Livestock as an Imperfect Buffer Stock in Poorly Integrated Markets

Simon Lange* Malte Reimers†

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Abstract

The present paper re-visits rural farm households' ability to smooth consumption ex-post via savings in the form of livestock. Previous studies find that livestock holdings in rural areas of the West African Semi-arid Tropics (WASAT) are often substantial yet there is little evidence for precautionary saving in the form of livestock out of transitory income. Exploiting two comprehensive panel datasets covering Burkina Faso's 2004 drought, we find that livestock sales increase significantly in response to drought. Consistent with consumption smoothing, the motive frequently cited by households for these extra sales is the need to finance food consumption. Using deviations in rainfall to extract the transitory component of crop profit, we find evidence that shocks are nevertheless to a large extent passed on to consumption expenditure. In line with the literature, we find that some consumption smoothing is achieved via adjustments to grain stocks while households apparently fail to smooth consumption by adjusting livestock holdings. We argue that this seemingly contradictory finding is largely due to a decrease in relative livestock prices during droughts. This suggests that selling livestock is a costly coping strategy which may be the reason that households rely on it only to a limited extent.

Keywords: precautionary saving, livestock, risk and coping strategies, price risk, Africa, WASAT.

JEL Classification Numbers: D91, O11, O16.

*Corresponding author. Economics Department, University of Göttingen. Platz der Göttinger Sieben 3, 37073 Göttingen, Germany. E-mail: simon.lange@wiwi.uni-goettingen.de.

†Economics Department, University of Göttingen

1 Introduction

The theory of optimal savings in the absence of formal insurance mechanisms and credit markets predicts that households facing covariate risks will use liquid assets for self-insurance [e.g. Deaton, 1990, 1991]. Understanding whether and how households are able to smooth consumption in the event of adverse income shocks is of great importance. Fafchamps and Pender [1997], for instance, argue that the need to hold precautionary savings prevents poor agents from undertaking irreversible and non-divisible investments that they could, in principle, undertake, thus generating a poverty trap. In a similar direction, Zimmerman and Carter [2003] show that subsistence constraints and a need to smooth incomes in the absence of insurance can generate similar poverty traps in which poor households hold defensive asset portfolios and thus forgo higher expected returns. If consumption smoothing via asset accumulation is costly, this would strengthen the case for governments to intervene in order to correct market failures.

It has long been hypothesized that one of the major buffer stocks in rural areas of developing countries is livestock. However, empirical studies investigating households responses to adverse shocks appear to be inconclusive. Based on data from India and war-time Rwanda, Rosenzweig and Wolpin [1993] and Verpoorten [2009] find that households increase sales of livestock in the event of drought and exposure to civil conflict, respectively. In contrast, Fafchamps et al. [1998], Kazianga and Udry [2006], and Carter and Lybbert [2012] find no evidence that households are able to generate additional revenues via sales based on data from rural Burkina Faso.

It is important to recognize that these two strands of the literature actually pursue two slightly differentiated questions which are both, however, related to distress sales:

1. Do households sell more livestock in the event of an adverse shock (e.g. droughts, conflict)?
2. Does net saving in the form of livestock vary positively with transitory income, i.e. do households generate revenues for consumption from sales of livestock in times of adverse income shocks?

The above studies differ in which of the two questions they address: while Rosenzweig and Wolpin [1993] and Verpoorten [2009] find evidence for an increase in sales in response to adverse shocks, studies that focus on precautionary savings typically find no relationship between savings in the form of livestock and transitory income.

The West African Semi-arid Tropics (WASAT), which have been the site of recurring droughts for as much as three millennia [Shanahan et al., 2009], are an ideal setting for researchers to study households' responses to shocks in terms of adjustments to livestock holdings. The set of strategies to cope with drought-induced shortfalls in income resident households can choose from is severely limited. Despite substantial risks [e.g. Carter, 1997], households typically lack access to formal insurance mechanisms [Binswanger and Rosenzweig, 1986, Binswanger and McIntire, 1987]. Informal insurance arrangements that do not extend beyond villages are ineffective as adverse shocks are to a large extent covariate as nearly all households depend on rain-fed agriculture and markets are poorly integrated [Carter, 1997].

While studies typically investigate one of the above questions in isolation, this paper addresses both questions in order to explain the apparent contradiction. We employ two large panel datasets from Burkina Faso that cover the harvests of 2003 and 2004 and 2004—2007, respectively, which saw considerable variation in rainfall including a drought in 2004. Our findings with regard to the first question suggest that livestock sales increase in response to adverse rainfall shocks at the level of provinces with no off-setting increase in purchases. Based on count data models, we also find that sales are negatively related to rainfall at the household-level. Consistent with a need to compensate for a decrease in revenues from cropping, households cite food consumption as the main motive for extra sales.

We then turn to the second question and ask whether households save in the form of livestock out of transitory crop profit based on an empirical strategy that identifies the transitory component of crop profit from unanticipated variation in rainfall. Our framework shares key components with specifications typically employed in the literature and results in similar findings. A large portion of transitory income is transmitted to consumption expenditure. There is no evidence for an important role of net sales of livestock in consumption smoothing, whereas adjustments to grain stocks are sizable. We also show that in our sample, this finding is not driven by behavioral differences between subgroups differentiated by livestock holdings as was suggested recently by Carter and Lybbert [2012].

Viewed in isolation, our results are largely in line with previous findings in the literature and beg the question of why there are addtional sales yet no additional revenues. We argue that prices account for this puzzle: in a province-level panel dataset, we show that cattle prices decline in the event of an adverse weather shock in both nominal and real terms. This is consistent with an increase in net sales in markets that are not fully integrated. This finding potentially explains the lack of a significant partial correlation between transitory income and net purchases of livestock evaluated in monetary terms: an increase in the net number of animals sold is off-set by a decrease in livestock prices. This renders adjustments to livestock holdings a costly strategy to smooth consumption. It also explains why households bear consumption cuts despite livestock holdings that would allow them to completely offset transitory income losses. At least some households will find that post-shock prices are too low for their livestock and hence abstain from selling.

In addition to contributing to the empirical literature on asset-based consumption smoothing under uncertainty and credit constraints [Rosenzweig and Wolpin, 1993, Fafchamps et al., 1998, Zimmerman and Carter, 2003, Kazianga and Udry, 2006, Park, 2006, Verpoorten, 2009, Carter and Lybbert, 2012], this paper is also related to a recent literature on intra-temporal arbitrage decisions by farmers in developing countries [e.g. Barrett, 2007, Stephens and Barrett, 2011, Burke, 2014]. We find that livestock sales are negatively related to prices which, in turn, are driven by weather shocks. If borrowing opportunities were available, at least some farmers should be observed taking advantage of such fluctuations by purchasing livestock during droughts. The above studies show that farmers do not take advantage of arbitrage opportunities resulting from intra-seasonal variation in grain prices and suggest that a lack of borrowing opportunities account for this.

The paper proceeds as follows: section 2 reviews the relevant literature and explains the setting of our empirical investigation. Section 3 introduces and compares datasets used in this study. Section 4 provides some descriptive evidence on behavioral responses to the drought in 2004. We show that crop output declined substantially and that the proportion of households reporting consumption cuts increased following the 2004 drought. In section 5 we show that sales at the province-level increase in response to adverse rainfall and that there is no off-setting change in purchases. We also detect a corresponding relationship at the household-level. Section 6 details the empirical strategy to identify the effects of transitory crop profit on consumption and savings in the form of grain storage and net purchases of livestock and presents our results. Section 7 investigates the price response to adverse rainfall and problems that this finding potentially poses to microeconometric investigations of consumption smoothing. Section 8 concludes and discusses policy implications.

2 Background

2.1 Literature review

The canonical model of saving under credit-constraints and uncertainty over future income suggests that precaution is one motive of risk-averse agents for holding assets [Deaton, 1990, 1991, Fafchamps et al., 1998]. In fact, for a high enough discount rate, it is the only motive for holding wealth [Deaton, 1992] and for large enough wealth, consumption is proportional to permanent income [e.g. Zeldes, 1989]. This further suggests that poor households will smooth consumption via adjusting buffer stocks as they are more likely to be credit-constrained. In line with this view, poor households in developing countries are usually found to hold considerable amounts of extra saving, for instance, in the form of grain stocks, jewelry, and livestock [Rosenzweig and Wolpin, 1993, Park, 2006].

Livestock in particular has long been thought of as the main buffer stock in drought-prone tropical environments such as the WASAT region [Binswanger and McIntire, 1987, Reardon et al., 1988]. Binswanger and McIntire [1987] argue that animals are more resistant to droughts as there might still be vegetative growth that provides fodder. Animals can also be shifted to neighboring areas in the case of local droughts. Animal husbandry was thus hypothesized to be associated with less production risk. Storage of grain, on the other hand, is expensive as stocks exhibit limited durability and are often affected by pests. There should thus be an upper bound to what households are willing to hold in storage (ibid.). Livestock is therefore the major form of wealth and an insurance substitute.

This notion has been formalized by Fafchamps et al. [1998] who model portfolio choices of risk-averse households in a dynamic setting with uncertainty over future incomes from farming. Liquid wealth is composed solely of grain stock and livestock, where livestock exhibits higher returns. This model suggests that livestock holdings are an increasing function of returns to livestock and losses associated with grain storage and a decreasing function of the (real) purchase price of cattle, livestock's labor requirements, the correlation between crop and livestock returns, risk aversion, and the variance of livestock returns. Since most households are believed to exhibit either constant or decreasing relative risk aversion, the authors conjecture that livestock holdings constitute a constant or increasing proportion of liquid wealth. The model thus predicts that livestock will be liquidated in response to an adverse income shock. If households have decreasing relative risk aversion, households will liquidate livestock over-proportionately as portfolios are adjusted.

The empirical literature paints a mixed picture concerning the role of livestock. Rosenzweig and Wolpin [1993] demonstrate convincingly that sales of bullocks play a crucial role in Indian farmers' strategies to smooth consumption. They show that bullocks account for a large share of households' non-land and building wealth, are bought and sold at considerably higher prices than other assets in well-developed, inter-regional markets, and are sold even when profit realizations are low. Similarly, Verpoorten [2009], who applies conditional logit models to retrospective reports of sales of livestock, finds that almost half of all cattle sales in Rwanda in 1994 were motivated by war-induced food shortages. Interestingly, households resorted to this coping strategy despite prices having fallen to about 50 percent of their pre-genocide level.

Conditions in India's rural economy, as well as circumstances in wartime Rwanda, however, differ in important aspects from conditions in the WASAT region. In the Rosenzweig and Wolpin-study, for instance, the authors find that markets are fairly well integrated and that livestock prices are therefore insulated from village-level shocks, a condition that cannot be easily maintained for most of the WASAT.

Nevertheless, anthropological and economic case studies set in this region initially seemed to support the claim that livestock sales[1] are an important mechanism to smooth consumption. Watts [1983], for instance, documents that Hausa farmers in northern Nigeria sold livestock in the aftermath of the drought in the early 1970s. Similarly, Swinton [1988] documents that farmers in Niger liquidated livestock in response to the 1984 drought in order to pay for food.

Formal tests of this hypothesis based on microdata followed suit yet results from such endeavors remain puzzling. Based on the ICRISAT farm-level data covering Burkina Faso's drought in the early 1980s, Fafchamps et al. [1998] report that if livestock is sold in times of adverse income shocks, the financing of consumption expenditure is by far the most important motive. However, regressing net sales of livestock on different measures of income shocks, the authors find that at most 30 percent of an unanticipated shortfall in income at the village-level is compensated in the form of asset sales. The actual figure, they reason, could be much closer to 15 percent.

A similar result emerges in Kazianga and Udry [2006] who also rely on the ICRISAT data yet also test for consumption smoothing directly. They conclude that "[n]one of the main risk coping strategies [...] hypothesized in the literature were effective during the crisis period [...]." To the contrary, they report that about 55 percent of changes in transitory income were passed

[1] Several studies find that killing livestock for meat is rare in this region. Livestock is usually sold and the proceeds used to purchase grain [e.g. Loutan, 1985].

onto consumption, a pattern entirely incompatible with the permanent income hypothesis. As in Fafchamps et al. [1998], they find a negligible role for livestock as a buffer yet a considerable role for grain stocks. Adding even further to the puzzle, livestock holdings reported by households after the drought were often large enough to have compensated entirely for the shortfall in consumption and the observed lack of *consumption smoothing* does not seem to have been driven by indivisibilities [Kazianga and Udry, 2006].

Fafchamps et al. [1998] acknowledge that general equilibrium-effects might be important. If shocks are spatially correlated and markets for buffer stock poorly integrated, the relative price of livestock will drop in response to adverse shocks to grain output inducing some households to hold on to their assets. Households' ability to use livestock as a buffer stock thus depends crucially on the integration of village grain and livestock markets with the outside world. Fafchamps and Gavian [1997] argue that in Niger, a country bordering Burkina Faso to the East, markets for livestock are poorly integrated. Relative prices nevertheless respond to changes in urban meat demand.

This route is explored further by Zimmerman and Carter [2003] who extend the model put forward by Fafchamps et al. [1998] in several interesting ways. Again, it is assumed that households choose between two different assets, one productive (livestock) and one unproductive yet safe (say, grain stocks). The productive asset is associated with higher expected returns yet more volatility. This is because prices are determined locally and incomes are subject to covariate shocks. Hence, local asset prices might react to covariate shocks; the high-yielding asset is associated with additional price risk. Finally, it is assumed that households, particularly poor households, see their subsistence at risk.

Simulating this model based on parameters estimated from the ICRISAT data, Zimmerman and Carter find that households' portfolio strategies quickly bi-bifurcate in this kind of model. Agents initially endowed with less wealth adopt a defensive strategy characterized by a lower portfolio value and by a less productive mix of assets. Agents endowed with more wealth, on the other hand, adopt a much more offensive strategy, holding only a negligible share of their liquid wealth in the form of the low-yielding asset. Despite the high-yielding asset exhibiting decreasing returns, low wealth-agents pursuing the defensive strategy end up with a portfolio yielding lower returns. This finding indicates that poor households pay high premiums in the form of foregone returns in order to stabilize incomes—it is thus in line with early empirical findings [Rosenzweig and Binswanger, 1993, Morduch, 1995] in the literature.

While both asset-rich and -poor households achieve some consumption smoothing, the asset-poor are less successful in doing so. While the former allow only one-third of the volatility in income to be passed on to consumption, the latter allow more than one-half to be passed on. It is interesting that the asset-poor could achieve more consumption smoothing, yet they deliberately de-stabilize consumption in order to protect the few assets they have. Zimmerman and Carter refer to this as *asset-smoothing*—in contrast to *consumption-smoothing*. This finding, basically a consequence of the threat to subsistence the poor face and the additional price risk livestock carries, is in stark contrast to much of the earlier literature on this topic. However, the assumptions imposed concerning the subsistence threat are rather stark. The consumption-productivity link is captured by the specification of a minimum subsistence level below which utility is zero for that period and all periods thereafter.

Only recently has this been put to the test in Carter and Lybbert [2012]. Based on the very same ICRISAT data, they apply Hansen's (2000) threshold estimator in order to test for a threshold in the space of livestock holdings that separates households into the two regimes predicted by Zimmerman and Carter [2003]. Their results indicate that there might indeed be a very small subsample of households that does respond to adverse changes in transitory income by selling livestock. However, the vast majority of households appears to belong to the asset-smoothing regime.[2]

A different strand of the theoretical literature stresses the importance of grain stocks as a means to smooth consumption [Saha and Stroud, 1994, Park, 2006]. Park [2006], in particular, formulates a model that captures the multiplicity of farmers' grain management options—storage, production, trade, and consumption—in a dynamic specification. His model accounts for both yield and endogenous price risk. Simulating the model he finds that households hold grain storage as a price hedge, not in lieu of credit or other *ex post* consumption-smoothing mechanisms. In the absence of price risk, households would abstain from storing any grain.

2.2 Agricultural production in Burkina Faso

Burkina Faso is a landlocked country located in West Africa. It is among the poorest countries in the world with a PPP-adjusted GDP per capita of about $450 (in 2005 dollars) in 2009 [World Bank, 2013]. More than two-thirds of the population live on less than $2-a-day. As in other Sahelian countries, most of the poor still live in rural areas where livelihoods depend crucially on rain-fed agriculture. While the share of agriculture in total output accounts for about one-third, the sector employs four in five persons in Burkina Faso. The rate of technological change in agricultural production in the WASAT is low. This was particularly the case before the 1980s [Eicher and Baker, 1982].[3]

[2] There are several problems with the empirical analysis in Carter and Lybbert [2012]. Most importantly, the subsample of households that are found to pursue consumption smoothing via asset sales is small, comprising as few as 16 households. This is despite the fact that the ICRISAT data are stratified as to overly cover well-to-do farmers that have access to animal traction. This result is problematic for two reasons: first, threshold-regression models are known to lack robustness when the threshold is located at the fringes of the sample [Greb et al., 2014]. Second, the threshold estimate itself is very large which leads one to question the practical relevance of consumption smoothing via livestock sales: depending on the specification considered, estimates in Carter and Lybbert [2012] imply that households that sell livestock to smooth consumption own livestock equivalent to at least 15 heads of cattle. In what seems to be their preferred specification, asset-rich households are even defined by owning more than 24 cattle-equivalents. In the EPA data, which are also stratified according to whether or not households rely on animal traction, the share of households that own that much livestock is only 14 and eight percent in any given year, respectively.

[3] Eicher and Baker [1982] explain that "[...] research on a number of problem areas—for example, irrigation—was almost non-existent until the 1970s" [Eicher and Baker, 1982, p. 116]. A transfer of high-yielding sorghum varieties from India failed in the late 1970s [Eicher and Baker, 1982, p. 119]. More promising results were achieved by the late 1970s for improved maize varieties in some experimental settings (ibid.).

According to definitions by Sivakumar and Gnoumou [1987], there are three distinct climatic zones in Burkina Faso:[4] a *Southern Sudanian Zone* to the south characterized by rainfall above 1,000mm annually on average, a rainfall season that lasts for more than six months, and comparatively low temperatures; a *Central North Sudanian Zone* with rainfall between 650 and 1,000mm that does not exceed six months; and a *Northern* or *Sahelian Zone* with a short rainy seasons, considerable variability in rainfall and high temperatures. These three climatic zones roughly coincide with the shaded areas in the map depicted as figure 1 which clearly shows the north-south-gradient in average annual precipitation in millimeters between 2001 and 2012. While onset dates differ somewhat across regions, most of the rain is typically received between June and September.

[Figure 1 about here.]

Crops grown for domestic consumption are mostly sorghum, millet, maize, and rice [see Kassam, 1979, for an early exposition]. Millet is the dominant staple crop in the arid northern provinces on steep slopes and otherwise poor soils, while sorghum is the principal subsistence crop elsewhere [Sivakumar and Gnoumou, 1987]. The most important cash crop is cotton, despite a sharp decrease in world market prices in the mid-2000s. The initial surge in production originated in reform efforts that date back to the early 1990s. The next ten years saw a more than three-fold increase in production [see Kaminski et al., 2011]. Today cotton accounts for more than half of the countries' export earnings [Amo-Yartey, 2008]. Production is concentrated in the southwestern regions. Driven by the boom in cotton production on the one hand and recurring droughts in the north on the other, the region has seen more rapid change than the rest of the country with a shift towards cotton and maize production, more rapid population growth due to intra-national migration, as well as higher adoption rates of advanced agricultural techniques such as animal traction and the use of anti-erosion sites [Gray, 1999]. In the Sahel, in contrast, cash crops include groundnuts and sesame but at a smaller scale [Traore and Owiyo, 2013].

Animal husbandry, dominated by goats, sheep, and cattle, is traditionally an important source of incomes in this region and in the east of the country [Sivakumar and Gnoumou, 1987]. More recent reports, however, point to a decline in the economic importance of livestock in the Sahel in recent years—particularly in response to droughts in 2004 and 2010. For instance, Traore and Owiyo [2013] point out an accelerated degradation of pastures in recent years due to a decrease in rainfall. Consistent with a shift towards more intensive livestock management practices, respondents in their study also report a shift away from purely cattle-based livelihoods towards a combination of crop production and livestock keeping.

[4] Some authors distinguish four distinct agro-ecological zones [e.g. Fontès and Guinko, 1995].

3 Datasets

For the empirical part of our paper, we are using two different panel datasets which both cover the 2004 drought (namely: *Enquête Permanente Agricole* (EPA) and *Deuxième Programme National de Gestion des Terroirs* (PNGT)) together with precipitation data from the Famine Early Warning Systems Network (FEWS) [USAID, 2013]. These datasets are separately described below.

3.1 EPA surveys

In comparison to the ICRISAT data that were used by most authors from the literature, the EPA panel datasets (years 2004–2007) have the great advantage that they are not as outdated as the ICRISAT data (collected between 1981 and 1985) and that their sample size is much larger (our balanced panel contains 2,364 households annually instead of just 126 households in the still unbalanced ICRISAT panel). In addition, the EPA data cover all 45 provinces of Burkina Faso and can therefore be considered much more representative for rural areas of the country than the ICRISAT data which are restricted to just two villages in each of the three agro-climatic zones (Sahelian, Sudanian, Guinean).

Besides these advantages, the EPA household data share many of the desirable features of the ICRISAT data. Most importantly, they rely on interviews conducted by local enumerators coming from the same area who are typically farmers themselves and are hence very familiar with the local conditions for agriculture. Furthermore, this proximity enables them to visit the surveyed households not just once, but at different points in time (mostly during the growing and harvest season). Lastly, given its major importance for the Burkinabe Ministry of Agriculture as a tool to collect information on past and expected future harvests, extraordinary efforts are made to capture each households agricultural production as precisely as possible. For example, each local enumerator is equipped with an isosceles triangle which is used at the first visit during the growing season to randomly mark on each plot an area of exactly 25m^2 with wood pegs (randomness is assured by following an exhaustive predefined process). Shortly before the plot is ready to be harvested, the household head then contacts the enumerator and agrees on a date when the household will be re-visited. This allows the enumerator to be present when the marked area is harvested, threshed, weighed and the measured output ultimately extrapolated to the entire plot area.[5] The above-described procedure together with very strict protocols also for other questionnaire modules lets us be confident that—in terms of data quality—the EPA data are of comparably high quality as the commonly used ICRISAT data.

[5] This procedure apparently worked quite well since, according to the data, an enumerator was present at the time of harvest in almost 60 percent of the cases.

3.2 PNGT surveys

In addition to the above-described EPA datasets, we are using two waves of the PNGT panel surveys for our analysis which were collected in May/June 2004 and 2005, respectively, and thus likewise cover the 2004 drought.[6] These surveys are administered by the University of Ouagadougou in collaboration with the Burkinabe Ministry of Agriculture and aim to quantify improvements in the livelihoods of households in rural Burkina Faso. The surveys cover a total of 60 villages in all 45 provinces of Burkina Faso and aim to be representative for rural Burkina Faso given that each village was drawn with a probability proportional to its population [Wouterse, 2011].

The motivation for additionally using the PNGT panel lies in the fact that the EPA datasets indeed provide reliable information on agricultural production, livestock holdings/transactions as well as grain stock holdings, but lack an explicit consumption module. The PNGT surveys provide remedy to this shortcoming since they were collected in each year's lean season and contain a very detailed expenditure module as well as a module asking for the food quantities consumed during the last seven days. This feature enables us to grasp the extent to which harvest shortfalls translated into actual reductions of food consumption without relying on flow accounting methods such as Kazianga and Udry [2006].

3.3 Descriptives

Table 1 reports descriptive statistics for some of the key variables in our analysis. As further detailed in section 4, our data cover a major drought in the northern part of Burkina Faso in the year 2004 which caused the grain output to be considerably lower. Households in the EPA data comprise on average around eleven members while households are slightly smaller in the case of the PNGT data. Also, we observe that the latter have younger household heads and fewer livestock holdings. The figures also seem to indicate that they have lower grain output despite cultivating more land.[7]

The drought year of 2004 is apparent in the data via a reduction in aggregate grain output and crop profit that is observed in both datasets. Grain stocks, which are only available from the EPA datasets, are much lower in 2005 few weeks before harvesting. However, averages reported in table 1 disguise considerable spatial variation. Therefore, section 4 scrutinizes the effects of the 2004 events in more detail with a particular focus on livestock related variables.

[Table 1 about here.]

[6] In fact, we also have access to a third PNGT wave that was collected in November 2006. However, after careful consideration, we decided not to use this third PNGT wave for our analysis given that the shift in the survey timing would complicate comparisons over time. Even more importantly, this shift also leads to a break in the panel structure of our data since we would then only have harvest data for agricultural seasons 2003/04, 2004/05, and 2006/07, but not for agricultural season 2005/06.

[7] A possible explanation for this is recall bias: output is directly measured in the case of the EPA data, often in the presence of enumerators, whereas the PNGT data rely on recalls elicited during the following lean season, i.e., several months after harvesting. On the other hand, recent experimental evidence suggests that recall bias is not a major concern in agricultural output data [Beegle et al., 2012].

3.4 Prices

A typical problem that we encounter with the otherwise excellent EPA data is the elicitation of crop prices. This is because the data neither come with a village level-survey in which local market prices were collected separately by enumerators as in the case of the PNGT data, nor do they include an actual consumption aggregate. Hence, the researcher is usually left with prices inferred from unit values calculated from households' reports on sales of its agricultural output.

Such sales, however, are rare in an environment characterized by subsistence farming and low incomes. In general, such households will sell their own-produced grains only when prices are particularly good. For instance, Barrett and Dorosh [1996] report that of their sample of rice-producing farm households in Madagascar only five percent of households accounted for about half of rice sales while about 60 percent purchased rice. Similarly, Budd [1999] shows that few of the farm households in Côte d'Ivoire that he studies were fully self-sufficient and very few were net sellers. This finding is usually attributed to high transaction costs in environments with poor infrastructure [e.g. Renkow et al., 2004, Park, 2006].

The same is true in our data: households are rarely net sellers of crops. Asked about the proceeds from the 2003 bumper crop in mid-2004, in as many as eight out of 45 provinces less than ten households report having sold millet. This share increases to 21 out of 45 provinces in 2004/2005. The problem is even more pronounced in the case of non-grain crops such as Wandzou for which we hardly ever observe more than ten transactions from which unit prices could be calculated.

Another potential problem is intra-seasonal price variation. Respondents were asked about sales of output between the last harvest and the time of the interview, a period of almost ten months in the case of the EPA surveys. Intra-seasonal prices in African agriculture are known to fluctuate substantially within localities, a phenomenon that has received some attention recently [Stephens and Barrett, 2011, Burke, 2014]. We would thus expect average unit prices based on reported sales to exhibit high variability within province-years.

We therefore rely on an alternative that takes advantage of the fact that the PNGT data provide us with village-level prices from all provinces at three different points in time between spring 2004 and fall 2006 (see also footnote 6). These data are used to calculate province-level prices and then supplemented with monthly crop price data for Ouagadougou from the *Statistical Yearbooks* of the *Institut National de La Statistique et de la Démographie* [INSD, 2012]. We impute province-level prices based on regression models. Details are reported in appendix A.

These prices, together with average expenditure shares estimated based on data from the PNGT surveys' consumption modules, are then used to compute a consumer price index (CPI) as follows: first, we calculate the average annual quantities consumed of the major food items for which we have prices in the PNGT village-level surveys over all households and years. Second, these quantities are valued using the current province-level market prices giving us the monetary value of the food basket. On average, food expenditure accounts for roughly two-thirds of total consumption expenditure of the households in the PNGT sample. For non-food expenditures, accounting for the other third of the basket of goods, we assume a moderate inflation rate of three percent annually. The resulting CPI is normalized to be unity on average across all households and time periods.

3.5 Precipitation data

The precipitation data used in this paper come from USAID [2013] and are estimated based on a combination of actual station-level rainfall data and satellite-measured cloud top temperatures. For our analysis, we downloaded province-level precipitation data for ten-day intervals for the years 2001 until 2012 (i.e. 36 data points per year and province). Based on these raw data, we calculate the amount of rainfall in millimeters for each province-year separately.

[Figure 2 about here.]

The resulting panel is depicted as a time series plot for all of Burkina's 45 provinces in figure 2. It is clear from this figure that 2003 was a particularly good year in almost all provinces whereas 2004 saw less rainfall.

4 The impact of the 2004 drought

Causes In terms of agricultural production, 2004 was a particularly bad year for farmers in the northern provinces of Burkina Faso. The rainy season started later than usual, precipitation was irregular and overall rainfall levels were considerably below the long-term mean [FAO, 2005].[8] This shortfall in rain is depicted in figure 3, where we report the proportional shortfall in 2004 relative to the long-term mean calculated for 2001–2012. On average, provinces experienced about ten percent less rain in 2004. Provinces most severely hit during that year were Sanmatenga, Namentenga, Soum, Séno and Oudalan. In the northernmost province, Oudalan, which is also one of the driest provinces within Burkina Faso, rainfall levels were about 30 percent below the long-term mean.

[Figure 3 about here.]

Crop Output The consequences of these events are reflected in figure 4 which depicts the shortfall in crop output per hectare relative to the 2004–2007 average. In line with the above explanations, the output shortfall was largest in the three provinces Oudalan, Séno and Soum which suffered from an average shortfall in excess of three-fourths. Also beyond these three provinces, the rainfall map in figure 3 and the output per hectare map in figure 4 match quite well and suggest a relationship between these two indicators. At the national-level, we observe an average shortfall in output per hectare of slightly more than 25 percent[9]

[8] In addition, there were reports of desert locust swarms from North Africa invading many West African Sahel countries including Burkina Faso [IFRC, 2005]. This phenomenon also affected primarily northern provinces and is likely to have further aggravated the loss of output and grain stocks in 2004.

[9] Both figures are unweighted averages across provinces.

[Figure 4 about here.]

Food Consumption Data from the PNGT surveys also allow us to examine how Burkinabe households reacted to the events of 2004 in terms of consumption. Figure 5 depicts the share of households reporting reduced food in-take during the last seven days (separately for men, women and children) as well as the share that had to leave out entire meals or abstain from food consumption for an entire day in this time period. Three issues are particularly noteworthy. First, a considerable share of households in rural Burkina Faso is structurally poor given that, even following a good year in terms of rainfall and output such as 2003, around 29 percent of households reported reduced food in-take for at least some household members. More than 15 percent of households even reported that they had to entirely abstain from food consumption for at least one day during the last week. Second, it seems that households try to protect their children from food cuts to the extent possible given that the share of men/women experiencing reduced food consumptions is in both years considerably higher than for children. Third, for all five indicators we see a clear upward shift between the years 2004 and 2005. Most notably, the share of households reporting reduced food in-take for men/women increased considerably to approximately 49 percent. This negative trend did not spare children since in the year 2005 approx. 26 percent of households reported food cuts for children (compared to 14 percent in 2004). Analogously, also the share of households abstaining from food consumption for an entire day increased to approximately 22 percent.

[Figure 5 about here.]

While these time trends are indicative it could be argued that they rely on rather subjective, categorical questions. Therefore, we analyze as a next step the daily food quantities consumed per capita for a total of nine crops.[10] As can be seen in figure 6 there has been a considerable drop in millet consumption between the years 2004 and 2005 (approximately 70g per person and day) and to a smaller extent also for Sorghum, Groundnut and Niébé. Even though these reductions appear small at first sight, they nevertheless correspond to a reduction in food intake of approximately 330kcal from these crops (using calorie conversion factors from FAO [2010]). In this context, it should be noted that these crops account for the median household in our dataset for approximately 70 percent of total food consumption.

[Figure 6 about here.]

Livestock ownership and trading Are the 2004 events also reflected in livestock budgets? Table 2 reports means of variables related to production and trading of livestock for all available years. Livestock holdings are substantial in this setting: about three-fifths of all households

[10] Namely, the contemplated crops are: Fonio, Groundnut, Maize, Millet, Niébé, Rice, Sesame, Sorghum and Wandzou. In figure 6, only six crops are shown since the avg. amounts of the other three crops (Fonio, Sesame, Wandzou) are negligible.

report owning cattle and more than four-fifths own small livestock. On average, families own more than five heads of cattle and more than 13 heads of small livestock in any year.

[Table 2 about here.]

The share of households selling is lower: less than one-fourth of all households sold cattle, while about half report having sold small livestock. While there is virtually no increase in the number of households selling cattle between 2003/2004 and 2004/2005, the average number of cattle sold increases in 2004/2005 from 0.54 to 0.68 animals. No such increase is observed for small livestock although sales were higher in 2004/2005 than in subsequent periods.

While the figures do not indicate that there was an increase in the number of animals that died as a result of drought, the number of animals slaughtered for own-consumption increases substantially in 2004/2005, albeit from a very low level. This is surprising as several previous studies find that households rarely kill animals for own-consumption [see Fafchamps et al., 1998, and the studies cited there].

These averages disguise important spatial variation in sales. Figure 7 depicts net livestock sales relative to initial holdings (in percent) between harvests in 2004 and 2005. As in table 1, we combine different categories of livestock by considering livestock holdings and net sales in TLUs. In line with our expectations, the proportion of animals sold net of purchases is highest for the most drought-affected provinces in the North of Burkina Faso where households on average sold more than 30 percent of their livestock.

Note, however, that this could also be a static effect. If households in northern provinces could have a higher tendency to be engaged in animal husbandry because of underlying differences in the rural economy. It is thus plausible that the pattern observed in figure 7 is unrelated to *changes* in rainfall and crop output. We will investigate this issue in more detail in section 5.

[Figure 7 about here.]

The EPA surveys also collect information on households' motives for livestock sales. The absolute number of sales of cattle and sheep and goat by motive is depicted in figure 8. We see that food purchases are the most prominent motive in all years, followed by family care. Other categories, such as obtaining funds to pay for school fees, ceremonies and festivities, agricultural equipment and inputs are less important. The pattern is fairly stable across years with the exception of sales to pay for food which increase substantially between harvests 2004–2005. The number of cattle, goat and sheep sold almost doubles from 2003–2004 to 2004–2005.

[Figure 8 about here.]

Taken together, the figures presented in this section show that livestock sales increased substantially during the agricultural season 2004/2005 and that the dominant motive behind sales was households' need to purchase food. It seems plausible that these extra sales were triggered by adverse rainfall conditions and the resulting shortfall in crop output. The next two sections investigate the relationship between rainfall and livestock sales more formally.

5 Rainfall and livestock trading

The above observations are consistent with households resorting to livestock sales in response to a poor harvest in 2004/2005 resulting from adverse weather conditions. To further investigate this conjecture, we first run fixed effects-regressions of the log quantity of livestock sold on log rainfall at the province level in section 5.1. In section 5.2, we then investigate the same relationship at the micro-level based on conditional Poisson regression models for the number of animals sold.

Since we control for unobserved, time-invariant variables at the level of provinces and households, respectively, the coefficient on log rainfall should be interpreted as the effect of changes in rainfall conditional on long-run averages. We show the appendix B that rainfall levels at particular locations across Burkina Faso do not exhibit any significant trends over time. Moreover, we find no evidence for serial correlation in the location-specific time series. It thus appears that deviations of rainfall from long-run means are unanticipated.

5.1 Rainfall elasticities of livestock sales and purchases

We first run regressions of the form

$$\ln(x)_{pt} = \delta \ln(rainfall)_{pt} + \rho_p + \tau_t + \epsilon_{pt}, \tag{5.1}$$

where x_{pt} denote either sales or purchases of cattle, sheep, or goats in province p during year t and ϵ_{pt} is the usual error term. Since both sales (purchases) and rainfall enter the regression in logs, the coefficient of interest, δ, should be interpreted as the elasticity of sales (purchases) with respect to rainfall. A negative coefficient in a regression of sales on rainfall is consistent with consumption smoothing, i.e. it is consistent with households selling livestock in order to stabilize consumption.

All regressions include complete sets of province- and year-fixed effects denoted ρ_p and τ_t, respectively. Province fixed-effects capture time-invariant differences in livestock production across provinces. For instance, it is plausible that some geographical regions provide a relative advantage in producing livestock such that rural households are more likely to engage in animal husbandry. In that case, we would expect higher sales and purchases in every year. Year-fixed effects, on the other hand, capture trends in the supply and demand conditions that affect all provinces to the same degree such as world market prices for meat.

[Table 3 about here.]

Results for cattle as well as sheep and goats combined are reported in table 3. Elasticities reported in columns (1) and (2) suggest that sales of both categories of animals decrease with better rainfall. The implied elasticities are large and significant at the five and ten percent-levels for cattle and sheep/goats, respectively. This finding is consistent with livestock serving as a buffer stock and differs from those reported by Fafchamps et al. [1998] in their study of consumption smoothing in six Burkinabe villages during the early 1980s. In particular, at the village-level they find no statistically significant relationship between rainfall and the number of cattle sold and only a weak relationship for sheep and goat. Kazianga and Udry [2006] and Carter and Lybbert [2012] do not investigate this reduced-form relationship but rely on the same data.

If village economies were completely isolated, we would observe a concomitant increase in purchases. In that case, we would see animals being traded between villagers forced to sell in the wake of a bad harvest and others taking advantage of an increase in supply. This could potentially explain the puzzle found in the literature that, on average, there is no relationship between revenues from net sales and transitory income shocks. However, this explanation seems unlikely: first, in any given year, we find that, on average, the number of animals sold exceeds the number of animals purchased by a factor of two (see table 2). We also estimate absolute rainfall elasticity of purchases. Results are reported in columns (3) and (4) of table 3. These suggest that purchases do not vary significantly vary with rainfall. Taken together with lower purchases, this implies that increased sales are not absorbed within provinces through concomitant increases in purchases through rural households covered in our sample. A plausible explanation for this is that livestock is sold to butchers in urban localities.

5.2 Count data models

Having examined the relationship between rainfall and sales at the province-level, we now turn to the relationship at the level of households. Since sales are nonnegative integers, count data models seem appropriate. An estimator that has several beneficial properties is the conditional (fixed effects) Poisson estimator (FEP) originally proposed by Hausman et al. [1984].[11]

The mean function is specified as

$$m(\mathbf{x}_{it}, \beta) = c_i e^{\mathbf{x}'_{it}\beta}, \tag{5.2}$$

where c_i is a multiplicative fixed effect, $\mathbf{x}$, the matrix of covariates, includes a constant and β is the vector of parameters of interest. Note that (5.2), by far the most popular choice for the mean function, has the advantage that parameters are easily interpreted as elastiticies if regressors are included in logs [Wooldridge, 2002, pp.647–648]. If they are included in levels, multiplying the coefficient by one hundred yields the semi-elasticity.

One drawback of the FEP estimator is that households for which the number of sales in all time periods is zero are not used in the estimation procedure.[12] The subsample to which the

[11] Inference in standard Poisson models relies on the *Poisson variance assumption* that states that the conditional mean must equal the conditional variance [Wooldridge, 2002, pp. 646–647]. There is, however, evidence for overdispersion in our data as the standard deviation of sales of cattle, sheep, and goats is typically about three times the mean. Wooldridge [1999] shows that the only assumption required for consistency and asymptotic normality of the FEP estimator is that the conditional mean be correctly specified. The distribution of the dependent variable conditional on covariates and the fixed effects is entirely unrestricted. In particular, there can be overdispersion (or underdispersion) in the latent variable model.

[12] The FEP estimator is based on quasi-conditional maximum likelihood methods. The sum of counts across

analysis applies is thus the set of households for which positive sales are observed at least once. This reduces the number of household-year observations available for estimation, particularly in the case of cattle as only about 44 percent of households actually sold cattle at least once. The share of households selling small livestock at least once, in contrast, is more than four-fifths. There are important differences between selling and non-selling households which we report on in appendix C. This is an important issue to keep in mind when comparing results from this section to those in section 6. Our way of dealing with this is to adjust samples in section 6 so that they match samples available for estimation in the present section.

Results are reported in table 4 for both categories of livestock. In addition to log rainfall, the main variable of interest, we also include year-fixed effects in order to control for aggregate shocks to demand and supply conditions. In addition, we include (but do not report) a set of household demographic variables in order to control for available family labor.

Other motives besides consumption smoothing might play a role in the decision to sell livestock [Moll, 2005]. In particular, households may make adjustments by selling livestock in order to maintain the optimal herd size. All regressions therefore include the number of animals purchased, born, and deceased over the last year. As a robustness check, models reported in columns (2) and (5) also include the number of animals owned and the log of the area cultivated in the previous period. Note that including these variables further reduces the number of observations available for estimation.

Finally, we also include an interaction term between log rainfall and a binary variable that is unity if the household owns more than 15 cattle equivalents on average over all time periods. Results are reported in columns (3) and (6). Zimmerman and Carter [2003] and Carter and Lybbert [2012] argue that consumption smoothing is only pursued by a subset of households with high levels of liquid wealth. In particular, Carter and Lybbert find that for the subgroup of households that own more than 15 cattle equivalents, livestock sales compensate for a large portion of shocks to transitory income. If this was the case, we would observe a negative coefficient on the interaction term that signals a higher elastiticity of sales with respect to rainfall in absolute terms for livestock-rich households.

[Table 4 about here.]

Results reported in table 4 indicate that cattle sales are responsive to rainfall with an elastiticy of about -0.7 (column (1)). The coefficient is significant at the five percent-level and remains unaltered if we include lagged stocks (column (2)). There is no indication that households with large stocks of animals exhibit a higher elastiticity of sales with respect to rainfall: the coefficient on the interaction term in column (3) is insignificant at conventional levels.

Recall that, on average, households in our data sell about 0.5 heads of cattle each year (see table 2) and that in affected provinces the shortfall in precipitation in 2004 relative to the long-run mean was about 30 percent. An elasticity of -0.7 would thus suggest that households facing such a shortfall would step up sales by about one-tenth of a cow.

time is conditioned on in order to remove the unobserved c_is.

The coefficient on log rainfall in the regression of sales of goats and sheep is also negative and significant at the five percent-level yet the elasticity is lower in absolute terms: a ten percent-increase in rainfall is associated with a decrease in sales by about 4.5 percent. Since an average household sells about 2.5 animals each year, a 30 percent-decrease in rainfall would be associated with an increase in sales by one-third of a goat or sheep. Again, we find no evidence for differences in the rainfall elastiticity between households differentiated by total livestock holdings. The estimated coefficient turns insignificant and is somewhat closer to zero if we include lagged stocks of sheep and goats, where our estimation sample now includes only 5,251 household-year observations rather than 7,578 as before.[13]

The number of animals purchased, born, and deceased, as well as the number of animals owned in the previous period are included in order to control for herd management considerations. Our results indicate that the number of animals purchased is positively associated with the number of animals sold for both categories of livestock. While all other coefficients are insignificant for cattle, we find that the number of animals born increases the number of sales for small livestock.

Overall, the results in this section indicate that deviations from rainfall from long-run means affect cattle sales and, to a lesser extent, sales of small livestock.

6 Saving out of transitory profits

We now investigate by which means farm households absorb adverse transitory income shocks. We start by motivating the empirical model. The PNGT data allow us to investigate the relationships between transitory income and consumption expenditure directly. Using the EPA data, we then consider saving in the form of grain stocks and livestock.

6.1 Empirical framework

The empirical model that we consider is

$$s_{it} = \alpha + \beta y_{it}^P + \gamma y_{it}^T + \delta \sigma_i^y + \nu_{it}, \tag{6.1}$$

where s_{it} denotes savings of household i in period t in the form of some stock (i.e. net purchases of livestock or the accumulation of grain stock), y_{it}^P and y_{it}^T are the permanent and transitory components of total income y_{it}, respectively, and σ_i^y is the variance of the household's income.

As noted by Paxson [1992], a savings equation that is linear in permanent income, transitory income, and the variance of income such as (6.1) can be obtained by maximizing a utility function that is strongly inter-temporally separable and has either quadratic or constant absolute-risk-aversion (CARA)-form. A linear specification also has the advantage that the coefficients have an easy interpretation: β and γ denote the propensity to save out of permanent and transitory

[13]A regression without these two variables but using only the the smaller sample excluding observations in 2004 reveals that this is not due to the inclusion of lagged stocks and area cultivated.

income, respectively: an increase in transitory crop profit by one CFA is associated with an increase in savings by γ CFA. While we remain agnostic about the degree of saving out of permanent income, we are interested in obtaining an estimate of γ, the propensity to save in different forms out of transitory income. The challenge is, of course, that both y^P and y^T are unobserved in practice. However, there are several ways in which γ might still be identified. As is common in the literature [Paxson, 1992, Fafchamps et al., 1998, Kazianga and Udry, 2006, Carter and Lybbert, 2012], we rely here on unanticipated variation in the level of rainfall in order to isolate the component of rainfall that is orthogonal to permanent income.

First, write $y_{it}^T = y_{it} - y_{it}^P$ such that

$$s_{it} = \alpha + \gamma y_{it} + (\beta - \gamma) y_{it}^P + \delta \sigma_i^y + \nu_{it}. \tag{6.2}$$

De-meaning this equation allows us to purge $\delta\sigma_i^y$. Write

$$\tilde{s}_{it} = \gamma \tilde{y}_{it} + (\beta - \gamma)\tilde{y}_{it}^P + \tilde{\nu}_{it}, \tag{6.3}$$

where the tilde simply denotes de-meaned variables. This is of course equivalent to introducing a set of household-fixed effects. Equation (6.3) relies solely on variation across time for identification.

Note that if permanent income were (close to) constant over time, an assumption that seems defendable in a setting where there is little technological progress [Deaton, 1992], we would actually also have purged permanent income from the equation just by the virtue of allowing for household-fixed effects.[14] If, however, permanent income is changing, IV techniques can be applied in order to estimate γ consistently. In practice, instrumenting is often found to safeguard estimates from attenuation bias due to measurement error. We will return to this issue below.

Allowing $(\beta-\gamma)\tilde{y}_{it}^P$ to be absorbed into the error term, γ can be estimated provided a suitable instrument is available that is correlated with changes in transitory income yet uncorrelated to changes in permanent income. Rainfall levels, conditional on household-fixed effects, are both relevant in the first stage and exogenous in the second. First, rainfall has been shown to be an excellent predictor of farm profits in the WASAT region. For instance, Carter [1997] shows that about half of the variation in crop profit in the ICRISAT data is accounted for by rainfall variability. While weak instruments are known to potentially result in large biases [Bound et al., 1995], Stock and Yogo's (2005) results from Monte Carlo Simulations provide guidance as to how strong instruments should be at the first stage.

The key assumption is that rainfall conditional on controls and household-fixed effects has no effect on savings other than through its effect on crop profit. There are two particular circumstances in which this assumption is violated that are tested routinely in the literature [e.g. Paxson, 1992, Fafchamps et al., 1998]. First, if there was a common trend in rainfall over time,

[14] In his work on consumption smoothing and saving in Côte d'Ivoire, Deaton [1992] assumes that incomes follow a stationary process. He cites very little real economic growth in rural areas in decades prior to his study in justification of that assumption, an argument that arguably applies to Burkina Faso in the mid-2000s.

it would seem likely that permanent income would also be trending into the same direction. Rainfall would thus be correlated with the error term which includes permanent income—see equation (6.3). While this could easily be remedied by considering only rainfall conditional on households-fixed effects *and* year-fixed effects—something that we will do below—we can also test for trends in rainfall data collected at eight rainfall stations across Burkina Faso that stretch back to the early 1970s. Results are reported in Appendix B. Since we find no evidence for linear trends in these data, we conclude that including a common time trend is not necessarily warranted. This result is in line with Fafchamps et al. [1998] who find no evidence for a trend over long stretches of their rainfall data.

Second, if rainfall were serially correlated, current deviations from long-term means would contain information on deviations in the future. If the AR(1)-parameter was positive and households were aware of this, they would reason that the likelihood of a bad rainfall-year increases following a bad year. This could lead them to hold on to buffer stocks. In fact, Deaton [1990] shows that serial correlation in the income-generating process will decrease the viability and desirability of precautionary saving. Also in appendix B, we show that there is no evidence for serial correlation in rainfall.

Our empirical strategy shares key ideas with approaches found in other studies in the literature but there are also some important differences. Fafchamps et al. [1998], Kazianga and Udry [2006], and Carter and Lybbert [2012] rely on an empirical strategy originally advanced by Paxson [1992] that proceeds in two steps: first, a regression model for crop profit is specified. This regression typically includes household and farm characteristics, as well as rainfall and interactions of rainfall with farm characteristics on the right hand-side. In addition, this regression typically includes household-fixed effects and, in some cases, village-year-fixed effects [e.g. Carter and Lybbert, 2012].

Second, crop profit is decomposed into its permanent, transitory, and unexplained component based on the resulting estimates: household-fixed effects and household- and farm-characteristics multiplied with the respective estimates account for permanent income, while transitory income is determined by rainfall and its interactions and, if included, village-year-fixed effects.[15] Finally, the residuals are taken to be unexplained income. Predicted income components are then used on the right hand-side of a regression of saving together with household-fixed effects and a set of controls. The functional form is similar to the one we start with in equation (6.1) in that it relates savings to permanent and transitory income in levels. The difference is that income variability does not appear on the right hand-side and that, instead, unexplained income is also included.

The first step in this strategy amounts to estimating a first stage-equation in an IV-framework manually. Our approach is very similar in terms of the main idea, the reliance on rainfall as an

[15] While Carter and Lybbert [2012] treat the village-year-fixed effect as part of transitory income, Kazianga and Udry [2006] maintain that it would be a mistake to do so as some of it may actually relate to permanent income changes. They do not consider village-year-fixed effects but include the main effect of village-level rainfall in their regression equation.

instrument for income in order to identify the effect of transitory income changes. In particular, the assumption that rainfall conditional on household-fixed effects is both unrelated to permanent income and the error term in the second stage is crucial in both frameworks.

In our view there are, however, two advantages of our framework: first, there is no need for us to adjust standard errors in the second stage. Carter and Lybbert [2012], for instance, bootstrap the two steps outlined above in order to account for the fact that the regressors in the second stage depend on estimated quantities. Second, it is unclear how to interpret coefficients on unexplained income. Finally, we can directly conduct tests of over-identifying restrictions relying on the general method of moments (GMM)-framework provided that more than one instrument is available for transitory income. We return to this this in section 7.

6.2 Consumption

We first investigate whether households adjust consumption in response to shocks to transitory income. Table 5 reports results from regressing consumption expenditure on crop profit, where both variables are in real terms and the latter is instrumented using rainfall levels. All models reported in this section include a full set of household-fixed effects and additional controls including the age of the household head, her age squared, her gender, and the number of family members in a total of eight gender-age cells as in section 5. Standard errors are clustered at the level of villages and reported in parentheses.

Columns (1) and (2) of table 5 report results from simple OLS-estimation without and with a year-2005-dummy, respectively. Since only two years of data are available from the PNGT dataset, this is equivalent to running the regression in first-differences.

[Table 5 about here.]

The estimates of the effect of transitory crop profit in columns (1) and (2) both suggest that for each increase in transitory per capita crop profit by 1,000 CFA, consumption per capita increases by about 100 CFA. While these coefficients are significantly different from zero, they are much lower than comparable estimates in the literature. Kazianga and Udry [2006], for instance, report estimates in the range of 0.50–0.75.

IV estimates based on 2SLS are presented in columns (3) and (4). Estimates are computed using Schaffer's `xtivreg28`-command in Stata [Schaffer, 2012]. We also report Cragg-Donald-F-statistics [Cragg and Donald, 1993] which can be compared to critical values provided by Stock and Yogo [2005]. Our instrument passes the weak identification-test only in the specification that does not include a year-2005-effects.[16]

These estimates are greater than OLS estimates by an order of magnitude. The point estimate in column (3) is at the upper end of the range reported by Kazianga and Udry [2006]. It suggests that more than three-fourths of transitory income is transmitted to consumption. However, since we only have two consecutive years of data for, standard errors on these coefficients are

[16]The critical value for an IV bias relative to the bias in OLS of at most ten percent is 7.03 in this case.

comparatively large. Based on OLS estimates, one could get the impression that households achieve a high degree of consumption smoothing. As mentioned above, we believe that the difference is due to measurement error in the main explanatory variable, crop profit, a problem that is often compounded when identification relies solely on within unit-variation. Similar discrepancies between OLS and 2SLS estimates with income as the main explanatory variable in a fixed effects-specification have been encountered recently by Bengtson [2010]. The problem has also been discussed in the literature on demand for calories [see Deaton, 1997].

At the same time, the standard errors on these coefficients are also substantially larger. In fact, while the estimate reported in column (4) is of a similar magnitude, we cannot reject that the coefficient is zero. The finding is not surprising considering the pattern of rainfall during harvests prior to the PNGT surveys (i.e. figure 2). Rainfall varies only at the province-level and over time. Considering only rainfall in 2003 and 2004, i.e. rainfall that drives crop profit reported by PNGT households during the lean seasons of 2004 and 2005, slightly more of half of the variation in rainfall is accounted for by province-fixed effects. However, if we also include year-fixed effects, roughly 95 percent of the total in rainfall is captured. Thus, our instrument lacks predictive power when both sets of fixed effects are included. It is important to note that this is not so much of a problem when we analyze EPA data as year-on-year changes in rainfall are much less uniform during later years. Province- and year-fixed effects explain only about 80 percent of the variation in rainfall if we consider the years 2004, 2005, and 2006. We also report results from estimating the reduced forms without and with the year-2005-effect in columns (5) and (6), respectively. Consistent with collinearity between rainfall and the year-fixed effect, the positive and statistically significant effect of our instrument on consumption expenditure vanishes if we include a year-2005-effect.

6.3 Grain stocks

Next, we investigate the importance of savings in the form of grain stocks in *ex-post* consumption smoothinig. This is done by regressing subsequent changes in grain stocks (i.e. forward first-differences), valued in real CFA, on crop profit and household-fixed effects and instrument crop profit again with rainfall levels. Hence, of the four years of data from 2004 to 2007 in the EPA surveys, the last contributes only one observation on grain stock levels required to construct the first-differenced dependent variable associated with crop profit in 2006. Results are reported in table 6. Again, all regression include additional control variables (not reported) that capture households' demographic make-up. In this case, we also include year-fixed effects in all regressions.

Before considering results from OLS and IV estimations in columns (1) and (2), respectively, note that in contrast to our findings for consumption, the reduced form-estimate indicates that rainfall predicts changes in grain stocks (columns (3)). The coefficient is positive and significantly different from zero at the one percent-level despite our inclusion of year-fixed effects. Since these results are based on EPA data, more time periods are available and the number of households observed in each year is greater. As a result, the Cragg-Donald F-statistic reported in column (2) of table 6 indicates that the partial correlation between crop profit and our instrument is sufficiently high [Cragg and Donald, 1993].[17]

The result from OLS is reported in columns (1) and from IV in column (2). Again, the difference is large: while both coefficients are significant at least at the five percent-level, the IV-estimate is larger by an order of magnitude. As noted above, this is likely due to attenuation bias that is a result of measurement error in the independent variable. The IV-estimate suggests that grain storage plays an important role in *ex post*-consumption smoothing: households absorb approximately one-fourth of transitory crop profit by adjusting grain stocks. This is in line with findings reported in Kazianga and Udry [2006] for Burkina Faso during the early 1980s and Udry [1995] for northern Nigeria.

[Table 6 about here.]

6.4 Livestock

We now turn to savings in the form of livestock by regressing net purchases of livestock on crop profit. The empirical set-up is the same as in the 6.2 and 6.3. The first three columns of table 7 report results from specifications that mirror those in table 6. The coefficient in the OLS regression reported in column (1) is statistically significant yet close to zero. Again, measurement error is suspected. The IV estimate in column (2) is larger by a factor of about ten yet insignificant at conventional levels of significance. It suggests that 20 percent of transitory crop profit is saved in the form of livestock. Finally, the reduced form coefficient is significant only at the ten percent-level, suggesting a weak partial correlation between rainfall and net purchases of livestock. Taken together, there is little evidence of significant savings out of transitory crop profit in the form of livestock.

[Table 7 about here.]

These negative findings are despite the fact that most households' holdings of livestock would have allowed them to completely absorb the income shock caused by adverse weather conditions. If we define the shock as the negative deviation in crop profit from its four-year-mean between 2004 and 2007 and compare this for 2004 to livestock holdings at the end of the lean season in 2005, we find that in each region more than half of the households disposed of enough livestock to compensate for the entire shortfall. In seven out of the 13 regions and including in the Sahel more than 80 percent of the households in our sample had sufficient means in the form of livestock.

Our findings here so far are in line with the literature as discussed in 2.1. In particular, Fafchamps et al. [1998] find that at most 30 percent and probably closer to 15 percent of income shortfalls are compensated via livestock sales. The latter is close to the point estimate reported

[17] The test statistic exceeds the critical value, 16.38, reported by Stock and Yogo [2005] that corresponds to a bias in the IV estimate relative to the OLS estimate of ten percent.

in column (2). While we cannot reject the hypothesis that the coefficient on crop profit in column (2) is equal to 30 percent, it is also insignificantly different from zero.

We also test whether poor and rich households differ in their propensity to save transitory income in the form of livestock by interacting crop profit with different binary indicators of livestock holdings in 2004. Our choice of indicators is motivated by recent contributions to the literature. Based on Hansen's (2000) threshold estimator, Carter and Lybbert [2012] find that households during the drought that Burkina Faso experienced in the early 1980s pursue consumption smoothing by stepping up net sales of livestock. The estimates of the threshold they report occurs at roughly 15 and 25 cattle equivalents, depending on whether household-fixed effects are included. We also interact crop profit with an indicator of whether the household uses animal traction in agricultural production.[18]

Results reported in columns (4)–(6) suggest that there are no significant differences between farmers differentiated by livestock holdings and animal traction. The coefficients on interaction terms are insignificant and the hypothesis that both the coefficient on crop profit and the one on the interaction term are jointly zero cannot be rejected at conventional levels of significance in all three specifications. We thus cannot reject the null of no heterogeneity along these dimensions. Note, however, that in this case we instrument with rainfall and its interactions with the indicator of livestock holdings. We thus have two instruments per regression which, in the case of animal traction, seem weak based on the Cragg-Donald F-statistic.[19]

The findings from savings regressions differ substantially from those obtained considering only the number of sales in section 5.2. As noted above, however, one concern is comparability: since households that are never observed selling livestock do not contribute to the conditional log likelihood in the case of FEP estimation, estimation in that section were based on subsamples that are potentially selective. We therefore also investigate savings behavior for the subset of households that owned either cattle, sheep, or goats after 2004 (column (7)); those that report positive sales in any of these categories between 2005 and 2007 (column (8)); and those that report postive sales of cattle over this period (column (9)). The last subsample corresponds closely to the subsample used in column (2) of table 4. While all three estimates of the propensity to save in livestock are positive and have the expected sign, they are insignificant at conventional levels.

Taken together, the above regressions show that cuts to consumption and adjustments to grain stock go a long way in explaining how households absorb transitory crop profit. For instance, if we would combine our estimates in columns (2) and (4) of tables 5 and 6, respectively, we would already be able to account for all of the change in transitory income.

[18] Most household surveys that cover rural Burkinabe households, including the ones used in this study and the ICRISAT data used by Fafchamps et al. [1998] and many others, are stratified by whether or not households use animal traction in agricultural production. Kazianga and Udry [2006] explain that this reflects the common belief that there are systematic differences between households with and without animal traction. Acquiring animals for traction possibly requires the disbursement of large amounts of cash or access to credit such that only well-off farmers would have access to that technology. It thus seems reasonable to assume a different response of households to income shocks differentiated by levels of technology.

[19] The critical values in this case are 7.03 and 4.58 for a ten and a 15 percent-relative bias, respectively [Stock and Yogo, 2005].

At least some households might have had the opportunity to resort to other sources of income in order to compensate for output loss due to adverse rainfall. Transfers (including in-kind transfers, remittances, and aid), revenue from non-agricultural businesses, wages from off-farm employment, and the use of credit might play a role in households' risk management. Reardon et al. [1988], for instance, show that the share of food aid accounted for 60 percent of transfers received by the poorest households in the Sahelian region of Burkina during the 1984 drought. Reardon et al. [1992] argue that non-farm activities of households in the same data were an important means of *ex ante* income diversification accounting for 30–40 percent of total income. A more recent study by Lay et al. [2009] that investigates patterns of income diversification in Burkina Faso between 1994 and 2003 concludes that the extent of income diversification stagnated. This issue is further investigated in appendix D. We find no evidence for a significant negative relationships between crop profit and alternative forms of income.

7 Rainfall, prices, and quantities

7.1 Evidence from province-level price regressions

In essence, our results above replicate the puzzle reported in the literature, albeit in a more pronounced way: in section 4, we have shown that there was indeed a rainfall-induced increase in livestock sales with no off-setting increase in purchases and that, if directly asked about the reason for sales, households cite the need to finance food purchases. This finding differs from what Fafchamps et al. [1998] find for aggregate sales at the village-level. At the same time, we find no evidence for consumption smoothing via asset sales in the preceding section.

One possible explanation for this apparent puzzle relates to price adjustments in the wake of adverse weather shocks. If prices for livestock decline in response to a rainfall-induced increase in market supply, the effect of rainfall on net purchases in monetary terms as investigated in 6.4, will be attenuated. To examine whether such an explanation for the puzzle is plausible, we investigate how prices for livestock react to changes in rainfall. We do so by regressing log prices for cattle, sheep, and goat on log rainfall. The resulting coefficient can thus be interpreted as the rainfall elasticity of livestock prices.

Our data allow us to include both province- and year-fixed effects in our regressions. The set-up is thus the same as in (5.1) only that prices are now on the left hand-side of the equation. The former account for province-specific differences in market structures that affect prices and are potentially correlated with levels of precipitation. The latter account for common shifts in demand and supply of livestock.

Prices are unit values calculated from the EPA data and then averaged within each province. The precision of these averages will depend on the number of sales reported. Hence, there is an econometric argument for weighting each province-year observation in the resulting panel dataset in proportion to the number of observations for which unit values could be calculated. However, this would give a higher weight to provinces in which many sales are reported, i.e. in which markets are well-functioning, potentially biasing our results towards a lower price response. Running both weighted and unweighted regressions, we find that the differences between the estimated elasticities are only minor. Therefore, we only report the former.

[Table 8 about here.]

Results are reported in table 8, where we consider both nominal (columns (1)–(3)) and real prices, i.e. prices divided by our CPI discussed in section 3 (columns (4)–(6)). The estimates reported are positive and statistically significantly different from zero for cattle but not for other types of livestock. The elasticity of the nominal cattle price is 0.30 percent and is significantly different from zero at the five percent-level. Estimated elasticities are also positive but lower for sheep and goat at 0.15 and 0.10 percent, respectively. In both cases, however, we cannot reject that they are zero at conventional significance levels. Estimates are very similar when real prices are considered (columns (4)–(6)).

These results are in line with Fafchamps and Gavian [1997] who find that livestock prices respond to droughts in Niger, a country neighboring Burkina Faso to the northeast. Several authors have also commented on the potential importance of general equilibrium effects in the context of consumption smoothing more broadly [Fafchamps et al., 1998, Zimmerman and Carter, 2003]. For instance, Fafchamps et al. [1998] point out that in the extreme case in which villages constitute closed markets, net sales of livestock will necessarily total zero and that prices will adjust downward accordingly. However, in section 5 we found no evidence of a positive elasticity between rainfall and purchases, suggesting that livestock was sold to economic agents not covered by our sample of rural farmers.

7.2 Rainfall, prices, and exclusion restrictions

The regression results concerning prices and rainfall potentially threaten the identification strategy of microeconometric investigations such as the one reported in section 6. The typical estimation equation that relates savings to permanent and transitory income (e.g. (6.1)) on which these investigations are based is derived from partial-equilibrium models, i.e. prices are taken to be exogenous. If rainfall affects prices, however, and, at the same time, local prices are important for the household's decision in which form to make provisions for the future—whether by investing in livestock or other assets—rainfall is potentially correlated to the error term in a specification such as (6.3). Hence, the exclusion restriction would no longer hold.

One way to test this is to include livestock and other prices on the right hand-side of the regression equation of interest. This amounts to testing an exclusion restriction. We are not suggesting that the resulting point estimates are in some way more valuable in judging whether households rely on livestock to smooth consumption. The relative price of livestock is held constant in these regressions. The hypothetical question of how household would react to transitory changes in crop profit *conditional on real livestock prices* is generally not of interest. Instead, we are solely interested in whether the identification strategy is valid. A significant coefficient on the log relative price of cattle should be interpreted as a sign that the exclusion restriction does not hold.

Moreover, the coefficients on prices are difficult to interpret. One would probably expect a negative sign on nominal livestock prices and a positive sign on the CPI as livestock purchases are less attractive if the price for cattle is high conditional on prices of other goods. Again, our main interest here lies with whether or not we can reject an important role of prices in households' decisions over whether and how to make provisions for the future.

[Table 9 about here.]

Results from a regression that includes the log of the nominal price of cattle and the log CPI on the right hand-side are reported in columns (2) of table 9. For comparison, we also report results from a regression without these prices in columns (1). This model corresponds to the one in column (4) of table 7 and is reported solely for comparison.[20] We cannot reject that the coefficients on log price of cattle and log CPI in column (2) are both individually and jointly zero in column (2).

One might also test exclusion restrictions directly based on the Hansen's J-test. However, this requires more than just one instrument; the model needs to be over-identified. One would then be able to estimate the model using efficient two-step GMM and test formally, based on Hansen J-test, whether excluded instruments are appropriately independent of the error process. One way of generating such additional over-identification restrictions is to specify a set of instruments as in Holtz-Eakin et al. [1988], where each time period of our panel is instrumented separately with rainfall and all off-diagonal elements of the instrument matrix are set to zero.[21] We thus have a set of three instruments that convey information about rainfall in 2004, 2005, and 2006, respectively.

A second option is to allow the rainfall to affect crop profit differently across Burkina Faso's 13 regions by specifying separate instruments for each region. The one column of the instrument matrix associated with a particular region then has all zero-entries except for those rows referring to observations in that particular region. This second approach results in a total of 13 moment restrictions that one can test. Both approaches convey slightly more information. However, it is the second approach that we think conveys more information as rainfall likely affects agricultural production differently across Burkina's regions. It also resembles the approach taken in the literature more closely, in which rainfall is typically interacted with farm characteristics. In both cases, the additional moment conditions will be perfectly valid if rainfall itself meets the exclusion restriction.

Under over-identifying restriction, Hansen's J-statistic can be used to gauge whether the

[20] The only difference is that we exclude households in three provinces, Boulkièmdé, Tapoa, and Loroum, in one year, 2005, for which there are no reports on livestock sales in 2005 and hence no lean season prices that we could calculate for 2004/2005. However, the resulting estimate is broadly in line with that reported in table 7.

[21] For the authors of the paper cited, such instrument sets are sometimes referred to as 'HENR'-instruments.

model is correctly specified.[22] It is consistent in the presence of heteroskedasticity and serial correlation. It should be noted, however, that the test is really a general specification test. If it is rejected, either the orthogonality conditions or other assumptions of the model or both are likely to be false [see Hayashi, 2000, pp. 198–201 and 217–218, for details]. In any case, a rejection will cast doubt on the appropriateness of the instruments employed.

Results from two-step efficient GMM-estimation are reported in columns (3) and (4). The degrees of freedom, χ^2-statistic, and p-value reported at the bottom of the table all refer to Hansen's J-statistic. The test statistics are sufficiently close to zero so that we cannot reject that our instruments are jointly valid (p-values of 0.49 and 0.73, respectively).

Taken together, the results presented in this section potentially explain the puzzling finding in the literature of no consumption smoothing via sales of livestock. In particular, two effects seem to be at work that to some extent have a tendency to cancel each other out. Rainfall affects crop profit positively. If during droughts prices for livestock drop as a result of increasing sales, net purchases, measured in real currency units, will tend to show less of a tendency to vary with rainfall. While this potentially explains a lack of association between rainfall and net purchases, it also calls into question the appropriateness of rainfall as an instrument for crop profit in a regression of savings on income as relative prices are likely to be important determinants of the decision to purchase livestock. However, based on an extended set of exclusion restrictions that rely on rainfall interacted with either year or region, we cannot reject that our instruments in a regression of net purchases on crop profit are valid.

8 Conclusion

The present paper re-visits a puzzle stated in the empirical literature on optimal saving in developing countries in the absence of formal insurance mechanisms. While livestock holdings were traditionally hypothesized to constitute the main means of households to smooth consumption in the wake of shocks, empirical work in this area usually finds no evidence for a significant relationship between the *monetary value of net livestock sales* and transitory income. On the other hand, studies with a focus on the *number of sales* often find evidence for a sizeable increase in sales in response to adverse shocks.

The event we study is a severe drought in the northern provinces of Burkina Faso that occurred in 2004 and a subsequent return to normal levels of rainfall. Our empirical investigation is based on two household-level datasets that provide ample information on consumption, grain stocks, and transactions of livestock.

Our results can be summarized as follows: we find that rainfall positively affects sales of livestock with no off-setting effect on purchases at the level of provinces. A similar increase in sales in response to adverse rainfall is observed at the household-level. Reportedly, extra

[22] Hansen's J-statistic is χ^2-distributed with degrees of freedom equal to the degrees of over-identification—two and twelve with the instrument sets described above.

sales were a reaction to an increased need to finance food purchases. However, we find no evidence for precautionary savings in the form of livestock—neither among the asset-poor, nor among the asset-rich. We also find evidence for a significant transmission of transitory income to consumption expenditure. Savings in the form of grain stocks, on the other hand, play an important role in *ex-post* coping.

We then show that cattle prices at the province-level vary positively with rainfall and our estimates suggest that the elasticity is high. This finding is consistent with a general equilibrium-effect that adversely affects revenues from livestock sales in times of harvest failure, rendering precautionary saving in the form of livestock a costly strategy to smooth consumption. While this finding might cast doubt on the appropriateness of rainfall as an instrument in econometric studies of optimal saving, we cannot reject that rainfall is correctly excluded in regressions of savings in the form of livestock.

In terms of policy implications, our findings underline the lack of market integration in rural Burkina Faso witnessed by massive price changes and inter-regional discrepancies over the course of the 2004 drought. These imply that savings in forms other than grain stocks are subject to major price risks. An increased focus on integrating livestock markets (e.g. by investing in road infrastructure) would potentially mitigate welfare losses incurred by farm households during episodes of economic distress. Ultimately, of course, appropriate insurance mechanisms should be put in place (e.g. rainfall insurance) that would allow households to stabilize incomes *ex ante*.

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A Imputation of Prices

We rely upon predicted crop prices based on a regression model fitted to PNGT data based on price data from Ouagadougou which is available for each month. Denote the price for crop c in province p in year t and month j (May or November) p_{pctj} and the contemporaneous price in Ouagadougou $p_{ctj}^{Ouag.}$. The model can then be written

$$\ln(p_{pctj}) = \phi_p \ln(p_{ctj}^{Ouag.}) + \rho_p + \gamma_c + \epsilon_{pctj}, \tag{A.1}$$

where ϕ_p is the province-specific elasticity of price with respect to capital city-price, ρ_p is a province-fixed effect, and γ_c is a crop-fixed effect. We allow the price-price-elasticity ϕ to vary across provinces as we expect different degrees of integration of local markets. The resulting model has an R^2-statistic of 71.7 percent and an adjusted R^2-statistic of 63.5 percent.

[Figure 9 about here.]

Figure 9 plots predicted prices against actual observed prices. While there are some outliers (i.e. deviations from the 45-degree-line) in the sense that the actual price was much higher than the predicted price, the overall fit seems reasonable. Figures 10 and 11 plot time series of predicted prices and prices in Ouagadougou for each province separately for sorghum and millet, the main staples in Burkina Faso, respectively. Also displayed are the actual province-level price observations from the PNGT data. Regional market prices are added for comparison. As one would expect for locally produced goods, the movement of our predicted prices track the price movements in Ouagadougou closely yet prices are lower and less volatile in the provinces.

[Figure 10 about here.]

[Figure 11 about here.]

In a second step, we regress log prices from the three PNGT datasets on capital city-log prices for Sorghum and Maize and a set of province-fixed effects for all remaining crops separately. These crops and the respective R^2-statistics are rice (40.3 percent), groundnut (41.3), cowpea (57.2), wandzou (55.9), sesame (52.6), and fonio (83.9). Figure 12 plots predicted against actual prices. Finally, prices for cotton are fixed as the state is the monopoly buyer of cotton.

[Figure 12 about here.]

B Levels of Rainfall Across Burkina Faso, 1970–2009

In this appendix we report results from analyzing time series data from eight rainfall stations across Burkina Faso for years prior to our study period. For the validity of our instrument in the empirical application of this paper, it is crucial that levels of rainfall neither exhibit significant trends over time nor that conditional on the long-term mean past observations provide any information about future rainfall. In that case, deviations of rainfall from its long-term mean will be orthogonal to permanent income; income associated with good rainfall will be transitory [see also Deaton, 1997, p. 290].

There is a long-standing tradition in development economics of using rainfall variability in order to distinguish between the effects of transitory and permanent income. Wolpin [1982] uses information on historical regional rainfall for rural Indian households assuming that households residing in regions with favorable weather conditions have higher permanent income. Paxson [1992] shows that the deviation of rainfall from its local mean is serially uncorrelated and thus unpredictable. It is therefore uncorrelated with permanent income yet in the context of unirrigated agriculture a strong predictor of transitory income.[23] More recent examples relying on rainfall in the WASAT region in order to compute transitory income include Fafchamps et al. [1998], Kazianga and Udry [2006], and Carter and Lybbert [2012].

The data analyzed here come FAO's *Climate Impact on Agriculture*-website[24] and contain information on monthly rainfall collected by eight weather stations. To prepare the series for analysis we first aggregate rainfall at the level of years, retaining only station-year-observations for which observations in each month were available. In a second step, we discard all stations for which we have less than 25 years of observations. The final time series are depicted in figure 13.

[Figure 13 about here.]

The location and elevation of these weather stations is reported in panel A of table 10, where weather stations are sorted from left to right by latitude from south to north. Given the geographical locations of weather stations which capture much of the agro-climatic differences across Burkina Faso, the data allow us to make statements about rainfall patterns in very different parts of the country and that the coverage in terms of the countries' total area is comprehensive.

First, we subject the series to simple tests for linear and exponential time trends. We regress rainfall and log rainfall on years for each series separately. Results of this exercise are reported in panel B of table 10. There is only one coefficient that is statistically significant at the ten percent-level, namely for the series from Ouagadougou. Second, we test for serial correlation. Results from the Breusch-Godfrey-tests [see Godfrey, 1978, Breusch, 1979] are reported in panel C. The null hypothesis of no serial correlation is not rejected for any of the eight series.

Taken together, we conclude that there is no evidence that deviations of rainfall from its long-term mean are predictable based on observation of rainfall levels in the past. Once can thus be confident that the deviations from long-term means (i.e. rainfall levels *conditional on household-fixed effects*) in rainfall levels are an appropriate instrument in the sense that they are orthogonal to permanent income.

[23] She argues that "[i]n order to construct transitory rainfall variables [...], one needs to know how current rainfall deviates from its expected value. If rainfall were serially correlated across years, one would have to forecast the expected value of rainfall for each region in each survey year" [Paxson, 1992].

[24] http://geonetwork3.fao.org/climpag/agroclimdb_en.php; accessed March 10, 2014.

[Table 10 about here.]

C Characteristics of Households Selling Livestock

Table 11 tabulates means and standard deviations for households stratified by whether or not they have reported sales of cattle and of small livestock at any time in 2004–2007. Only about 45 percent of our households report sales of cattle. We also calculate differences and conducted regression-based t-tests (clustered standard errors in parentheses). We see that cattle-selling households are older, more likely to be headed by males, have more members, and are more likely to be residents of Burkina's Sahel region. The differences in average herd sizes is substantial: cattle-selling households own on average ten heads of cattle more than non-selling households. The picture that emerges for small livestock is very similar except that the proportion of households that has never sold small livestock is only about 20 percent.

[Table 11 about here.]

D Off-farm Income and Transfers

This appendix considers income diversification and substitution between different sources of income. We show that alternative income sources are unlikely do not play an important role in households' risk management in our sample. We employ the PNGT data to that end as it records (gross) incomes from sources other than farming and livestock in much detail. Our results suggest that, first, the share in the total of income other than farming and livestock herding is small in most regions and that, second, income from these sources is positively correlated with crop profit over time.

In addition to crop profit and net sales of livestock as defined above, our data allow us to calculate (gross) revenues from households' non-cropping enterprises, net transfers, wages earned, and use of credit. However, crop profits account for more than 50 percent of the total in eleven out of 13 provinces. Only in the Centre-Nord region and in the Sahel is the share smaller. Trading in livestock is important in these two regions accounting for slightly less than one-fourth of the total. Revenues from own businesses are the second most important source of income according to this graph. However, as noted above, we are likely to overestimate their importance. Net transfers and wages earned working outside the family farm are negligible in comparison.

To investigate whether alternative sources of income become important in case of an adverse shock to crop output, we run regressions of these alternative income sources, net transfers received, revenue from own business, and wages earned, on crop profit. The results are reported in table 12. Since we are interested in partial correlations once time-invariant variables are controlled for, all regressions include household-fixed effects.[25] Every other regression also includes

[25] Since only two years of data are available from the PNGT dataset, this is equivalent to running the regression in first-differences.

a year-fixed effect and further controls that capture the households demographic make-up.[26] All variables are measured in 1,000 CFA.

[Table 12 about here.]

Results reported in table 12 indicate that there is no alternative source of income that would allow households to smooth consumption *ex post*. While our data do not allow us to rule out that revenues from own business are an important source of income, there is no evidence for a negative correlation between this source of income and crop profit. In fact, the coefficient on crop profit is positive and significant in the OLS regression (column (1)), suggesting that if at all, revenues from own business will decline if crop profit does. As noted by Fafchamps et al. [1998], the finding is also consistent with anecdotal evidence reported in Sen [1981] who argues that droughts often lead to a collapse in the demand for local services and crafts.

As expected given the low share of net transfers and wages and total income, the coefficients here are insignificant, both statistically and in terms of magnitude (columns (3)–(6)). We hence conclude that net transfers and off-farm labor play no important role in managing risks *ex ante* for households in our sample. Our findings for credit use are similar in that the coefficients are positive (columns (7) and (8)).

[26] We include the number of households members in certain age groups and by sex: the number of children below the age of seven, the number of adolescents between the age of seven and 14, the number of adults (15–64), and the number of elderly (65+)—all separately by gender for a total of eight variables.

Table 1: Descriptive statistics: means and standard deviations by year.

	EPA				PNGT		
	2004	2005	2006	2007	2003	2004	2005
Household size	10.95	10.97	10.92	10.95	–	9.21	10.10
	(6.74)	(6.85)	(6.94)	(6.83)		(5.79)	(6.30)
Age of HH head	50.99	51.27	51.53	51.77	–	48.26	49.21
	(14.90)	(14.85)	(14.47)	(14.60)		(15.50)	(15.32)
Mean age of HH members	22.37	22.70	23.02	23.14	–	22.31	22.31
	(7.96)	(8.52)	(8.61)	(8.56)		(8.93)	(8.71)
Cultivated area (ha)	4.03	4.15	4.04	4.09	–	5.31	5.09
	(3.37)	(3.58)	(3.47)	(3.48)		(5.08)	(5.41)
Agg. grain output (kg)	2,233.43	2,955.98	2,861.26	2,566.60	1,716.10	1,206.49	–
	(2,388.95)	(2,968.61)	(2,870.08)	(2,914.91)	(1,825.60)	(1,345.96)	
Crop profit (1,000 CFA)	486.63	572.81	567.36	463.56	322.43	273.43	–
	(547.04)	(607.03)	(575.17)	(551.02)	(430.60)	(340.09)	
Agg. grain stock (kg)	324.61	116.04	283.23	301.96	–	–	–
	(753.25)	(408.43)	(625.40)	(690.89)			
Herd size (Cattle equiv.)	8.13	7.67	7.90	7.53	–	4.67	4.79
	(20.35)	(18.35)	(22.55)	(18.78)		(11.73)	(12.36)
Observations	2,364	2,364	2,364	2,364	1,492	1,492	1,492

Standard deviations reported in parentheses. To calculate tropical livestock units (TLUs) we follow Jahnke [1982]: cattle enters with a weight of unity while sheep and goats enter with a weight of one-seventh. TLUs are thus 'cattle equivalents.'

Table 2: Livestock balance for cattle, sheep, and goats, 2004–2007.

	2004	2005	2006	2007
A. Cattle				
% of households owning livestock	0.60	0.59	0.60	0.58
% of households reporting sales	0.22	0.23	0.23	0.22
# of animals owned	6.04	5.76	5.97	5.64
# of animals sold	0.54	0.68	0.54	0.58
# of animals deceased	0.48	0.49	0.40	0.37
# of animals slaughtered	0.03	0.21	0.03	0.02
# of animals purchased	0.34	0.38	0.30	0.31
# of animals born	1.31	1.29	1.17	1.07
B. Sheep and Goat				
% of households owning livestock	0.85	0.82	0.83	0.83
% of households reporting sales	0.55	0.50	0.52	0.46
# of animals owned	14.59	13.40	13.52	13.22
# of animals sold	2.59	2.60	2.22	2.10
# of animals deceased	2.65	2.60	1.72	1.92
# of animals slaughtered	0.84	1.70	0.76	0.69
# of animals purchased	1.26	1.09	0.85	0.84
# of animals born	5.98	5.60	5.13	5.08

Based on EPA data.

Table 3: Rainfall elasticities of sales and purchases of cattle and sheep/goat, 2004–2007.

	Log quantity sold of...		Log quantity purchased of...	
	...cattle.	...sheep and goats.	...cattle.	...sheep and goats.
	(1)	(2)	(3)	(4)
Log rainfall	-0.72^{**}	-0.81^{*}	0.08	0.09
	(0.34)	(0.44)	(0.30)	(0.36)
Obs.	178	180	179	180
R-squared	0.80	0.58	0.81	0.71

Robust standard errors clustered at the province-level in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. All regressions include province- and year-fixed effects. Based on EPA data.

Table 5: Estimates of the effect of transitory crop profit on consumption expenditure (both 1,000 CFA).

	OLS		IV		Reduced form	
	(1)	(2)	(3)	(4)	(5)	(6)
Crop profit (1,000 CFA)	0.09^{**}	0.09^{**}	0.78^{**}	0.84		
	(0.04)	(0.04)	(0.34)	(0.64)		
Precipitation (mm)					0.13^{**}	-0.18
					(0.05)	(0.13)
Year 2005		-37.43^{***}		2.86		-83.95^{**}
		(13.06)		(39.86)		(34.51)
Cragg-Donald F statistic (weak identification test).						
F-statistic			11.91	1.93		
# of obs.	2,946	2,946	2,922	2,922	2,972	2,972
# of groups	1,485	1,485	1,461	1,461	1,486	1,486

Robust standard errors clustered at the village-level in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. Consumption expenditure and crop profit measured in 1,000 CFA. All regression include a complete set of household-fixed effects and additional regressors: age of the household head and age squared, the gender of the head, and the number of households members in a total of eight gender-age cells. Based on PNGT data.

Table 4: Results from conditional (fixed effects) Poisson models for the number of sales of cattle, sheep, and goat, 2004–2007.

	Cattle			Goats and sheep		
	(1)	(2)	(3)	(4)	(5)	(6)
Log rainfall	−0.69**	−0.73***	−0.75**	−0.45**	−0.25	−0.52**
	(0.27)	(0.25)	(0.31)	(0.23)	(0.26)	(0.25)
Log rainfall × I(TLUs > 15)			0.14			0.20
			(0.25)			(0.23)
Log area cultivated in $t-1$		0.07			−0.04	
		(0.08)			(0.06)	
# of animals owned in $t-1$		0.00			0.00	
		(0.00)			(0.00)	
# of animals purchased	0.02*	0.02	0.03*	0.01***	0.02**	0.01***
	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.00)
# of animals born	0.00	0.00	0.00	0.03***	0.03***	0.03***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
# of animals deceased	0.01	0.00	0.01	0.00	−0.01*	0.00
	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)
# of obs.	4,172	2,808	4,172	7,578	5,251	7,578
# of groups	1,044	937	1,044	1,902	1,759	1,902

Robust standard errors clustered at the province-level in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. All results stem from conditional (fixed effects) Poisson regressions. All regressions include year-fixed effects and further controls: the age of the household head and age squared, the gender of the head, and the number of households members in a total of eight gender-age cells (the number of males and females below the age of seven, between seven and 14, between 15 and 64, and 65 and above). Based on EPA data.

Table 6: Estimates of the effect of transitory crop profit on subsequent changes in grain stocks (both 1,000 CFA).

	OLS (1)	IV (2)	Red. (3)
Precipitation (mm)			0.08***
			(0.03)
Crop profit (1,000 CFA)	0.02**	0.26**	
	(0.01)	(0.12)	
Year 2005	38.66***	18.10	36.22***
	(3.38)	(11.57)	(4.11)
Year 2006	28.02***	8.70	28.36***
	(3.47)	(10.18)	(3.27)
Cragg-Donald F statistic (weak identification test).			
F-statistic		20.62	
# of obs.	7,071	7,071	7,092
# of groups	2,357	2,357	2,364

Robust standard errors clustered at the village-level in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. Changes in grain stock and crop profit measured in 1,000 real CFA. All regressions include a complete set of household-fixed effects and additional regressors: age of the household head and age squared, the gender of the head, and the number of households members in a total of eight gender-age cells. Based on EPA data.

Table 8: Results from province-level fixed effects-regressions of log nominal and log real prices for livestock on log rainfall, 2004–2007.

	Nominal price			Real price		
Log price of...	...cattle.	...sheep.	...goat.	...cattle.	...sheep.	...goat.
	(1)	(2)	(3)	(4)	(5)	(6)
Log rainfall	0.30**	0.15	0.10	0.28**	0.13	0.08
	(0.13)	(0.13)	(0.11)	(0.13)	(0.12)	(0.11)
Obs.	177	177	177	177	177	177
R-Squared	0.75	0.88	0.77	0.77	0.89	0.83

Robust standard errors in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. All regressions include year- and province-fixed effects. Based on EPA data.

Table 7: Estimates of the effect of transitory crop profit on subsequent net purchases of livestock (both 1,000 CFA).

	OLS	IV	red. form	IV w. interactions			Owners	Sellers	Sellers (only cattle)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Precipitation (mm)			0.06*						
			(0.03)						
Crop profit (1,000 CFA)	0.02***	0.19		0.18	−0.00	0.29	0.18	0.21	0.42
	(0.01)	(0.12)		(0.14)	(0.00)	(0.71)	(0.12)	(0.13)	(0.30)
Crop profit × +15 cattle equiv.				0.02					
				(0.20)					
Crop profit × +25 cattle equiv.					0.00				
					(0.00)				
Crop profit × traction animal						0.73			
						(2.98)			
Year 2005	−7.17	−21.33**	−7.74*	−20.97*	0.04	−69.84	−22.14**	−27.31**	−66.52
	(4.88)	(10.22)	(4.57)	(10.84)	(0.16)	(218.04)	(10.60)	(12.67)	(41.75)
Year 2006	−12.10**	−25.24**	−10.99**	−24.81**	0.16	−63.93	−26.14**	−32.91**	−64.27**
	(5.20)	(10.94)	(5.09)	(11.31)	(0.17)	(179.67)	(11.19)	(13.36)	(29.33)
Cragg-Donald F statistic (weak identification test).									
F-statistic		20.00		6.10	3.97	0.21	19.85	19.37	6.26
# of obs.	7, 027	7, 025	7, 048	7, 025	9, 428	7, 025	6, 650	5, 561	2, 783
# of groups	2, 357	2, 355	2, 364	2, 355	2, 357	2, 355	2, 230	1, 865	935

Robust standard errors clustered at the village-level in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. Net purchases of livestock and crop profit measured in 1,000 real CFA. All regressions include a complete set of household-fixed effects and additional regressors: age of the household head and age squared, the gender of the head, and the number of households members in a total of eight gender-age cells. Based on EPA data.

Table 9: Tests of over-identification restrictions: net purchases of livestock in 1,000 CFA.

	2SLS		GMM	
	(1)	(2)	(3)	(4)
Crop profit (1,000 CFA)	0.22*	0.27	0.21**	0.04
	(0.13)	(0.20)	(0.10)	(0.03)
Log price of cattle		−34.59		
		(43.42)		
Log CPI		93.94		
		(314.95)		
Year 2005	−18.94*	−28.75	−18.14**	−5.61
	(10.92)	(41.28)	(8.26)	(3.70)
Year 2006	−22.64*	−18.91*	−21.90**	−5.37
	(11.74)	(11.07)	(9.01)	(4.29)
Cragg-Donald F statistic (weak identification test).				
F-statistic	18.59	9.75	44.72	126.87
p-value	0.00	0.00	0.00	0.00
Hansen/Sargan-test (over-identification test of all instruments):				
Degrees of overidentification	0	0	2	12
χ^2-statistic	0.00	0.00	1.43	8.73
p-value			0.49	0.73
# of obs.	6,857	6,857	6,857	6,857
# of groups	2,353	2,353	2,353	2,353

Robust standard errors clustered at the village-level in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. Net purchases of livestock and crop profit measured in 1,000 real CFA. All regressions include a complete set of household-fixed effects and additional regressors: age of the household head and age squared, the gender of the head, and the number of households members in a total of eight gender-age cells. Based on EPA data.

Table 10: Analysis of station-level rainfall data, 1970–2009.

	Gaoua	Bobo-Dioulasso	Boromo	Fada-N'Gourma	Ouagadougou	Dedougou	Ouahigouya	Dori
Panel A. Location of weather station.								
Latitude	10.33	11.17	11.75	12.03	12.35	12.47	13.57	14.03
Longitude	−3.18	−4.32	−2.93	0.37	−1.52	−3.48	−2.42	−0.03
Elevation (m)	335	460	271	309	306	300	336	277
Panel B. Testing for time trends.								
Coef.: rainfall on year	0.97	−4.21	−2.04	4.06	−3.78*	0.78	4.78	−0.38
	(3.70)	(3.07)	(3.29)	(3.80)	(2.15)	(2.64)	(3.63)	(2.22)
Coef.: log rainfall on year	0.00	−0.00	−0.00	0.00	−0.00*	0.00	0.01	−0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)
Panel C. Breusch-Godfrey Lagrange multiplier test for serial correlation.								
F-value	0.308	0.454	2.539	0.678	0.005	0.894	0.000	2.474
p-value	0.584	0.506	0.124	0.418	0.944	0.354	0.997	0.128

Standard errors in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. Both consumption and crop profit are measured in per capita-terms and 1,000 CFA. All regression include a complete set of household-fixed effects. Sorted by latitude (rather than alphabetically). Based on data from FAO's *Climate Impact on Agriculture*-website.

Table 11: Balance table comparing households that sold a particular type of livestock at some point between 2003 and 2007 to those that never sold.

	Cattle			Sheep and goat		
	Never sold	Sold	Difference	Never sold	Sold	Difference
Age of head	50.75	52.20	-1.45^{***}	50.38	51.63	-1.25^{**}
	(0.37)	(0.40)	(0.52)	(0.62)	(0.30)	(0.62)
Male household head	0.91	0.98	-0.07^{***}	0.90	0.95	-0.05^{***}
	(0.01)	(0.00)	(0.01)	(0.01)	(0.00)	(0.02)
Household size	9.16	13.21	-4.05^{***}	8.25	11.60	-3.35^{***}
	(0.15)	(0.22)	(0.33)	(0.24)	(0.15)	(0.37)
Per hectar grain output (kg)	662.14	667.46	-5.32	690.54	658.16	32.38
	(7.54)	(8.05)	(20.24)	(14.07)	(5.93)	(24.17)
Per capita cultivated land (ha)	0.39	0.38	0.00	0.41	0.38	0.03
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.02)
# of cattle	1.30	11.61	-10.31^{***}	1.77	6.85	-5.07^{***}
	(0.07)	(0.79)	(0.98)	(0.21)	(0.45)	(0.59)
# of sheep and goat	8.42	20.33	-11.91^{***}	3.41	16.18	-12.77^{***}
	(0.25)	(0.61)	(1.02)	(0.25)	(0.38)	(0.75)
Sahel region	0.03	0.13	-0.10^{**}	0.03	0.08	-0.06^{**}
	(0.00)	(0.01)	(0.05)	(0.01)	(0.01)	(0.03)
# of total obs.		2,364			2,364	
# never sold		1,320			462	
# selling at least once		1,044			1,902	

Robust standard errors of means and differences in means clustered at the village-level and reported in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. The dataset is collapsed to obtain means over four years. Based on EPA data.

Table 12: Estimates of the effect of components of crop profit on other forms of income (both in 1,000 CFA and per capita).

	Revenue from business		Net transfers		Wages		Credit	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crop profit (1,000 CFA)	0.15*	0.86	−0.01	0.03	0.01	0.13	0.03***	0.20
	(0.08)	(0.57)	(0.01)	(0.12)	(0.01)	(0.13)	(0.01)	(0.13)
Cragg-Donald F statistic (weak identification test).								
F-statistic		11.91		11.91		11.91		11.91
Obs.	2,946	2,922	2,946	2,922	2,946	2,922	2,946	2,922

Robust standard errors clustered at the village-level in parentheses. *, **, and *** denote significance at the ten-, five-, and one-percent level, respectively. Net purchases of livestock and crop profit measured in 1,000 CFA. All regression include a complete set of household control variables including the age, age squared, gender, and education level of the household head and indicators of the number of household members by sex and age. All regressions further include a full set of household-fixed effects. Based on PNGT data.

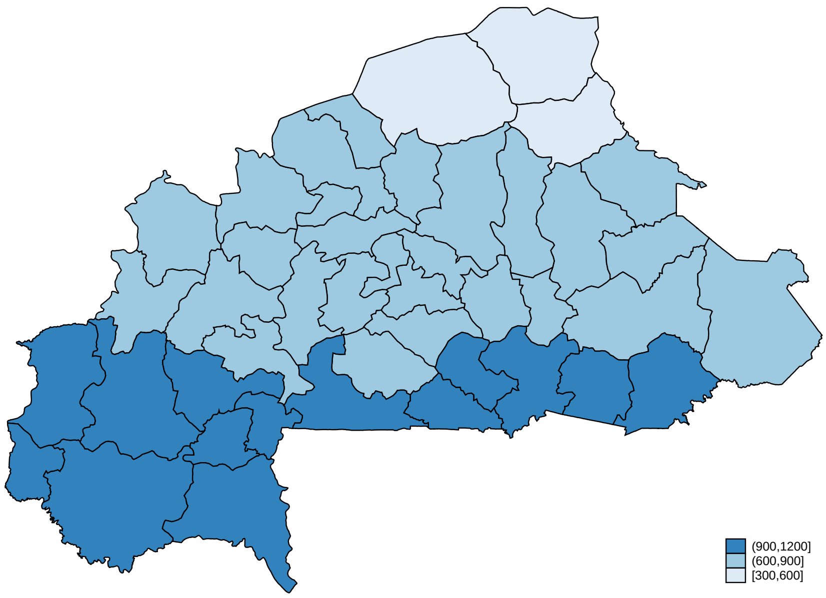

Figure 1: Average annual precipitation in millimeters, 2001–2012.

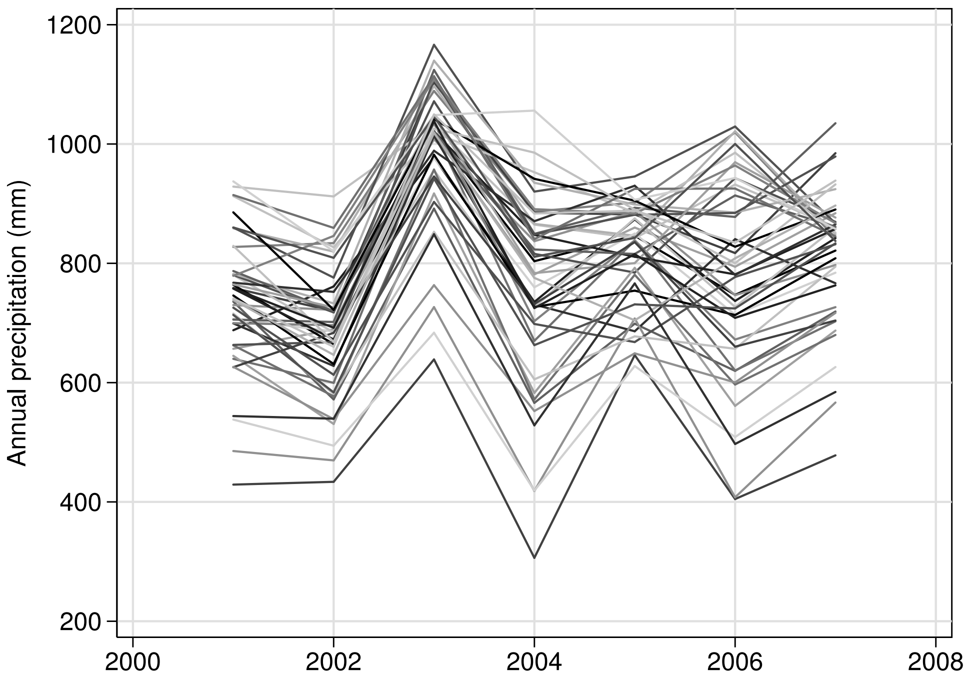

Figure 2: Annual precipitation in 45 provinces, 2001–2007. Authors' calculation based on data from FEWS 2013.

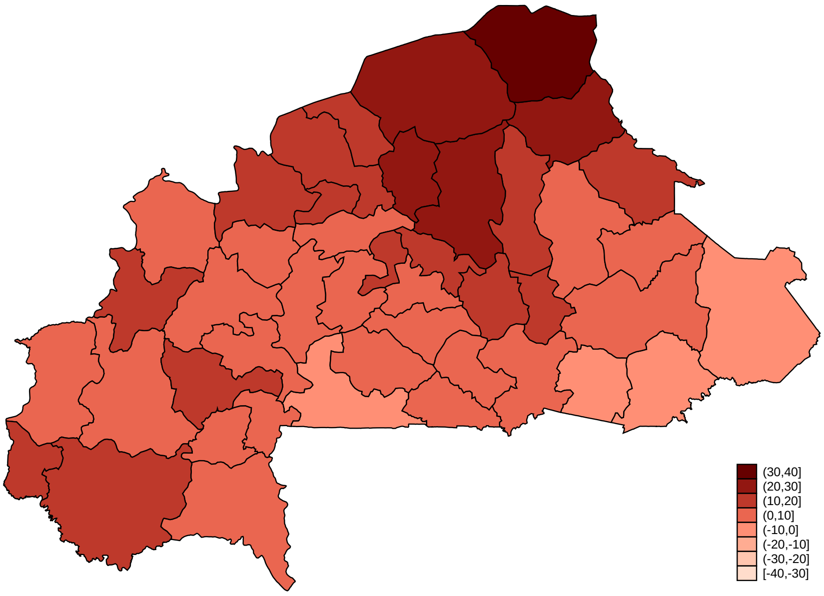

Figure 3: Shortfall in precipitation relative to long-term mean, 2004. Authors' calculation based on data from USAID [2013], 2001–2012.

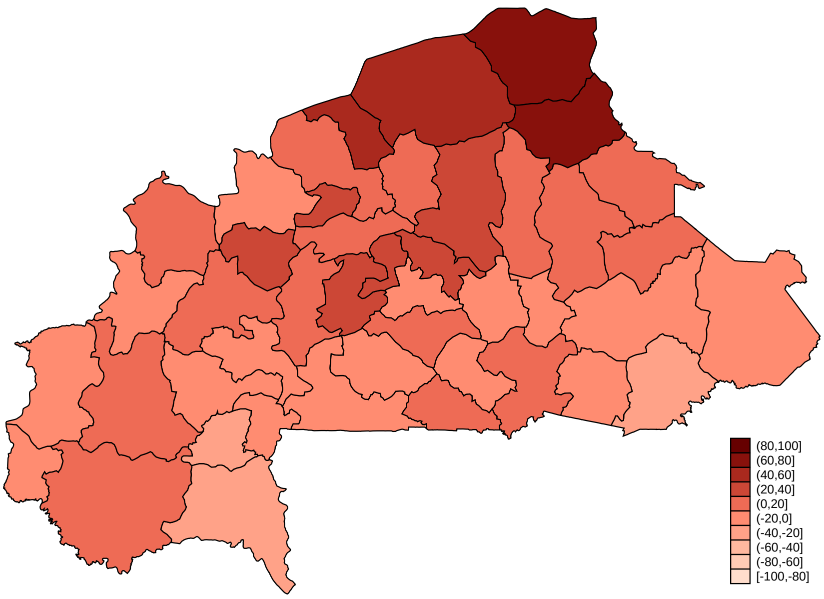

Figure 4: Shortfall in crop output relative to 2004–2007 average, 2004. Authors' calculations based on EPA data, 2004–2007.

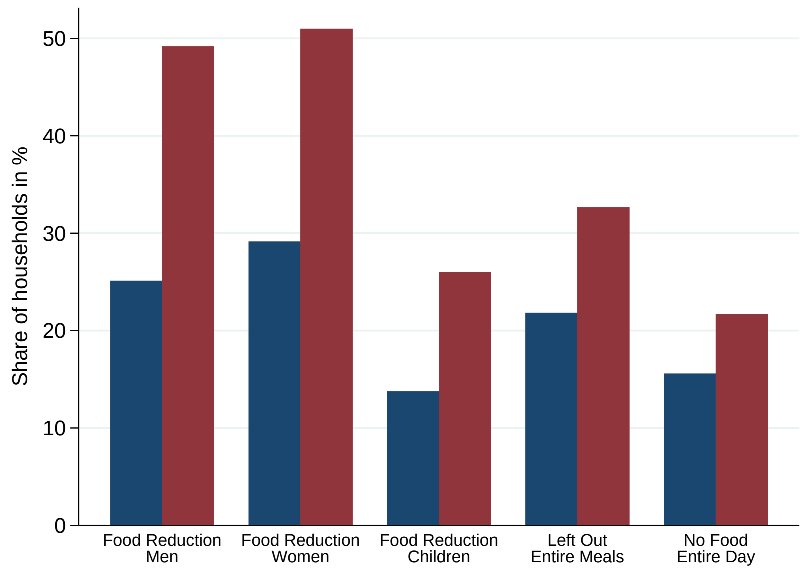

Figure 5: Reported cuts in food consumption during the 2004 lean season (blue bars) and the 2005 lean season (red bars). Authors' calculations based on data from PNGT surveys.

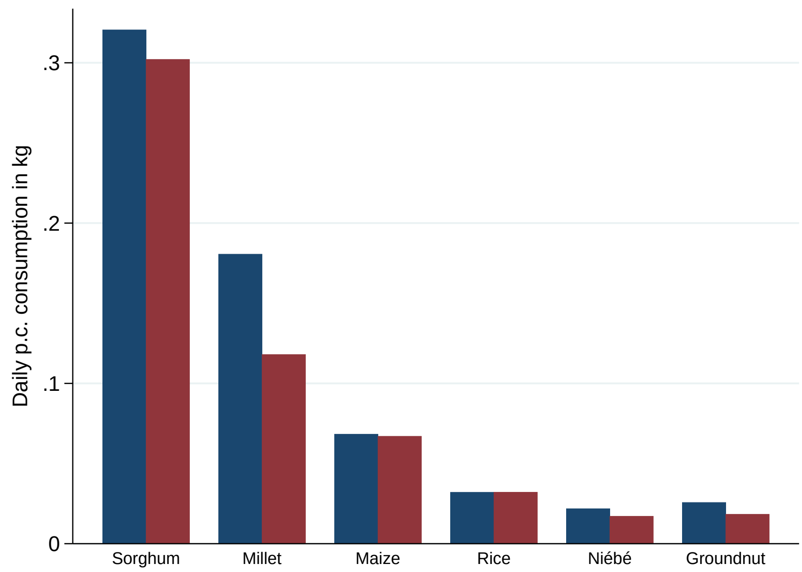

Figure 6: Per capita consumption (kg) of staple food during the 2004 lean season (blue bars) and the 2005 lean season (red bars). Authors' calculations based on data from PNGT surveys.

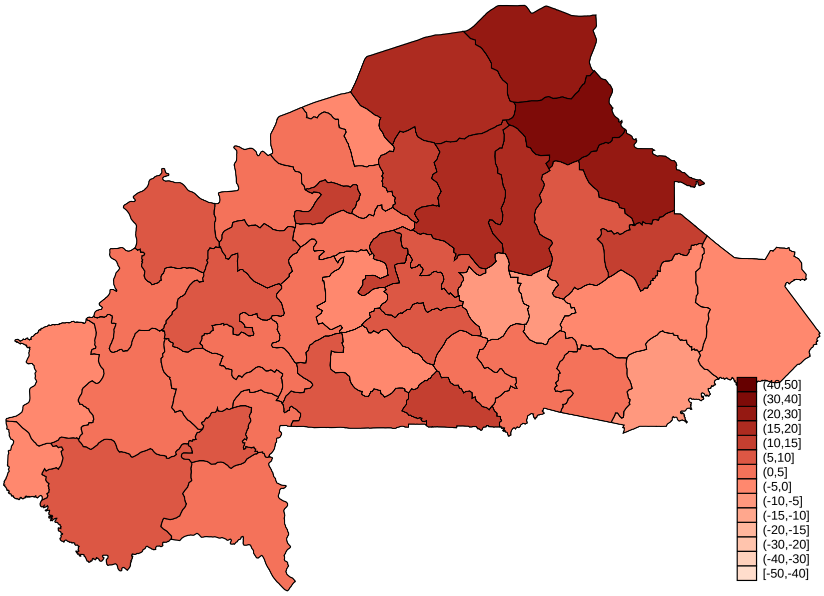

Figure 7: Net sales of livestock relative to holdings, 2004–2005. Authors' calculations based on EPA data, 2004–2007.

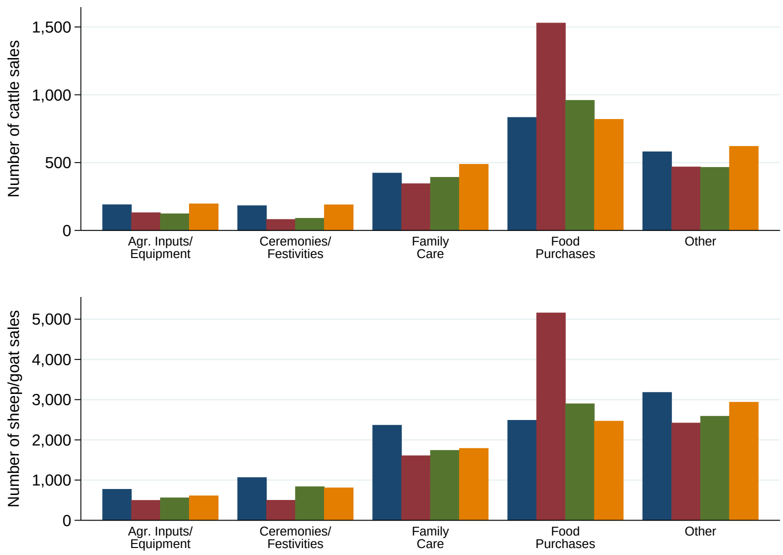

Figure 8: Motive for sales of cattle (top panel) and sheep and goat (bottom panel) between harvests of 2003–2004 (blue bars), 2004–2005 (red), 2005–2006 (green), and 2006–2007 (yellow). Authors' calculations based on EPA data, 2004–2007.

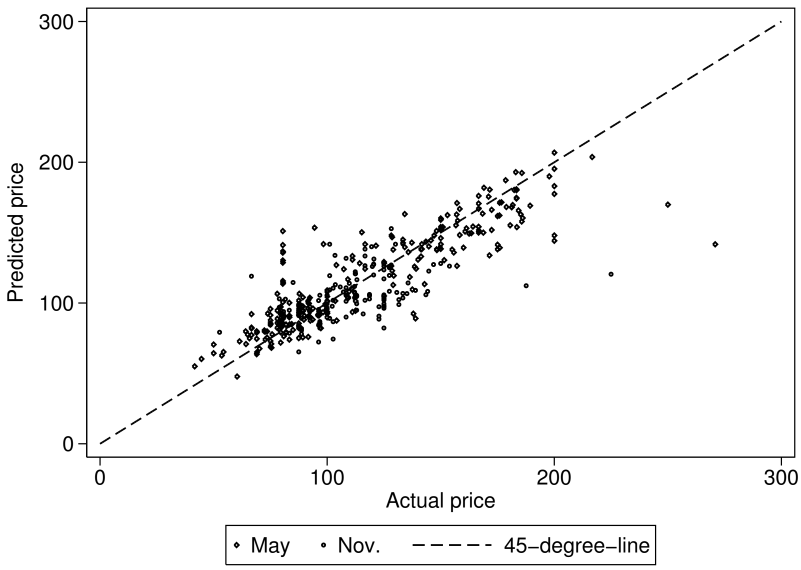

Figure 9: Predicted vs. actual prices for Sorghum, Millet, and Maize; May 2004, May 2005, and November 2006.

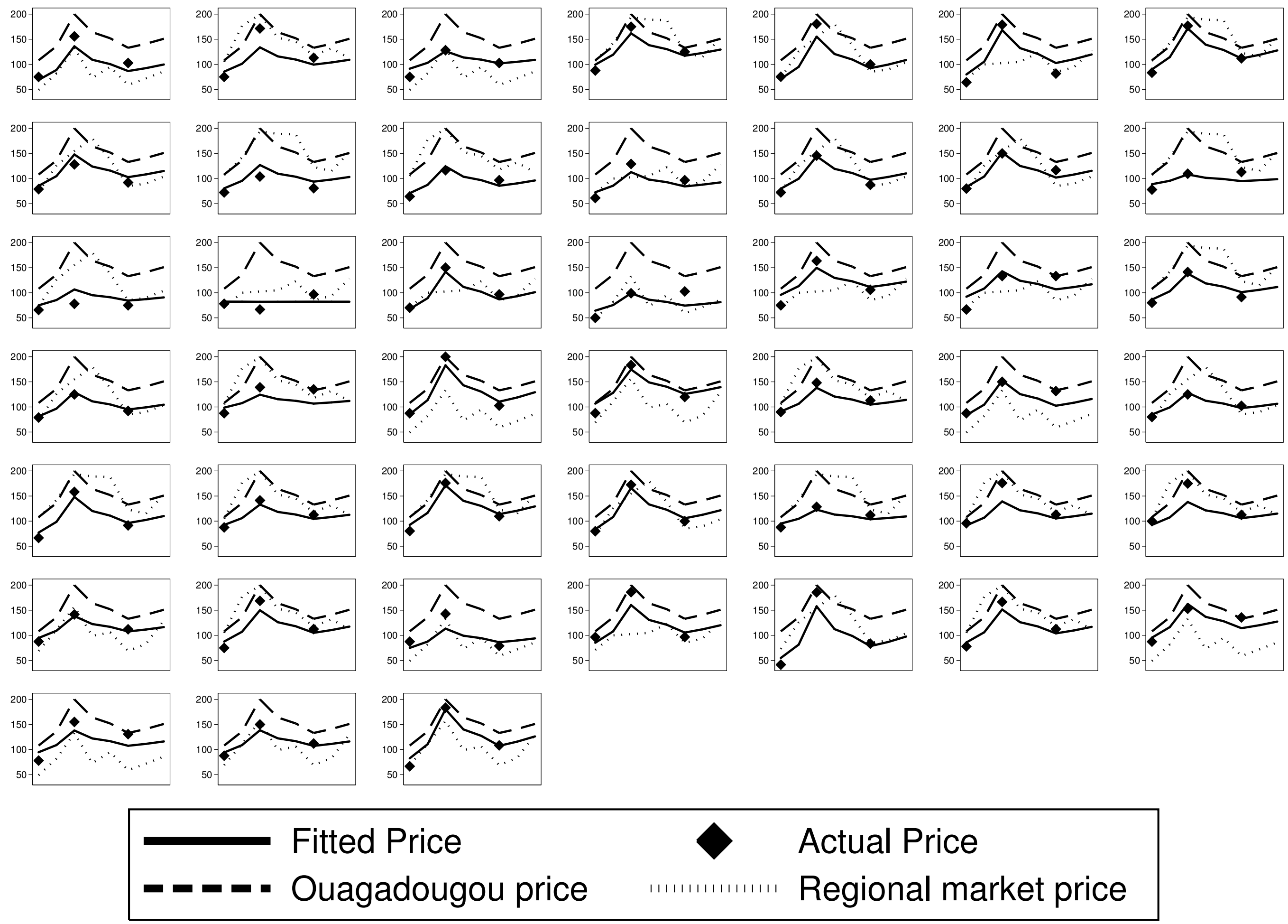

Figure 10: Actual, imputed, and nearest large city-, and capital city-prices for Sorghum, May and November 2004, 2005, 2006, and 2007.

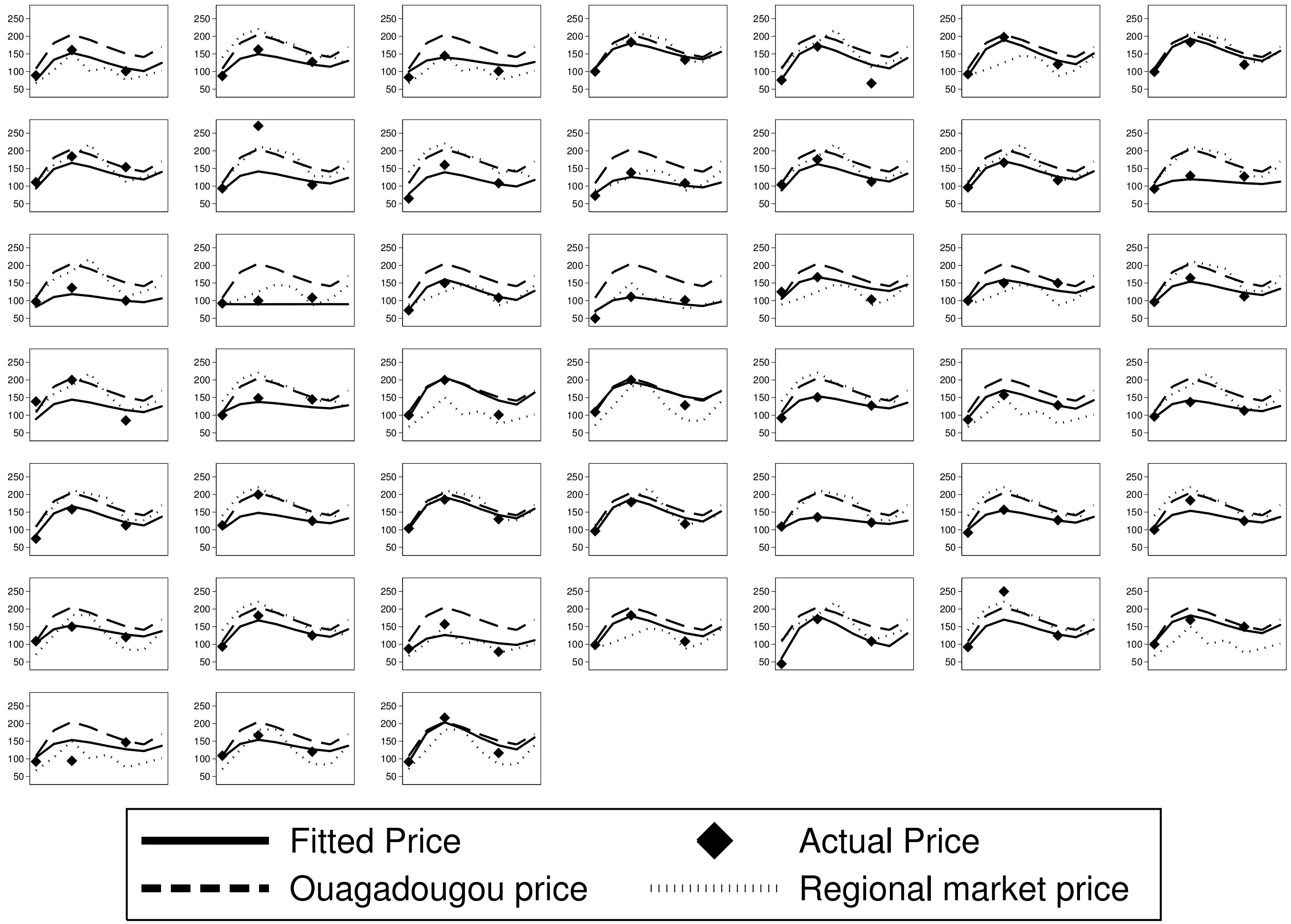

Figure 11: Actual, imputed, and nearest large city-, and capital city-prices for Millet, May and November 2004, 2005, 2006, and 2007.

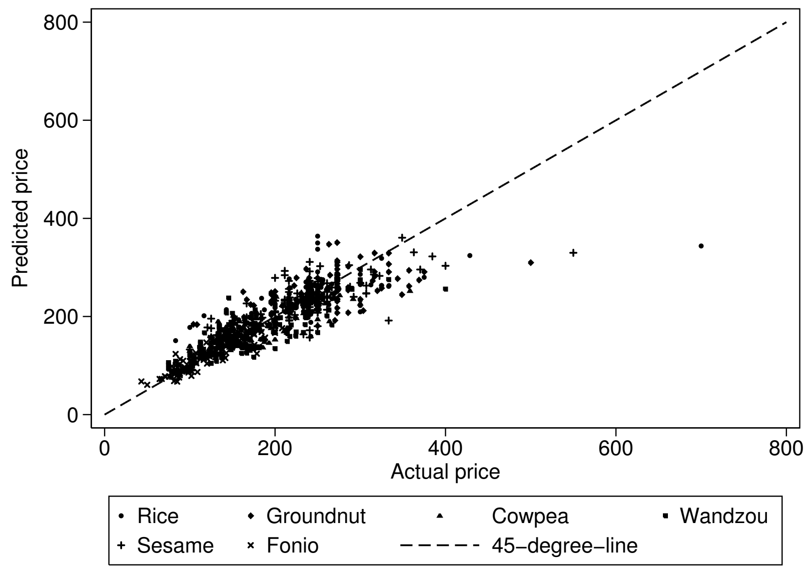

Figure 12: Predicted vs. actual prices for Rice, Groundnut, Cowpea, Wandzou, Sesame and Fonio; May 2004, May 2005, and November 2006.

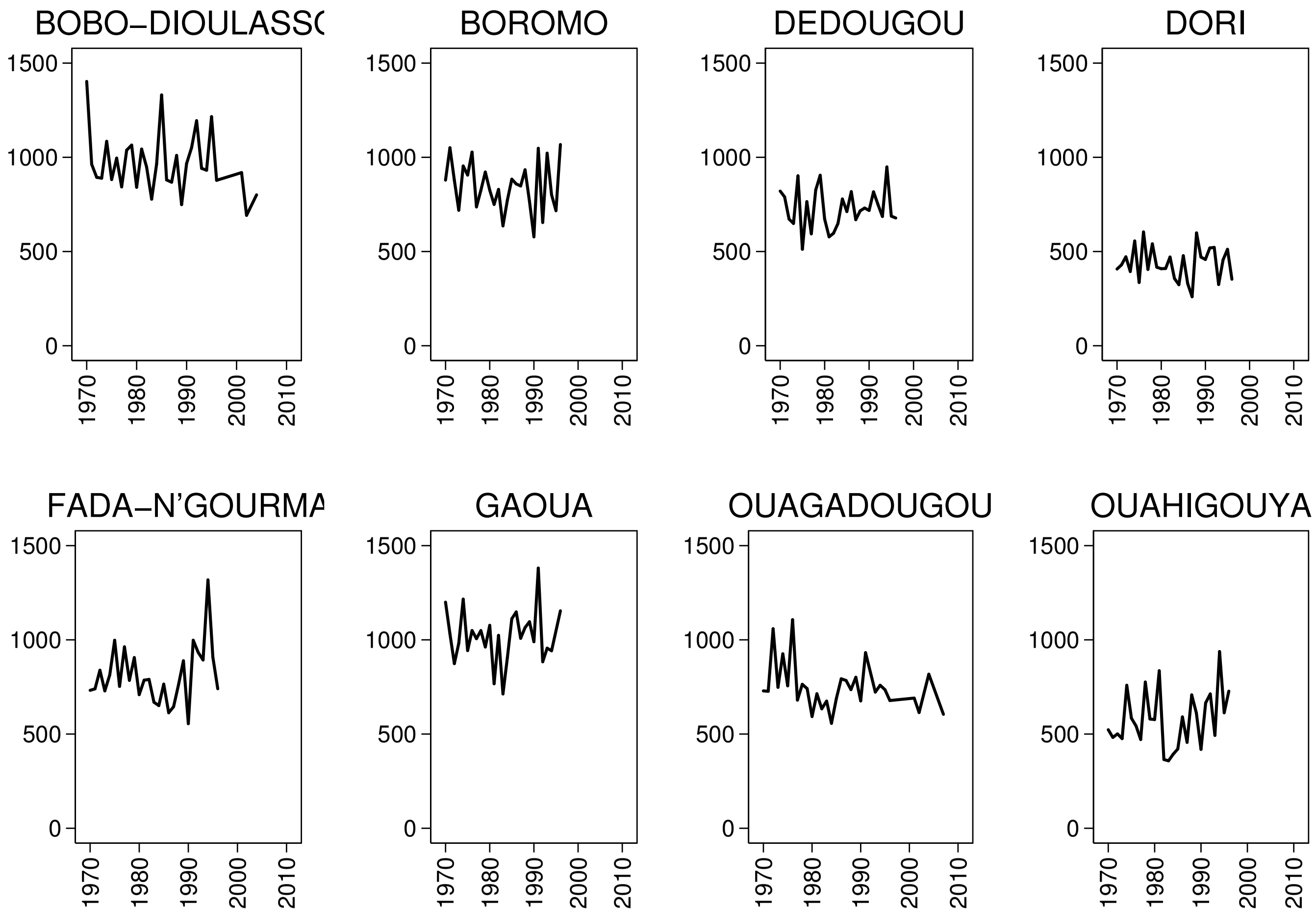

Figure 13: Rainfall levels recorded at eight stations across Burkina Faso, 1970–2009.