	0.0000	0.0000
Land cultivated (ha)	1.07	0.95	0.89	0.88	0.0000	0.0000
Rainfall deviation (mm)	-61.04	310.30	-78.24	336.16	0.0585	0.5730
Distance to bank (km)	17.81	12.20	17.18	11.79	0.0629	0.3080
Distance to MFI (km)	12.78	12.07	13.25	11.89	0.1577	0.0720
Distance to market (km)	23.66	5.20	24.09	5.52	0.0042	0.0025
PSNP in kebele	0.37	0.48	0.45	0.50	0.0000	0.0000
Observations	2606		2450			

* p<0.1, ** p<0.05, *** p<0.01

All income and consumption figures reported in 1000 Ethiopian Birr, per adult equivalent

F test 1: Significance of high or low regime in determining the value of the listed variable

F test 2: Includes the addition of controls for region-specific fixed-effects

Table 5 reports the mean values and standard deviations for key variables above and below (equal to) $\hat{\gamma} = 2$. F-test 1 reports a standard test of the significance of inclusion in either regime, in predicting the values of the listed variables, while F-test 2 conducts the same test, with the inclusion of regional fixed-effects. This second test is necessary when assessing the similarity of rainfall deviations experienced by the two regimes, as both cattle holdings and the impact of the drought will vary widely between different regions. Although the impact of the drought is unlikely to be equivalent at the national level, at the regional level, households should have experienced similar rainfall deficits.

The table indicates significant differences in demographics between the two regimes. Those households in the small herd group have fewer member, on average, and are more likely to have a female household head. Total consumption and food consumption are also significantly lower in the small herd regime, as is the area of land cultivated by the households. The rainfall deviations experienced during the survey initially appears to be more negative in the small herd group. As previously noted, however, both the proportions of households in the two regimes, and the impact of the drought, will certainly not be distributed uniformly. Therefore, F-test 2 provides a more appropriate measure of the difference in rainfall deviation. This second test indicates that, after partialing out the regional fixed-effect, there is no evidence that either regime was significantly worse affected by the drought. Proximity to a market is different between the groups, as is the likelihood that a household resides in an area covered by the PSNP. Households in the low cattle regime are both more likely to be covered by the safety net programme, and to be found further from a weekly market. In summary, table 5 indicates that variables generally considered to be good predictors of overall poverty status increase the probability of inclusion in the lower cattle regime.[20]

5.3 Smoothing consumption

Table 6 present the results from the consumption smoothing model shown in equation (5), with OLS and household-level fixed-effects estimations reported for each group.[21] The dependent variable is the total value of household consumption, measured in 1000 Ethiopian Birr, per adult equivalent.

[20] The possibility that γ may actually be detecting heterogeneity, due to more general patterns of household wealth, is considered in section 5.5.

[21] The variable measuring the % of members with no formal education is omitted in the following estimations (tables 6 and 7) to limit collinearity with the permanent income measure.

Table 6: The effect of income shocks on household consumption

	(1)	(2)	(3)	(4)
	$A_{it} > 2$ OLS	$A_{it} > 2$ FE	$A_{it} \leq 2$ OLS	$A_{it} \leq 2$ FE
Transient income	0.0590	0.0853	0.2236***	0.1868***
	(0.0747)	(0.0777)	(0.0400)	(0.0540)
Permanent income	0.2096***	0.2696	0.1721***	0.2622
	(0.0431)	(0.6016)	(0.0276)	(0.3604)
Unexplained income	0.1076***	0.1501**	0.1564***	0.2277***
	(0.0392)	(0.0600)	(0.0294)	(0.0447)
Household size	-0.5612***	-0.1321	-0.4523***	-0.5101***
	(0.0821)	(0.3515)	(0.0493)	(0.1970)
Age of head	0.1096	0.1921	-0.0887**	0.2479
	(0.0767)	(0.3140)	(0.0451)	(0.1700)
Age of head squared	-0.0010	-0.0017	0.0008*	-0.0016
	(0.0007)	(0.0033)	(0.0004)	(0.0014)
Distance to market (kms)	-0.0160		-0.0346	
	(0.0267)		(0.0225)	
Distance to bank (kms)	-0.0243*		-0.0095	
	(0.0134)		(0.0099)	
Distance to MFI (kms)	0.0085		-0.0007	
	(0.0160)		(0.0088)	
PSNP	-0.8041***		-0.1505	
	(0.2863)		(0.2399)	
2015-16 wave	-0.6545**	-0.6296*	-0.3011	-0.2763
	(0.3016)	(0.3692)	(0.2163)	(0.2967)
Household fixed-effects	No	Yes	No	Yes
Region fixed-effects	Yes	No	Yes	No
Observations	2606	2606	2450	2450
R^2	0.1024	0.0439	0.2222	0.2506
Hansen J (p-value)	0.7301	0.7001	0.2940	0.8076
Cragg-Donald Wald F †	67.1701	29.4709	49.1860	20.4315
Test: $\theta_2 = 0$ p-value	0.4299	0.2720	0.0000	0.0005
	OLS models (1) and (3)		FE models (2) and (4)	
Test: $\theta_2^\ell = \theta_2^h$ p-value	0.0521		0.2831	

Bootstrapped standard errors in parentheses * p<0.1, ** p<0.05, *** p<0.01

† Stock-Yogo maximal IV bias (OLS): 5% = 19.86, 10% = 11.29, 20% = 6.73

† Stock-Yogo maximal IV bias (FE): 5% = 19.28, 10% = 11.12, 20% = 6.76

All income and consumption measured in 1000 Ethiopian Birr, per adult equivalent

Focusing on the coefficients on the transient income shock in Table 6, it is not possible to reject the hypothesis of full consumption smoothing, amongst the large herd group, in either the household fixed-effects or OLS estimations (at any common level of significance). For those households with smaller numbers of cattle, however, the coefficients on transient income, shown in columns 3 and 4, indicates that the shock has a significant effect on consumption expenditure. For this group, between approximately 18.7% and 22.4% of the value of the shock is passed directly to consumption.[22] A test of the equality of the transient income coefficients between the two regimes (test $\theta_2^\ell = \theta_2^h$ in table 6) indicates the two effects are only different from each other at the 10% level, and only in the OLS estimations. However, the result that the income shock is only significantly different from zero in the small herd regime, lends early support to the poverty trap hypothesis.

The Hansen J statistic p-values > 0.1 on all models, indicates that is impossible to reject the validity of the first stage rainfall instruments. In addition, the Cragg-Donald Wald F statistic and Stock-Yogo critical values (reported below table 6) also indicates the degree of bias, as a result of the IV estimation, is consistently below 5% (relative to OLS). The similarity of estimates obtained via both OLS and FE also suggest that these results are not unduly influenced by measurement error in the independent variables.

5.4 Smoothing assets

Establishing that households with a higher level of cattle holdings are more capable of smoothing consumption is not sufficient evidence to conclude the existence of an asset-based poverty trap. Similar results could indicate a variety of different underlying mechanisms.[23] It is therefore necessary to determine whether the extent to which cattle are used as a buffer against consumption shortfalls also depends on a household's pre-shock cattle holdings. Table 7 reports the results of an estimation of the asset change model (7), where the dependent variable in all estimations is the change in herd size ΔA.

[22] Although highly significant, the estimated size of the effect is still relatively small in comparison to similar studies. For example, in their analysis of the drought which affected Burkina Faso in the early 1980s, Kazianga and Udry (2006) estimated that between 54% and 64% of the transient income shocks was passed to consumption.

[23] For example, differential access to credit and insurance, amongst rich and poor households (Rosenzweig and Binswanger, 1993; Jalan and Ravallion, 1999).

Table 7: The effect of income shocks on household cattle holdings

	(1)	(2)	(3)
	$A_{it} > 2$ OLS	$A_{it} \leq 2$ OLS	$0 < A_{it} \leq 2$ OLS
Transient income	0.2348***	0.0515	0.0445
	(0.0347)	(0.0329)	(0.0371)
Permanent income	0.0986***	0.0721***	0.0699***
	(0.0358)	(0.0163)	(0.0172)
Unexplained income	0.0688*	-0.0305*	-0.0243
	(0.0370)	(0.0170)	(0.0180)
Household size	0.0585	0.1371**	0.1230**
	(0.0535)	(0.0570)	(0.0612)
Age of head	0.0468	0.0161	0.0813
	(0.0491)	(0.0441)	(0.0495)
Age of head squared	-0.0003	-0.0001	-0.0006
	(0.0005)	(0.0004)	(0.0005)
Distance to market (kms)	-0.0698***	0.0246	0.0143
	(0.0183)	(0.0175)	(0.0193)
Distance to bank (kms)	-0.0301***	-0.0252***	-0.0351***
	(0.0091)	(0.0093)	(0.0102)
Distance to MFI (kms)	-0.0124	-0.0238**	-0.0237**
	(0.0100)	(0.0095)	(0.0103)
PSNP	-1.0646***	-1.0235***	-1.0837***
	(0.2006)	(0.1847)	(0.2044)
Region fixed-effects	Yes	Yes	Yes
Observations	1416	1060	879
R^2	0.1344	0.1224	0.1508
Hansen J (p-value)	0.1067	0.1080	0.1376
Cragg-Donald Wald F †	50.0608	27.8640	236770
Test: $\alpha_2 = 0$ p-value	0.0000	0.1180	0.2308
	models (1) and (2)	models (1) and (3)	
Test: $\alpha_2^\ell = \alpha_2^h$ p-value	0.0001	0.0002	

Bootstrapped standard errors in parentheses * p<0.1, ** p<0.05, *** p<0.01

† Stock-Yogo maximal IV bias: 5% = 19.28, 10% = 11.12, 20% = 6.76

All income and consumption measured in 1000 Ethiopian Birr, per adult equivalent

The coefficient on the transient income shock again, indicates a large degree of heterogeneity between the two regimes. For those households with a pre-shock herd size of three or more animals, the positive coefficient in column 1 implies that a fall in agricultural income is associated with a decline in cattle holdings. In contrast, column 2 indicates that the transient income shock has no significant impact on the herd size of households below (equal to) γ.

Although rural households with no involvement in cattle rearing are omitted from the sample (see sample description in section 3), the dataset still contains observations where a household owns no cattle in one of the two survey waves. The final column in table 7 is intended to test whether the non-significant effect, in the small herd group, is a result of some households entering the period of the income shock with no cattle available to sell (whether they would otherwise, choose to or not). Table 7 reports that it is still not possible to reject the hypothesis of no effect in this adjusted sample, at any of the significance levels reported. Testing whether the effect of the income shock differs between the estimations in models (1) and (2), and models (1) and (3) (see test $\alpha_2^\ell = \alpha_2^h$) leads to a strong rejection of the null of homogeneity in shock responses within the two regimes. As in the consumption regressions in table 6, tests of overidentification (Hansen J statistic) and weak instrument bias (Cragg-Donald Wald test) suggest the rainfall instruments are both valid and sufficiently strong to minimise bias in the estimated coefficients.

To summarise the key findings of the previous sections, those observations coming from households with pre-shock cattle holdings of three or more animals experience a reduction in herd size, as a result of the shock to income. For this group, it is also impossible to reject the hypothesis that consumption is fully insulated from the shock. In the case of observations coming from households with two or fewer cattle, however, there is no evidence of any adjustments to herd size, yet a fall in agricultural income is associated with a significant decline in household consumption. This heterogeneity in coping strategies is entirely consistent with the existence of an asset-based poverty trap, as described in section 1.

5.5 Robustness

5.5.1 Choice of sample splitting variable

In using cattle herd size as the variable defining γ, it is possible that the estimation procedure may actually be detecting heterogeneity defined by more general patterns of household wealth. For example, Table 5 suggests there exists a correlation between cattle holdings and measures such as consumption, area of land cultivated and remoteness. To test this hypothesis, the sample splitting procedure is repeated, using the variables measuring land ownership and distance to a weekly market.[24]

Table 8: Test for threshold effect in other variables

	$\hat{\gamma}$	RSS	MSE	Bootstrap repetitions	p-value
Owned land (ha)	0.33	98216	19.84	1000	0.2990
Distance to market (kms)	18.00	97971	19.79	1000	0.1260

The table indicates that the most likely candidate for γ in cultivated land is at approximately 3300m^2. However, splitting the sample around this value does not generate significant diferences in the high and low regime coefficients (p-value = 0.2990). Similarly, splitting the sample, based on the distance of a household from a weekly market also fails to generate a significant difference in the coefficients either side of the respective candidate γ value (18kms). These findings suggest that it is household cattle holdings specifically, which generate the heterogeneity in shock responses.

5.5.2 Uniqueness of $\gamma = 2$

When assessing the residual sum of squares (RSS) generated by splitting the sample at possible values of γ, a value of $\hat{\gamma} = 3$ provided a RSS only slightly exceeding that for $\hat{\gamma} = 2$ (see Figure 8). It is therefore, worth considering the implications of splitting the sample at the alternative herd size of 3.

Table 9 reports the coefficients on the transient income shock for households with pre-shock cattle holdings in a high and low asset regime, separated by $\hat{\gamma} = 3$. Columns 1 and 2 indicate that consumption response follows the same pattern as Table 6, although the difference in the coefficients between the two regimes is far less pronounced. Again, however, only the coefficient in the high cattle regime is significantly different from zero.

[24] A household's distance from a weekly market should be a strong indicator of poverty status. In rural Ethiopia, the proportion of those falling below the national poverty line is found to increase by 7% for every 10kms travelled from a market town (World Bank, 2016).

Table 9: Splitting the sample at $\gamma = 3$

Transient income coefficients and standard errors reported				
	(1)	(2)	(3)	(4)
Dependent variable:	Total consumption		Change in herd size	
	$A_{it} > 3$	$A_{it} \leq 3$	$A_{it} > 3$	$A_{it} \leq 3$
	FE	FE	OLS	OLS
Transient income	0.0961	0.1205**	0.2454***	0.0699**
	(0.0983)	(0.0512)	(0.0383)	(0.0280)

Bootstrapped standard errors in parentheses
* p<0.1, ** p<0.05, *** p<0.01

The coefficients representing the effect of the income shock on herd size (columns 3 and 4) indicate evidence of a response in cattle holdings, for households in the lower cattle regime, where none was present when splitting the sample at $\hat{\gamma} = 2$ (see Table 7). This is evidence that at least some households with a pre-shock herd size of 3 animals were willing to use these assets to protect consumption. Testing the null hypothesis that the effect of the income shock is equivalent, however, generates a strong rejection (p-value $= 0.0002$).

In light of both sets of results, therefore, it is possible to conclude that splitting the sample at a pre-shock herd size of $\hat{\gamma} = 3$ would also generate significant heterogeneity in coping strategies between the high and low cattle groups. Although, the difference in shock-responses appears more pronounced under the condition that $\hat{\gamma} = 2$.

5.5.3 Choice of inclusion within the sample

To avoid the inclusion of large-scale, commercial farms in the analysis, it was necessary to set upper-bounds on cattle holdings and cultivated land (see section 3). The initial cut-off points were at 5 hectares of land or 30 head of cattle. The uppermost section of table 10 tests the sensitivity of key findings to alternative cut-off levels. Only the effect of the transient income shock variable, on total consumption (columns 1 and 2) and the change in cattle holdings (columns 3 and 4), is reported in each case.

Omitting households who posses more than 4 hectares of land or 25 cattle, in any wave, reduces the sample from 5056 to 4865. However, table 10 indicates this does little to alter the interpretation of the results. Similarly, increasing the cut-off for sample inclusion to 6 hectares of land or 35 cattle, increases the sample to 5067 households, but again, does not alter the overall pattern of results.

Table 10: Robustness of results to alternative choice of sample

Transient income coefficients and standard errors reported				
	(1)	(2)	(3)	(4)
Dependent variable:	Total consumption		Change in herd size	
	$A_{it} > 2$	$A_{it} \leq 2$	$A_{it} > 2$	$A_{it} \leq 2$
	FE	FE	OLS	OLS
Alternative cut-off for sample inclusion				
Land<4 ha and cattle<25	0.0915	0.1329**	0.2836***	0.0172
	(0.0754)	(0.0567)	(0.0390)	(0.0275)
Land<6 ha and cattle<35	0.0868	0.1727***	0.2555***	0.0603
	(0.0726)	(0.0526)	(0.0357)	(0.0378)
Omission of regions				
Tigray omitted	0.1165	0.1794***	0.2458***	0.0813*
	(0.0763)	(0.0539)	(0.0355)	(0.0491)
Amhara omitted	0.0805	0.1580**	0.2881***	0.0566
	(0.1007)	(0.0689)	(0.0400)	(0.0557)
Oromia omitted	0.1056	0.1184**	0.2570***	0.0165
	(0.0802)	(0.0491)	(0.0427)	(0.0334)
SNNP omitted	0.0747	0.1759***	0.2478***	0.0795*
	(0.0839)	(0.0575)	(0.0447)	(0.0424)
Other regions omitted†	0.0609	0.2156***	0.2334***	0.0725*
	(0.0885)	(0.0649)	(0.0321)	(0.0420)

Bootstrapped standard errors in parentheses
* p<0.1, ** p<0.05, *** p<0.01
† Afar, Somalie, Benishagul Gumuz, Gambela, Harari, Diredwa

As the type of farming practised in Ethiopia varies substantially between different agro-climatic zones, it is important to determine whether any specific region is responsible for driving the main results of the analysis. The lower section of table 10 tests the robustness of key results to the omission of observations from the four most populous rural regions.[25] Table 10 also reports tests from a sample

[25]Tigray, Amhara, Oromia and SNNP, representing approximately 10.2%, 21.6%, 20.6% and 28.3% of the sample, respectively.

which omits all observations from the remaining six regions (listed below table 10). Any changes in the coefficients are not sufficient to warrant any new interpretation of the results (although, the significance of the coefficients does vary to a small degree in some cases). It is therefore, possible to conclude that no specific, single region is driving the main results of the analysis.

5.5.4 Alternative construction of transient income shocks

Reporting both fixed-effects and OLS estimations in table 6, is intended to asses the possible influence of measurement error in the regressors. However, there also exists the possibility of measurement error in the dependent variables of equations (5) and (7), leading to biased estimators if this error is correlated with the right-hand side covariates. This may be of particular concern, due to the use of recall data in the dependent variable for the asset model (7). Arguably, the most likely source of this form of bias will stem from a correlation with the education level of the respondents. For example, it is often found that consumption is under-reported amongst households with lower levels of education (Beegle et al., 2012). With an apparent positive correlation between education and income (see table 2), such under-reporting would imply income coefficients in the consumption regressions would be biased upward, due to the error term μ in (5) being more negative at lower levels of income. If education is correlated with measurement error in ΔA_t however, the direction of bias in the asset equation is less clear. Assuming the recalled herd size is more likely to be miss-reported, the direction of bias would depend on whether recalled herd size was systematically overstated or understated, relative to the current measure.[26]

To establish whether results are unduly influenced by this potential source of bias, models (5) and (7) are re-estimated with the education variable omitted. The results of these estimations are reported in table 11, where again, only the coefficients on the transient income shock are reported. As a further robustness test, the interactions of rainfall deviations and cultivated land characteristics are omitted from the first-stage income decomposition. If these interactions are in some way correlated with the error terms in the structural equations, the IV procedure could also generate substantial bias.

[26]It is important to recognise however, that the nature of the asset being recalled (cattle) represents an extremely salient factor in the lives of rural households, which is both discrete and generally owned in small quantities (See Figure 5).

Table 11: Robustness of results to alternative construction of income shocks

Transient income coefficients and standard errors reported				
	(1)	(2)	(3)	(4)
Dependent variable:	Total consumption		Change in herd size	
	$A_{it} > 2$	$A_{it} \leq 2$	$A_{it} > 2$	$A_{it} \leq 2$
	FE	FE	OLS	OLS
Variables omitted from income decomposition				
Non-educated % omitted	0.0917	0.1726***	0.2528***	0.0623*
	(0.0739)	(0.0502)	(0.0332)	(0.0377)
Rainfall*land interactions omitted	0.1240	0.1598***	0.3370***	0.0596
	(0.0763)	(0.0594)	(0.0341)	(0.0431)

Bootstrapped standard errors in parentheses
* p<0.1, ** p<0.05, *** p<0.01

Table 11 indicates that the pattern of results is not strongly altered by these changes. Therefore, any bias derived from a correlation between levels of education and measurement error, in either of the dependent variables, is not sufficient to warrant any new interpretation of the findings. Table 11 also indicates that the results are robust to decomposing income, using only rainfall deviations to generate exogenous variation.

5.6 Heterogeneity within regimes

Significant differences in smoothing behaviour, amongst households with two or fewer cattle, mirrors the findings of Hoddinott (2006), in a study conducted in rural Zimbabwe. The key reason suggested for this effect, in the Zimbabwe sample, was the need to provide enough animal traction to ensure fields could be ploughed in the following season. The wide variety of crops and farming practices found in Ethiopia provides an opportunity to test this hypothesis.

In the Ethiopian case, the traditional plough (known as a *maresha*) requires oxen to operate. If the household does not posses these animals they must either obtain them by other means (short-term hire, for example) or cultivate the land without animal traction. Either option is likely to have a negative impact on the following season's net farm profits. In turn, lower profits in future harvests would be expected to hinder a household's efforts to bring its herd size back to the minimum number of animals required. It is therefore, highly possible that such circumstances could generate the type of bifurcating growth path illustrated in Figure 1.

Formulating a suitable test of this hypothesis, requires utilising the wide variety of crops and farming methods employed in Ethiopia. Approximately three-quarters of the total cultivated land in Ethiopia is dedicated to the production of cereal crops such as teff, wheat and maize (Taffesse et al., 2012). In almost all areas, this form of agriculture is highly dependent on the traditional ploughing methods described above. In contrast, farmers who specialise in the cultivation of non-cereal crops are far less reliant on cattle for the purpose of ploughing and preparing land. For example, in the South-West of the country, households rely heavily on the enset palm as a principle source of food, a crop which is cultivated using a wooden hoe, and requires no animal traction (Westphal and Stevels, 1975). Similarly, many farmers dedicate significant proportions of their land to tree crops, such as coffee, or vegetables, such as cabbage, onions and peppers (Taffesse et al., 2012). As a result, if the need for animal traction determines γ, the requirement to retain a minimum number of cattle should be more evident amongst those households growing predominantly cereal crops.

$$\Delta A_{it} = \begin{cases} \alpha_1^h \hat{y}_{it}^P + \alpha_2^h \hat{y}_{it}^T + \alpha_3^h \hat{y}_{it}^U + \alpha_4^h C_{it} + \alpha_5^h (\hat{y}_{it}^T * C_{it}) \\ \qquad + \beta' H_{it} + \tau_t + \xi_i + \upsilon_{it}, \text{ if } A_{it} > 2 \\ \alpha_1^\ell \hat{y}_{it}^P + \alpha_2^\ell \hat{y}_{it}^T + \alpha_3^\ell \hat{y}_{it}^U + \alpha_4^\ell C_{it} + \alpha_5^\ell (\hat{y}_{it}^T * C_{it}) \\ \qquad + \beta' H_{it} + \tau_t + \xi_i + \upsilon_{it}, \text{ if } A_{it} \leq 2 \end{cases} \tag{9}$$

Model (9) modifies the original asset change equation, by interacting the income shock $\hat{y}_{it}^T$ with a continuous variable, indicating the share of a household's cultivated land dedicated to cereal crops C_{it} (taking values between 0 and 1). Based on this model, a significant interaction effect in the coefficient α_5 would indicate that the response of cattle holdings to the income shock is dependent on the share of cultivated land dedicated to cereal crops.[27]

[27] The cereal crops considered are teff, wheat, maize, barley, millet, sorghum and oats.

Table 12: Heterogeneous effects of income shocks on cattle holdings

	(1)	(2)	(3)
	$A_{it} > 2$	$A_{it} \leq 2$	$0 < A_{it} \leq 2$
	OLS	OLS	OLS
Transient income	0.3131***	0.1247**	0.1433**
	(0.0479)	(0.0558)	(0.0643)
%cereal crop	0.1866	-0.0723	-0.0228
	(0.2431)	(0.2555)	(0.2865)
Transient income*%cereal crop	-0.1317**	-0.1382**	-0.1819**
	(0.0661)	(0.0675)	(0.0758)
Permanent income	0.0963***	0.0734***	0.0708***
	(0.0354)	(0.0166)	(0.0177)
Unexplained income	0.0681*	-0.0305*	-0.0240
	(0.0368)	(0.0175)	(0.0188)
Household size	0.0593	0.1465**	0.1345**
	(0.0535)	(0.0570)	(0.0610)
Age of head	0.0407	0.0155	0.0773
	(0.0490)	(0.0440)	(0.0491)
Age of head squared	-0.0002	-0.0000	-0.0006
	(0.0005)	(0.0004)	(0.0005)
Distance to market (kms)	-0.0712***	0.0242	0.0123
	(0.0183)	(0.0175)	(0.0192)
Distance to bank (kms)	-0.0291***	-0.0263***	-0.0362***
	(0.0091)	(0.0092)	(0.0100)
Distance to MFI (kms)	-0.0123	-0.0224**	-0.0220**
	(0.0100)	(0.0094)	(0.0102)
PSNP	-1.0742***	-1.0123***	-1.0695***
	-0.1999	-0.1845	-0.2046
Region fixed-effects	Yes	Yes	Yes
Observations	1416	1060	879
R^2	0.1379	0.1279	0.1518
Test: $\alpha_2 = 0$ p-value	0.0000	0.0255	0.0259
Test: $\alpha_5 = 0$ p-value	0.0462	0.0405	0.0164

Bootstrapped standard errors in parentheses * p<0.1, ** p<0.05, *** p<0.01
All income and consumption measured in 1000 Ethiopian Birr, per adult equivalent

Table 12 reports the results from an estimation of model (9). The results indicate the interaction term is significant within both groups. In the small herd regime, the coefficient on the main effect of the income shock now also represents a significant effect (again, at 5%), where none was present in the initial regression (see Table 7). This implies that cattle holdings will respond to an income shock in the small herd sub-sample, but *only* when the share of cereal crops approaches zero. The coefficient on the interaction term indicates that the strength of this correlation decreases, the greater the share of land these households dedicate to cereal crops. Overall, these findings lend strong support to the hypothesis that heterogeneity in the degree to which cattle are used to smooth consumption exists due to the need to protect a minimum number of animals to allow for the ploughing of fields in the following season.

6 Summary and concluding remarks

Using a nationally representative dataset of agricultural households in rural Ethiopia, this paper finds evidence of two distinct methods of response to the income shock caused by the onset of a period of drought between 2013-15. A threshold estimation approach is used to separate the sample into two groups, according to each household's pre-shock level of cattle holdings. Analysis of these sub-samples concludes that households with an initial herd size of 3 or more animals effectively used these assets as a buffer stock to protect consumption from the drought-induced, income shortfall. In contrast, those households with 2 or less cattle did not reduce their cattle holdings in response to the drought, instead choosing to protect their current herd size, at the cost of lower consumption. These results are consistent with the hypothesis of a poverty trap threshold, defined by household cattle ownership.

The key findings of this analysis contradict results obtained from direct estimations of the asset growth path (see section 5.1). Modelling the relationship between current and lagged herd size directly produces no evidence of the type of multiple equilibria, which would characterise a poverty trap. The likely explanation for this disparity lies in this paper's use of behavioural changes to indirectly identify the existence of an asset threshold. With this approach, it is possible to identify such a threshold, even where no household's asset stock ever falls below it. Modelling the asset path directly however, will only identify a threshold which is observed to have negative consequences on a household's asset wealth.

Extending the main results uncovers further heterogeneity within the small herd group. The degree to which cattle are used as a buffer stock within this group is shown to depend on the extent to which these households dedicate land to the cultivation of cereal crops. As cattle are an essential source of animal traction in cereal cultivation, this result suggests that a change in smoothing behaviour, between a herd size of 3 and a herd size of 2, is a response to the need to retain sufficient animals to allow for the preparation of land for the following season.

This analysis is not without its limitations however. In particular, the use of recalled information, to generate an appropriate change in herd size variable, is unfortunately imposed by the timing of both the various survey instruments and the survey waves themselves. A further limitation of this study is the treatment of consumption shortfalls as uniform to all household members. While convenient, this approach does not attempt to ascertain how the negative cost of protecting assets impacts on vulnerable members. If such costs are borne disproportionately by children within the households, short term drops in consumption may have very long term consequences (see Dercon and Porter, 2014). Determining the extent to which the asset smoothing strategies employed by some households influence the outcomes of future generations, will be a topic considered in future research.

The findings of this study highlight some of the complexities of assessing vulnerability to drought in rural populations. Even with the availability of social protection and safety nets, it is inevitable that some households will still be faced with a choices of either reducing consumption now or undermining productivity in the future. Such stark choices draw attention to the need for improvements in the coverage and design of agricultural insurance programmes, particularly in more drought-prone rural areas. Encouraging, the implementation and uptake of insurance products, where financial literacy and monitoring capacity are low, will likely require some degree of public sector involvement. Yet, if the country is able to effectively manage the substantial weather risk to small-scale agricultural, the removal of such a binding constraint may see Ethiopia turn recent development gains into long-term, economic growth.

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Appendices

Appendix 1. Model parameterisation

Low technology: $f^{\ell}(A_t\theta_t) = \theta_t A_t^{0.3}$

High technology: $f^{h}(A_t\theta_t) = \theta_t A_t^{0.45} - 0.45$

Depreciation rate: $\delta = 0.08$

Discount factor: $\beta = 0.95$

$u(c_t) = \frac{c_t^{1-\sigma}-1}{1-\sigma}$, with: $\sigma = 1.5$

Probability distribution of θ approximated as:

$$\theta = \begin{cases} 0.05 \;\; if \;\; \theta_t = 0.8 \\ 0.10 \;\; if \;\; \theta_t = 0.9 \\ 0.70 \;\; if \;\; \theta_t = 1 \\ 0.10 \;\; if \;\; \theta_t = 1.1 \\ 0.05 \;\; if \;\; \theta_t = 1.2 \end{cases}$$

Probability distribution of θ (post-shock) approximated as:

$$\theta = \begin{cases} 0.05 \;\; if \;\; \theta_t = 0.4 \\ 0.10 \;\; if \;\; \theta_t = 0.5 \\ 0.70 \;\; if \;\; \theta_t = 0.6 \\ 0.10 \;\; if \;\; \theta_t = 0.7 \\ 0.05 \;\; if \;\; \theta_t = 0.8 \end{cases}$$

A_t and A_{t+1} approximated using a grid of discrete values $A_t = \{0.1,\ 0.2 \ldots\ldots 45\}$

Appendix 2. Test of attrition bias

The upper panel of table A1 indicates the mean and standard deviation of important household characteristics. These are reported for observations included in the sample and those which were omitted due to missing values (see Section 3). The F-test in the right-hand column of the table indicates that omission from the sample is not a significant predictor of any of the listed variables, at the levels considered.

Table A1: Tests for non-random attrition due to missing variables

	Sample		Omitted		F-test
	mean	sd	mean	sd	p-value
Household size	5.54	2.16	5.42	2.27	0.1263
Age of head	46.61	14.40	46.24	14.44	0.4362
Head is literate	0.40	0.49	0.40	0.49	0.9123
Number of cattle	4.09	4.16	4.18	3.79	0.4765
Land cultivated (ha)	0.98	0.92	0.95	0.91	0.3516
Total consumption	4.84	7.29	5.08	4.02	0.1434
Food consumption	3.95	7.07	3.99	3.20	0.7654
Total farm income	4.88	11.88	4.56	17.29	0.6630
Rainfall deviation (mm)	-69.37	323.17	-64.48	277.25	0.5960
Regions					
Tigray	0.10	0.29	0.09	0.29	0.7842
Afar	0.01	0.10	0.01	0.12	0.4207
Amhara	0.22 0.22	0.41	0.20	0.40	0.3722
Oromia	0.20	0.40	0.21	0.41	0.7230
Somalie	0.07	0.26	0.09	0.28	0.1680
Benishagul-Gumuz	0.03	0.16	0.02	0.15	0.3787
SNNP	0.27	0.44	0.27	0.44	0.9809
Gambela	0.03	0.17	0.04	0.18	0.4609
Harari	0.04	0.19	0.03	0.17	0.1492
Diredwa	0.04	0.19	0.04	0.20	0.6765
Observations	5060		651		

* p<0.1, ** p<0.05, *** p<0.01

All income and consumption figures measured in 1000 Ethiopian Birr, per adult equivalent

Similarly, the lower panel of table A1 reports that inclusion within the sample is not significantly more likely for any of the 10 survey regions. This implies the sample used should still be considered as nationally representative of agricultural households in rural Ethiopia.

Appendix 3. Estimation of γ

The following describes the procedure used to estimate γ. It is useful to follow Hansen (1999) and represent the two parts of (5) in a single equation. Collecting the right-hand side variable $\{y_{it}^P, y_{it}^T, y_{it}^U, H_{it}, \xi_t\}$ in a vector X_{it}, and representing all associated coefficients for the low and high asset regimes as β_ℓ and β_h, respectively, the empirical model (5) can be written as follows.

$$c_{it} = \beta_\ell' X_{it} I(A_{it} \leq \gamma) + \beta_h' X_{it} I(A_{it} > \gamma) + \psi_i + e_{it} \tag{a1}$$

In equation (a1) the bracketed terms indicates the position of the household, relative to γ, where $I(.)$ is an indicator function. A further simplification combines the coefficient vectors for the high and low regimes, and represent the separation of the data as follows.

$$c_{it} = \beta' X_{it}(\gamma) + \psi_i + e_{it} \tag{a2}$$

where

$$\beta = (\beta_\ell', \beta_h')'$$

$$X_{it}(\gamma) = \left\{ \begin{array}{c} X_{it} I(A_{it} \leq \gamma) \\ X_{it} I(A_{it} > \gamma) \end{array} \right\}$$

Subtracting the mean, over the time-index t, for each household i, yield the transformed, fixed-effects model, where * denotes the transformed variables, and the fixed-effect ψ_i is eliminated.

$$c_{it}^* = \beta' X_{it}^*(\gamma) + e_{it}^* \tag{a3}$$

For a given γ, equation (a3) can be estimated via ordinary least squares (OLS), yielding both the vector of regression residuals $\hat{e}_{it}^*(\gamma)$ and the residual sum of squares $S(\gamma)$.

$$\hat{e}_{it}^*(\gamma) = c_{it}^* - \hat{\beta}'(\gamma) X_{it}^*(\gamma) \tag{a4}$$

$$S(\gamma) = \hat{e}_{it}^*(\gamma)' \hat{e}_{it}^*(\gamma) \tag{a5}$$

The most likely candidate for a possible splitting point is found through a process of searching over the range of values of the herd size variable A_{it}. The candidate value $\hat{\gamma}$ is the herd size which minimises the residual sum of squares from an OLS estimation of (a3) (Hansen, 1999).

$$\hat{\gamma} = \min_{\gamma} S(\gamma) \tag{a6}$$

Testing for the significance of differences in the high and low regime coefficients is a test of the null hypothesis, $H0 : \beta_h = \beta_\ell$ in equation (a1), with γ replaced by $\hat{\gamma}$. However, under the null hypothesis, the indicator function $I(.)$ has no place in the estimation and the pooled model (4) is the appropriate choice. Similarly to equation (a3), under the null hypothesis, model (4) can be written as follows, where the subscript p indicates the vector of coefficients relate to the pooled model.

$$c^*_{it} = \beta'_p X^*_{it} + \eta^*_{it} \tag{a7}$$

Estimation of (a7) again generates the predicted standard errors $\hat{\eta}$ and the residual sum of squares S_p.

$$\hat{\eta}^*_{it} = c^*_{it} - \hat{\beta}' X^*_{it} \tag{a8}$$

$$S_p = \hat{\eta}^{*\prime}_{it} \hat{\eta}^*_{it} \tag{a9}$$

The test statistic for determining the significance of differences in regime coefficients takes the form in (a10). However, as the sample splitting point is not identified under $H0$, the asymptotic distribution of F is non-standard and strictly dominates χ^2_k (Hansen, 1999).

$$F = \frac{S_p - S(\hat{\gamma})}{\hat{\sigma}^2} \tag{a10}$$

Hansen (1996, 1999) describe a bootstrap procedure which can be used to generate an asymptotically valid p-value for the test of the significance of differences in the regime coefficients. The procedure involves cluster re-sampling (with replacement) of the predicted errors $\hat{e}^*$ from an estimation of (a3). These errors are then used to generate a bootstrapped dependent variable in equation (a7), by holding the values of X^* and the variable A fixed (in all bootstrap samples), while allowing the coefficients β'_p to assume any arbitrary value.[28] The generated bootstrap sample is then used to estimate the residual sum of squares, under the null and alternative

[28]This is permitted, as F is not dependent on β'_p, under the null hypothesis (Hansen, 1999).

hypotheses, and compute a bootstrapped version of the F statistic (a10). In repeated samples, the proportion of draws, in which this bootstrapped statistic exceeds F, is the bootstrapped p-value for the null hypothesis of no threshold effect. Further details of this procedure can be found in Hansen (1999), pages 350-351.

Appendix 4. Adult equivalency measures

All income and consumption variables used in the analysis are expressed per adult equivalent. The weighting used to construct these variables is shown in table A2. These weights are based on the suggested construction of consumption aggregates, provided with the ESS data (2011-12).

Table A2: Adult equivalency scales

Age range	Male	Female
age $\leq$ 1 year	0.33	0.33
1 year $<$ age $\leq$ 2 years	0.46	0.46
2 year $<$ age $\leq$ 3 years	0.54	0.54
3 year $<$ age $\leq$ 5 years	0.62	0.62
5 year $<$ age $\leq$ 7 years	0.74	0.70
7 year $<$ age $\leq$ 10 years	0.84	0.72
10 year $<$ age $\leq$ 12 years	0.88	0.78
12 year $<$ age $\leq$ 14 years	0.96	0.84
14 year $<$ age $\leq$ 16 years	1.06	0.86
16 year $<$ age $\leq$ 18 years	1.14	0.86
18 year $<$ age $\leq$ 30 years	1.04	0.8
30 year $<$ age $\leq$ 60 years	1	0.82
60 year $<$ age	0.84	0.74

Appendix 5. Parametric estimation of the evolution of cattle holdings

Table A3 reports the results of an estimation of equation (8). The fitted values from this estimation are used to generate the herd size growth path, shown in Figure 7. The dependent variable in table A3 is the current number cattle owned by each household A_{it}, and the model is estimated using OLS. The panel sample used for the estimation of (8) includes a recalled measure, for the herd size in 2014/15 (see section 4.3), alongside the two recorded waves (2013/14 and 2015/16). As no additional information is available for households in 2014/15, other than herd size, all control variables come from the first survey wave only.

Table A3: Lagged polynomial estimation of herd size dynamics

	(1)		
$A(t-1)$	-0.2574**	% children 0-14	-0.0147***
	(0.1009)		(0.0037)
$A^2(t-1)$	0.1126***	% women 15-60	-0.0029
	(0.0227)		(0.0045)
$A^3(t-1)$	-0.0054***	% older 61-100	-0.0090*
	(0.0016)		(0.0049)
$A^4(t-1)$	0.0001**	Distance to market (kms)	0.0030
	(0.0000)		(0.0090)
Household size	0.1385***	Distance to bank (kms)	-0.0117***
	(0.0301)		(0.0044)
Age of head	0.0159	Distance to MFI (kms)	0.0068
	(0.0209)		(0.0047)
Age of head squared	-0.0001	PSNP	-0.7508***
	(0.0002)		(0.0992)
% No education	0.0000	2015-16 wave	-0.5685***
	(0.0015)		(0.0957)
Region fixed-effects			Yes
Observations			4952
R^2			0.3146

Standard errors in parentheses * p<0.1, ** p<0.05, *** p<0.01
All control variables are measured from 2013/14 wave