

# Post-Harvest Loss in Sub-Saharan Africa

## What Do Farmers Say?

*Jonathan Kaminski*

*Luc Christiaensen*

The World Bank  
Africa Region  
Office of the Chief Economist  
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## Abstract

The 2007–2008 global food crisis has renewed interest in post-harvest loss, but estimates remain scarce, especially in Sub-Saharan Africa. This paper uses self-reported measures from nationally representative household surveys in Malawi, Uganda, and Tanzania. Overall, on-farm post-harvest loss adds to 1.4–5.9 percent of the national maize harvest, substantially lower than the Food and Agriculture Organization’s post-harvest handling and

storage loss estimate for cereals, which is 8 percent. Post-harvest loss is concentrated among less than a fifth of households. It increases with humidity and temperature and declines with better market access, post-primary education, higher seasonal price differences, and possibly improved storage practices. Wider use of nationally representative surveys in studying post-harvest loss is called for.

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# Post-Harvest Loss in Sub-Saharan Africa – What Do Farmers Say?

Jonathan Kaminski and Luc Christiaensen<sup>1</sup>

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<sup>1</sup> Jonathan Kaminski (corresponding author, [kaminski.jonathan@gmail.com](mailto:kaminski.jonathan@gmail.com)) and Luc Christiaensen ([lchristiaensen@worldbank.org](mailto:lchristiaensen@worldbank.org)) are in the Chief Economist Office of the Africa Region of the World Bank. The authors would like to thank Saswati Bora for useful comments during the “Agriculture in Africa – Telling Facts from Myths” workshop in November, 2013 at the World Bank in Washington DC. The findings, interpretations, and conclusions expressed are entirely those of the authors, and do not necessarily represent the view of the World Bank, its Executive Directors, or the countries they represent.

## 1 Post-harvest loss in perspective

With global food supply struggling to keep up with demand since the 2007-2008 world food crisis (World Bank, 2011a), all supply and demand components have come under scrutiny once again. This also holds for food loss and waste occurring along the chain from farm-to-fork (Lipinski et al., 2013). FAO (2011) estimated it at 32 percent of all food produced. In Africa South of the Sahara, where hunger and food insecurity remain highest,<sup>2</sup> it is estimated to be as high as 37 percent.

Such saving opportunities suggest a need for greater attention to post-harvest loss (PHL) in addressing the world's food challenge (World Bank, 2011b). It also begs the question why such significant losses have persisted in the face of continuous undernourishment and hunger, and sluggish yield gains, especially in SSA. Why have farmers "tolerated" them and why has the international community not acted more forcefully to reduce them?

Interest in the reduction of post-harvest loss (PHL) of staple crops is indeed not new. As now, it stood high on the international agenda after the mid-1970s food crisis, with considerable development investment going into it (FAO, 1981; World Bank, 2011b). But international attention ebbed away, once real commodity prices resumed their historical downward trend and the economic benefits from preventing PHL declined.

More strikingly, in a thought-provoking article in 1982, Lipton also questioned the widely held premise of high post-harvest loss between farm and fork, quoted in the 30–50 percent range at the time and which was considered especially high in traditional post-harvest technology systems among smallholders. He further doubted that reducing it by modern capital intensive post-harvest technologies could be done cost effectively and, even if it could, that it would make a major dent in the incidence of hunger. Based on a review of the available literature and a series of case studies, he found that on-farm grain losses seldom exceed 10-12 percent of grain output and typically range

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<sup>2</sup> This holds when looking at the share of the population with insufficient caloric intake. According to the Global Hunger Index (which also accounts for the proportion of under-five-year-olds that are underweight and the under-five mortality rate), South Asia was the most hungry continent in 2013, with SSA ranking second (IFPRI, Concern Worldwide, and Welthungerhilfe, 2013).

between 5 and 8 percent and those simple locally-produced improvements in traditional post-harvest technology systems, are often already cost effective. Is this time different?

To begin, the global FAO estimates quoted above hide a large degree of heterogeneity with estimates varying substantially depending on the metric, crop and stages in the chain considered. When expressed in terms of calories for example, as opposed to weight, the overall food loss in Sub-Saharan Africa (SSA) is estimated at 23 percent (Lipinski et al., 2013), as opposed to 37 percent in weight (FAO, 2011). And instead of 37 percent for all foods, the PHL for cereals alone is estimated at 20.5 percent (again in weight, FAO, 2011). The latter discrepancy follows from the fact that both roots and tubers (R&T) and fruits and vegetables (F&V) have a much higher water content than cereals<sup>3</sup>, while the similarity in the PHL estimates for food (in calories) and cereals (in weight) reflects the fact that cereals still constitute the major share of SSA's caloric intake (around 40%, FAOSTAT).

Loss estimates also differ substantially depending on the stage in the farm-to-fork chain considered. In particular, FAO (2011) considers five stages in quantifying the ratio of PHL to total production, i.e. losses 1) during harvesting such as from mechanical damage and/or spillage, 2) during postharvest handling, such as drying, winnowing, and storage (insect pests, rodents, rotting), 3) during processing, 4) during distribution and marketing (wholesale, supermarkets, retail and wet markets), and 5) during consumption (i.e. good quality food fit for consumption being discarded).<sup>4</sup> In SSA, most PHL happens during harvesting and post-harvest handling and storage, with for example 68 percent of the 20.5 percent cereal PHL estimated to occur during harvesting on the field (6 percentage points) and postharvest handling and storage (8 percentage points).<sup>5</sup>

The latter estimates are also closer to the ones advanced by Lipton. They also highlight the discrepancy between the broad PHL concepts and metrics commonly used to motivate PHL

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<sup>3</sup> The energy of roots and tubers is about one-third of that of an equivalent weight of grain, such as rice or wheat (FAO, 1990). Consequently, even though the weight losses post-harvest for roots and tubers and fruits and vegetables are substantially higher than those of cereals (54 and 66 percent respectively compared with 20.5 percent for cereals), equivalent weight losses post-harvest still lead to much lower losses in calories.

<sup>4</sup> Losses during the first 4 stages are often labelled "food loss", losses during the consumption stage "food waste".

<sup>5</sup> In the developed world on the other hand, PHL is concentrated in the latter stages of the chain—during distribution (especially retail) and consumption (Lipinski et al., 2013).

investments and interventions and the more narrow, traditional focus of many of these interventions on on-farm storage techniques, where losses are substantially lower (in the 5-15 percent range) (World Bank, 2011b; De Groot, 2013). Success stories in promoting improved on-farm storage technologies have indeed been rare in SSA (World Bank, 2011b). Past interventions too often proved to be financially unsustainable, ill-aligned with farmer's economic incentives to store and better protect food, or too short to pay off.

To be sure, these findings and observations do not negate possible benefits from improved storage and post-harvest handling practices in advancing food security in SSA, even when only *on-farm* grain losses are considered. More importantly, they underscore the need for more and better quantification of (on-farm) grain loss (which can then be compared with the costs of improved post-harvest practices)<sup>6</sup> as well as a better understanding of farmers' behavior in adopting improved post-harvest technologies.

The nationally representative household surveys in six African countries south of the Sahara collected under the Living Standards Measurement Study-Integrated Surveys on Agriculture initiative (LSMS-ISA)<sup>7</sup> provide an opportunity to contribute to this agenda. In particular, under the LSMS-ISA surveys information is collected on households' demographic characteristics, their agro-ecological and market environment, their consumption patterns, assets and income sources (including detailed information on their agricultural production) and most importantly, also self-reported estimates of their post-harvest loss by crop.

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<sup>6</sup> Benefits from improved storage technologies are seldomly systematically compared with their costs. Exceptions are Kimenju and De Groot (2010) and De Groot (2013) whose initial findings highlight that either prices and seasonal price differences or post-harvest losses need to be sufficiently high for modern storage technologies to pay off, and that technologies such as metal silos, which also pay off when prices/losses are low, require higher upfront investments, consistent with Lipton's (1982) earlier proposition. This poses usually a challenge for credit constrained smallholder farmers in SSA.

<sup>7</sup> The initiative, which started in 2009, is funded by the Bill and Melinda Gates Foundation and other donor agencies and implemented by the Research Department of the World Bank and the national statistical agencies. The countries include Malawi, Uganda, Tanzania, Ethiopia, Nigeria and Niger. The data is publicly available on [www.worldbank.org/lms-isa](http://www.worldbank.org/lms-isa) and fully documented with questionnaires, details on survey design and implementation, and enumerators' manuals.

Unlike the PHL estimates from the Africa Post-harvest Loss Information System (APHLIS)<sup>8</sup> and FAO , which are based on national extrapolations from purposively sampled (and often older) in depth case studies of both on-farm and off-farm post-harvest loss, the estimates reported in this study are based on recent nationally-representative samples of self-reported (on-farm) post-harvest loss per household. This has a number of advantages. First, possible sample selection bias is avoided, given the nationally-representative nature of the sample. Second, harmonization in the survey methodology facilitates comparison across countries.

Third, while subjective and thus more prone to measurement error, self-reported loss estimates are also more likely to reveal the losses that farmers deem important. They are more likely to be incentive compatible and informationally relevant from a behavioral and operational perspective, than objective measures, which are in effect also hard to come by and also subject to multiple sources of measurement error and framing bias given non-harmonized definitions and measurement protocols.<sup>9</sup> Finally, even though most likely largely limited to on-farm losses, the use of household survey based estimates is still relevant in the African context, given that the bulk of food losses in SSA is concentrated on the farm.

Results are reported for three LSMS-ISA countries, Malawi, Uganda and Tanzania, where the systematic roll out of the survey data collection throughout the year enables the construction of *annual* on-farm post-harvest loss estimates. These countries are also explicitly covered in APHLIS. For Tanzania, the analysis of the drivers of farmers' post-harvest loss and the use of improved storage practices across different agro-ecological and market environments is further conducted. Finally, while farmers in LSMS-ISA surveys report the post-harvest loss for all their crops, the study here focuses on on-farm post-harvest grain loss, in particular this of maize. Grains continue to provide the bulk of (rural) households' caloric intake in East and Southern Africa (where maize makes up 40

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<sup>8</sup> [www.aphlis.net](http://www.aphlis.net)

<sup>9</sup> In addition to practical considerations—continuous data collection efforts throughout the post-harvest season would be needed—there are also methodological challenges such as distinguishing between irreducible and avoidable losses. Some amount of spillage, such as discarded amounts that do not fit market or consumption standards and natural weight and volume shrinkage, is unavoidable. In an economic sense, it may not even be truly lost if used as animal feed.

percent of the cereal production) and remain an important part of their income. Millet and sorghum, two other important staple grains, are cultivated more widely in drier parts of SSA. Their humidity content is usually lower when harvested, rendering them more resistant to post-harvest pest attacks than maize (World Bank, 2011b).

It is found that between 7 (Malawi) and 22 (Uganda) percent of maize farmers report to incur on-farm PHL for maize, losing between 21 to 27 percent of their harvest. This adds up to 1.4 to 5.9 percent of the national maize harvest being lost on-farm which is substantially lower than the FAO (2011) post-harvest handling and storage loss estimate for cereals in SSA of 8 percent as well as the APHLIS estimates of 12-20 percent (all PHL before marketing but without processing). PHL increases with storage duration, humidity and temperature and declines with better market access, higher seasonal price differences, and likely also with improved storage practices. With at most 5 percent of the households applying both, adoption of improved storage practices remains however rather limited.

The paper proceeds as follows. Section two presents the PHL estimates and the underlying data in more detail, including the stated reasons for the reported losses and the prevalence of adopted storage and crop protection technologies. The behavioral and market drivers of PHLs are subsequently examined in more detail in a multivariate setting in section three using the 2008/9 survey round from Tanzania. Section four concludes.

## **2 On-farm PHL for maize is limited, but concentrated**

The nationally representative household surveys from Malawi (2010-11), Tanzania (two years: 2008-09 and 2010-11), and Uganda (2009-10) collected under the LSMS-ISA initiative form the information base of the study. In addition to standard survey modules on household characteristics, assets, income and consumption, they contain detailed self-reported crop-level information on PHLs, their stated causes, and the storage and crop protection modalities used together with post-harvest management features, such as the amount still stored and the timing and amount of past sales. Geo-



referencing of all households further enables merging of the data with the areas' agro-ecological and geographic characteristics (including distance to markets and population centers and food market prices). The effect of environmental and market factors on PHLs can thus also be studied.

Two PHL measures are derived from the crop sections of the agricultural modules of the main<sup>10</sup> cropping season: 1) whether the household incurred PHL for maize (conditional on having a strictly positive amount of maize harvested) and 2) the proportion of harvested maize lost as a share of total production (expressed as a ratio between 0 and 1. In particular, following questions about the amount harvested for each crop, households were asked for each crop with a strictly positive harvest: "Did you incur any PHL due to rodents, pests, insects, flooding, rotting, theft, and other reasons?" and if yes, "What proportion was lost?"<sup>11</sup> The measures thus mainly concern on-farm PHL during handling and storage after the harvest, essentially excluding losses incurred by traders and retailers or during consumption. That they also include some of the farmers' field drying and marketing losses can however not be totally excluded, and the measures should be seen as upper bounds of on-farm-PHL during storage and handling.

In each survey, households were only surveyed once, though not during the same months. Specifically, the surveys were each time conducted throughout the year, with the households to be interviewed during a particular period, each time sampled from across the country so that they would enable a nationally representative picture of the situation in the country during that period. A household could thus have been surveyed shortly after the harvest or several months thereafter, though for each period they constitute together a representative sample of the country. This feature of the survey is exploited to annualize each household's self-reported PHL. Annual adjustment is

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<sup>10</sup> Only in Uganda and Tanzania are there households with a second cropping season, but they are few, and limited to specific AEZs. The study has abstracted from them in calculating the PHL statistics (Tables 1-3), but controls for their potential effect indirectly through the inclusion of AEZ indicator variables in the multivariate analysis of PHL drivers (Table 4).

<sup>11</sup> The first question was the same across the four surveys; the second question differed only slightly. In Tanzania, it was asked: "Out of 10 units, how many were lost?" In Uganda, farmers reported PHL as a percentage of total quantities produced instead. In Malawi, farmers were given the option of either reporting a total amount of losses in local units (subsequently converted in kilograms and divided by produced quantities to obtain the PHL measure), or directly reported the losses in percentages, as in Uganda. Very few outliers (PHL measure beyond one) were detected for Malawi, and in such cases, PHL values were replaced by one.

necessary to avoid underestimation of the total loss, as the proportion of on-farm PHL increases cumulatively over time.<sup>12</sup> It makes all households comparable in their PHL, as if they were all interviewed just before the new harvest of the new agricultural season (see technical appendix A1 for more details on the adjustment procedure as well as a graphical presentation).

Both rural and urban households were included and through the application of the household sampling weights (or more specifically, their inverse to obtain the expansion factor), nationally representative estimates of the incidence and proportion of PHL (as well as other PHL related indicators) were obtained. To correct for differences in total maize output per household in obtaining national maize PHL estimates per household, household expansion factors were further multiplied by each household's total maize production (in kg). Application of the household expansion factor alone would give the average maize PHLs for a nationally-representative household as opposed to the national maize PHL per household on average. It would overemphasize the losses of small versus big producers. Both estimates are reported (Table 1).

The proportion of maize harvest lost on-farm among households who have finished their maize harvest<sup>13</sup> and who have strictly positive harvested quantities, ranges on average between 1.4 percent in Malawi and 5.9 percent in Uganda. In Tanzania, it fluctuates between 4.4 percent during the 2008-9 survey and 2.9 percent during the 2010-11 survey. When expressed in terms of the representative household, the on-farm PHL proportion of the maize harvest is lower, ranging between 1.9 (Tanzania) and 3.9 percent (Uganda), except for Malawi where it amounts to 2.9%.

Clearly, this is substantially less than the average 8 percent on-farm handling and storage post-harvest loss (in weight) for cereals reported by FAO (2011) for SSA or the post-harvest maize weight losses reported by APHLIS for those three countries in those particular years. The latter range between 17 (Tanzania) and 21 percent (Malawi) when including the losses during all stages of

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<sup>12</sup> On-farm PHL for maize tends to increase rapidly three to four months after the harvest, when insect pests really start to cause havoc (Stathers, Lamboll, and Mvumi, 2013), while additional losses gradually decline thereafter (mainly because stocks are increasingly depleted towards the beginning of the new harvest).

<sup>13</sup> Among the maize farmers in Uganda, Malawi and Tanzania, almost all reported strictly positive harvested quantities (99.2 percent, 95.4 percent and 94.3 percent respectively).

the supply chain (excluding processing, and consumption or food waste), between 14 (Tanzania) and 18 percent (Malawi) when only looking at estimated losses before marketing, and between 6 (Tanzania) and 11 percent (Malawi) when only considering platform drying and farm storage.

Farmers who report a loss typically report substantial losses—on average between 21 to 27 percent of total production in Malawi and Uganda respectively (Table 1), though only a minority reports a loss (between 7 and 22 percent of the sample in Malawi and Uganda, with one in 5 to one in 7 maize farmers reporting a loss in Tanzania, depending on the survey year). Both the relatively low incidence of PHL as well as the relatively high losses incurred among households reporting PHL, highlight the need for proper targeting of PHL interventions<sup>14</sup> as well as the importance of using nationally-representative samples in quantifying PHL to avoid sample selection bias. PHL estimates based on non-random samples are likely biased upwards if non-randomness in the sample selection leads to overrepresentation of areas or groups with higher likelihood of incurring PHL, such as hot, humid areas, which experience higher pest infestations, or poorer households, which are likely to use less effective storage technologies.<sup>15</sup>

Further inspection of the PHL survey data suggests that the self-reported national PHL estimates presented here are internally consistent, providing confidence in the approach. From an agronomic perspective, the occurrence of PHL is more likely and the reported losses are likely higher in hot and humid areas (Stathers, Lamboll, and Mvumi, 2013). Consistently, in the equatorial and sub-humid tropical climate of Uganda, which has warmer and more humid agro-ecological zones (AEZ), self-reported PHLs are highest, followed by Tanzania, which is largely sub-humid with some semi-arid areas, and they are lowest in Malawi, where semi-arid and sub-humid AEZs are equally represented.

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<sup>14</sup> In each country, among those reporting a loss, between 60 and 70 percent report a loss under 20 percent, suggesting a high concentration of the incidence of high PHL, further reinforcing the case for targeting.

<sup>15</sup> Alternatively, small losses may not be sufficiently accounted for in the self-reported estimates presented here. Yet if so, they would likely not be considered economically or nutritionally meaningful either by farmers, resulting in lesser likelihood of adopting PHL prevention measures. Some small losses are likely also inevitable.

In addition, the PHL estimates of both survey rounds in Tanzania are of a similar order of magnitude (4.4 and 2.9 percent), with the decline in national annual PHL between both survey rounds consistent with an increase in the share of marketed harvest (from 19.4 to 26 percent)<sup>16</sup> as well as the increased share of the maize harvest stored in improved storage facilities (from 5.9 to 11.5 percent) and treated with crop protection (smoking or chemical spraying) (from 37.2 to 49 percent) (Table 2). Improved modern storage facilities include the use of modern stores, improved local structures, and air-tight drums. Traditional storage structures include granaries. Plastic bags, in-house storage, and unprotected piles are considered poor storage techniques.

A more detailed multivariate analysis of the drivers of post-harvest loss is pursued for Tanzania below. Note however that the adoption of improved storage technologies is in general low, also in the other LSMS-ISA countries studied here, with only 0.6 percent of the maize production in Uganda and 2 percent in Malawi subject to improved storage techniques, while the use of crop protection (spraying or smoking) is much more prevalent (63.1 percent of the maize harvest treated in Uganda and 10.8 percent in Malawi) (Table 2).

Finally, respondents in all three countries indicate insects and rodents/pests (biotic factors) as the most important reasons for their reported loss of maize post-harvest (Table 3). Insects such as the maize larger grain borer (LGB, *Prostephanus truncatus*) and pests such as fungal rotting and mycotoxin contamination, as well as rodents are also the most widely discussed factors of on-farm PHL in the scientific literature (World Bank, 2011b). The prevalence of these reasons as reported causes of PHL, is also consistent with the interpretation advanced above that the self-reported PHL estimates in the LSMS-ISA surveys mainly capture post-harvest on-farm handling and storage losses. In Uganda, “other” reasons are also frequently mentioned to explain PHL, further increasing Uganda’s PHL incidence to the highest level among the three countries.

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<sup>16</sup> The higher the marketed share, the lower the storage duration and opportunities for incurring on-farm losses—most commercialization happens within 3 months after harvest.

### 3 Climate and economic incentives drive PHL

The proximate drivers of PHL have been well identified in the agronomic literature.<sup>17</sup> In its most elementary form, (on-farm) grain PHL depends on the storage depletion pattern—the faster stocks are depleted, the lower is the proportion lost. This depends in turn on farmers’ marketing and auto-consumption behavior.<sup>18</sup> With most cereal sales typically taking place shortly after the harvest<sup>19</sup> given credit or liquidity constraints (Stephens and Barrett, 2011), higher degrees of commercialization are expected to lower grain PHL given shorter storage time (Hodges, 2010). But, such savings may be offset by losses during marketing (due to transport, handling and sorting). Marketing losses are avoided if cereals are mainly stored for auto-consumption, though this comes with more gradual stock depletion and thus higher risks of losses due to pest, insect infestation and/or rodents as time goes by. Whether storage for marketing or auto-consumption leads to higher or lower PHL is ultimately an empirical matter.

PHL may also increase with higher production quantities, for example, when this creates labor shortages and less attention to harvest conservation, or indirectly through lengthier storage duration, so as to benefit from inter-temporal arbitrage on markets, or through lower general equilibrium price levels when there is overall a bumper crop, and thus lower gains from loss prevention (World Bank, 2011b). Everything else equal, PHL is further expected to decrease with the use of improved storage technologies and crop protection and to increase with humidity and temperature, with hotter, more humid environments fostering pest infestations and rotting.

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<sup>17</sup> For a critical review of grain PHL drivers and systems, see Greeley (1982; 1986), Boxall (1986; 2001), or Grolleaud (1997).

<sup>18</sup> Henkes (1992) for example found that over a 9-month storage period, cumulated maize PHL in a number of small farms in Tanzania was 2/3 lower when maize had been stored for auto-consumption than when depletion followed purely from commercialization (two extreme cases). However this study might not depict a representative picture of the reality when marketing is concentrated in the first three months after harvest rather than being evenly spread over time.

<sup>19</sup> For example, in the sample surveys analyzed here, between 84 and 91 percent of the total share of maize marketed, had been marketed within 3 months. This compares with an average storage duration of 5.5-7 months.

Storage duration, marketing share and auto-consumption levels, the harvested quantities, and storage and crop protection technologies used as well as the climatic conditions (temperature and humidity) of the storage environment are also used by APHLIS to refine their within country regional PHL estimates and update them on annual basis. To shed preliminary light on the drivers of the self-reported PHL estimates presented here and further assess their internal validity, the estimated effects of the proximate determinants are briefly examined first (estimates in Appendix A2), before proceeding to a more reduced form and causal analysis using (more) exogenous explanatory variables (Table 4).<sup>20</sup> The following model is estimated:

$$PHL(t)_i = \pi f(t) + \alpha Y_i + \beta(1 - s(t)_i) + [\gamma_1 + \gamma_2 \theta_i]m(t)_i + \delta T_i + \xi X_i + v_i + \varepsilon_{it} \quad (1)$$

where  $PHL(t)_i$  represents the proportion of maize harvest lost, reported by household at time  $t$  of the interview, with  $t$  equivalent to the number of months between the time of the survey and harvest completion (i.e. *unadjusted* for the timing of the survey),  $f(t)$  is a function of  $t$  (either quadratic or logarithmic)<sup>21</sup> to control for differences across households in the timing of the survey,  $Y_i$  is the total maize harvest at time  $t=0$ ,  $1 - s(t)_i$  is the depletion rate of storage observed at time  $t$ , i.e. 1 minus the ratio of maize quantities still stored at the time of the interview over quantities harvested,  $m(t)_i$  is the commercialization rate, and  $\theta_i$  is a vector of average marketing conditions at the household level (transportation distance and frequency),  $T_i$  reflects the post-harvest storage and crop protection technologies used,  $X_i$  the agro-ecological conditions (proxied with AEZ indicator variables), and  $v_i$  are indicator variables of the month of harvest and geographic region of the household to

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<sup>20</sup> The proximate determinants discussed above are all choice variables (except temperature and humidity), which may be correlated with unobserved household factors that also affect the amount of PHL reported (Wooldridge, 2002). As a result, the estimated effects of the proximate determinants on PHL may also capture the effect of these other unobserved factors they are correlated with and which also affect PHL directly, but which are not controlled for in the equation. Care must thus be taken in the interpretation of the findings and they cannot be seen as causal.

<sup>21</sup> Results are presented with logarithmic specifications for expositional purposes, but the quadratic ones are preferred by the data. The size and sign of the other coefficients remains robust to each specification. See the appendix A1 for PHL adjustment using the coefficients of quadratic specifications.

control for differences in rainfall patterns during the time of harvest and general geographic characteristics. The last component  $\varepsilon_{it}$  is a random error term that follows an iid normal law centered in zero.

As the PHL variable is censored between 0 and 1, equation (1) is estimated using the Tobit type I estimator (Wooldridge, 2002). The empirical application is to 2008-09 survey of Tanzania.<sup>22</sup> PHL declines as the storage depletion rate increases (Table A2 column 1), though it is not statistically significant and no longer holds when storage and crop technologies are controlled for, suggesting that the use of improved storage technologies and depletion are negatively correlated, i.e. the faster the depletion and the shorter the storage period, the lower the use of improved storage techniques. This is consistent with the observation by Stathers, Lambell and Mvumi (2013) that households usually only treat grains that are to be stored for more than 3 months, as insect populations usually do not reach damaging intensities until 4 months storage.

Consistently, the use of improved storage technologies reduces PHL—with the use of modern storage technologies having a higher PHL effect than the use of traditional storage technologies) (Table A2, Tobits 1 and 2). The use of poor storage is associated with an increase in PHL, as is the use of crop protection technologies.<sup>23</sup> Nonetheless, while indicative and consistent with the literature, the effects are all imprecisely estimated and further investigation is needed.

When it comes to marketing versus auto-consumption, losses appear higher when a larger share of the maize harvest is marketed, a loss which is reinforced the higher the number of sales hinting that the self-reported PHL estimates may include some of the losses incurred during

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<sup>22</sup> The Tanzania 2008-09 survey round is chosen because PHL was higher than in 2010-11. The TZ 2008-2009 survey has also been used to provide regional aggregates of the seasonal variables required to update the APHLIS PHL profiles. For TZ this led to 21 different data points (21 different PHL regions considered in APHLIS, compared with 4 regional breakdowns in Uganda, and 3 in Malawi). Regional APHLIS PHL estimates were adjusted with updated estimates of storage duration, share of marketed quantities during the first three months after harvest, regional production, and occurrence of rainfall at harvest, derived from the LSMS-ISA data. This induced larger cross-regional PHL heterogeneity, though mainly in the losses at harvest, during storage and marketing.

<sup>23</sup> Locally-available crop protection chemicals are often of poor quality (fake, expired) and the instructions (dosage, timing) for their use inadequately applied (Stathers, Morris, Riwa, and Mvumi, 2004). They may also be especially used by more PHL-prone farmers (or promoted by development projects in more PHL-prone regions), with their PHL reducing effects not sufficient to offset higher PHL for other (unobserved) reasons among these farmers.

marketing. Maize PHL is also positively associated with the size of the harvest. Surprisingly, no statistical difference was found across AEZ (with some of the signs even counterintuitive).

The estimated coefficients (their statistical significance and sign) on the proximate determinants of PHL are broadly consistent with the literature, adding to the credibility of the “subjective” PHL measures used in this paper. Yet to enable a more causal (and quantitative) interpretation of the findings, a more reduced form approach is necessary. Each of the proximate determinants of PHL (storage depletion, marketing behavior, storage infrastructures and crop protection technologies) is itself a function of the household’s characteristics (such as its labor availability, the educational status of its members, its income) and those of its economic and agro-ecological environment.<sup>24</sup> As they may also affect PHL directly, beyond their effect on the proximate determinants (e.g. more educated households may have a better understanding of how to avoid PHL), omitting them would lead to biased estimates of the coefficients on the proximate determinants. In addition, there may be other unobserved factors that are correlated with the proximate determinants and also affect PHL directly.

The explanatory variables considered are thus reduced to those which are not obviously correlated with unobserved factors that would also influence PHL, leading to the following reduced form, empirical model:

$$PHL(t)_i = \pi f(t) + \xi Z_i + v_i + \varepsilon_{it} \quad (2)$$

whereby  $Z_i$  is a vector of variables representing household characteristics and those of its economic and agro-ecological environment. In particular, the effects of the gender, age and education level of the household head are explored, while income and labor availability within the household are

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<sup>24</sup> For a comprehensive grain storage management model in the economic literature and the role of climate in PHL, see Fuglie (1995), Park (2006) and Stathers, Lamboll and Mvumi (2013) respectively.



proxied by an asset index<sup>25</sup> and the household size respectively. Together they help control for a household's risk and time preferences as well as labor, liquidity, and credit constraints emanating from household specific factors. The use of assets to proxy for income is motivated by the need to circumvent simultaneity in the acquisition of income and the occurrence of post-harvest loss, whereby a household could for example be forced to engage in additional income earning activities when its harvest is eaten away through LGBs<sup>26</sup>. This could lead to an estimation bias.

To further capture the economic incentives from the broader economic environment facing households when making their decisions on storage, marketing, and PHL prevention through labor input, storage technology and crop protection, following proxies are included: 1) the location of the household (rural/urban and the geographic region) through indicator variables; 2) the distance to the main population center and the market place<sup>27</sup> to reflect market accessibility and thus the ability to rely on the market as opposed to home storage for food, with greater market access increasing the opportunity cost of loss during storage, suggesting an increase in PHL with increasing distance to markets; and 3) the wholesale and retail seasonal maize price gaps in the neighboring markets, with higher gaps increasing the opportunity cost of PHL during storage, suggesting a decline in PHL as seasonal price gaps increase.<sup>28</sup>

To represent the climatic environment, temperature and rainfall related variables are added.<sup>29</sup> In addition to controlling for the AEZ, which only provides a very broad climatic

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<sup>25</sup> The asset index is the score along the first principal component of a principal component analysis applied to households' assets (comprising durable goods of the household and livestock) (See Sahn and Stifel, 2003 for applications in other contexts).

<sup>26</sup> For an illustration, see "Catherine's plight" in Stathers, Morris, Riwa and Mvumi (2004).

<sup>27</sup> Distance to the main population center has been calculated using the travel distance to the nearest town of more than 20,000 inhabitants, drawing on national census data, AfriPop sources and a gridding algorithm. Similarly, the distance to the nearest market place has been calculated as the travel distance to the closest FEWSNET market center.

<sup>28</sup> Seasonal price gaps were obtained through econometric identification of the individual and independent month effects on maize prices in Tanzania's 20 major (retail and wholesale) maize markets based on 13 years of monthly-based price series obtained from the Tanzanian national statistical office (Kaminski, Christiaensen, Gilbert and Udry, 2013). The gap was measured as the maximum monthly price spread for each of the markets and the price gap of the nearest market was mapped to each household, with the nearest market identified as the market with the shortest travel distance to the household's enumeration area.

<sup>29</sup> Values for each household were obtained as an inverse-distance weighted average of the values of the respective variables in the cell points on the climatic grid (their center coordinates) around the household.

categorization, average annual rainfall and temperature patterns as well as those during the wettest quarter measured at a much higher resolution<sup>30</sup>, were included. The total annual amount of rain and the amount during the wettest quarter of 2007-8 and 2008-9 were also controlled for to reflect pre- and post-harvest rainfall patterns of the survey year (source: NOAA CPC, resolution 6' or about 140 km<sup>2</sup>). Rainfall patterns pre-harvest help proxy for the total harvested quantities and humidity conditions, while rainfall conditions during and after the harvest have a key influence on PHLs at the harvesting and drying stages. They foster early pest infestation and affect the dry matter content before storage, suggesting an increase in PHL when post-harvest rainfall is higher (Hodges 2010).

Finally, while the household sample is nationally-representative, this is not necessarily the case for the sample of maize growers considered in the estimations here. Maize growers may systematically differ from non-maize growers in ways that also affect PHL. Households not growing maize (which is more prone to PHL than sorghum/millet (World Bank, 2011b)) may do so, for example, because they are less able to deal with the challenge of PHL. This would induce a sample selection bias and biased coefficients, when such characteristics are not controlled for. The Heckman technique<sup>31</sup> is used to control for this, whereby the likelihood of growing maize is estimated first using a Probit model (which is applied to the whole national sample of households) and controlled for in the (second stage) PHL regressions through the inclusion of an inverse Mills ratio<sup>32</sup>.

Descriptive statistics on each of the explanatory variables are in appendix Tables A3 and A4. The estimated results are in Table 4. They include Tobit estimates of the proportion of maize harvest lost post-harvest (column 1) as well as Probit estimates of the probability of reporting a harvest loss (column 2). The latter are added to examine the marginal effect of the different determinants on the

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<sup>30</sup> It concerns the average weather conditions during 1960-2000 at a resolution of 30" (or about 1 km<sup>2</sup>) from the WorldClim database: [www.worldclim.org](http://www.worldclim.org)

<sup>31</sup> See Heckman (1979).

<sup>32</sup> Successfully doing so requires instruments, i.e. variables that affect the decision of growing or not growing maize, but not the amount of post-harvest loss, beyond their effect on growing maize (i.e. the exclusion restriction). Elevation, slope, terrain roughness, and nutrient availability of the soils, all variables that affect the choice of crop portfolio, but without immediate effects on PHLs, function as our instruments. They prove highly correlated with the choice of growing maize, and also pass the empirical over-identification test (the Hansen-Sargan statistic is equal to 2.5, below the 10% significance levels, indicating that the instruments meet the exclusion restrictions).

probability of experiencing a post-harvest loss (yes or no). The Tobit coefficients on the other hand, reflect a combined effect, i.e. the marginal effect of a particular determinant on the probability of incurring a post-harvest loss times the average PHL among those who incur a loss *plus* the marginal effect of that variable on the amount of PHL times the probability of incurring a loss. They reflect the effect on “expected PHL”, either by increasing/decreasing the likelihood of PHL occurring or by changing the amount of PHL among those who already experience PHL. There are only slight signs of selection bias from restricting the sample to households with non-zero maize harvests—the coefficient on the Inverse Mills ratio is only significant at the 10% level and only in the Probit regression.<sup>33</sup>

When examining PHL in relation to the household’s features, it is especially female-headed households and households where the household heads enjoyed post primary education (but not when only primary education was completed) that experienced lower rates of PHL. With female headed households and heads with post primary education 22.6 and 69.7 percent less likely to report PHL, respectively, the effects are substantial. Expressed in terms of “expected PHL”, they experience 11 and 27 % less respectively. Larger households also report slightly lower PHL, though no differentiation was observed by household’s wealth status.

When it comes to the economic environment, it is especially the seasonal price gap which has a large effect, both for retail and wholesale prices, with an increase in the wholesale ( retail) gap by one standard deviation, reducing the likelihood of reporting PHL by 28%(resp. 19%) points. Over the past decade the price spread between highest and lowest month, was on average 30 percent across all markets. The higher opportunity cost of losses during the storage process (either from having to buy maize on the market at a higher price if stocks run out prematurely, or from financial losses from foregoing higher sales prices later in the season) induces households to reduce their PHL rate. As hypothesized, PHL also increases in more remote areas.

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<sup>33</sup> The regressors of the selection equation are available from the authors upon request.

From an agronomic point of view, it is especially the interaction between heat and humidity that is most challenging to preserve food, as is borne out by the PHL increasing effect of the average temperature during the wettest quarter. The effect is substantial, with a 2.3 degree increase, which corresponds to one standard deviation of the average temperatures during the wettest quarter observed in the sample, increasing the likelihood of PHL by 23 % points and expected PHL by 1.35% points. In contrast, higher temperatures by themselves, which reduce humidity and accelerate drying, tend to reduce PHL. In addition, the year and season specific rainfall conditions also matter, with the amount of rainfall during the wettest quarter increasing PHL, even though overall rainfall levels during the post-harvest season were surprisingly found to have a mitigating effect. When combined however, their effect was negative. Pre-harvest rainfalls were not found to affect PHL.

In summary, both economic incentives (most notably the seasonal price gap, and also distance to the market place) and climatic factors (particularly lower temperatures and rainfalls during the wettest periods) lower PHL substantially, with general post primary education also associated with a substantial decline in PHL. When households are female headed, their PHL also tends to be substantially lower, an important insights when targeting interventions. Poverty was not found to be associated with the degree of PHL and after controlling for regional characteristics, no additional effect was found from living in rural or urban areas.

## **4 Concluding remarks**

Following the 2008 food crisis, post-harvest food loss and waste are back high on the policy agenda, with FAO estimates suggesting that as much as 32 percent of food produced is lost and wasted (running up to 37 percent in SSA). These estimates are weight (as opposed to calorie) based, cover all crops (including more perishable roots/tubers and fruits and vegetables with a higher water content and lower caloric contribution), and comprise all losses during each step of the food supply chain (harvesting, on-farm handling/storage, processing, marketing, consumption). PHL estimates for cereals in SSA are typically lower (23 percent) with the bulk of it happening during harvesting, on-

farm handling and storage. This is also what most PHL interventions have traditionally focused on (World Bank, 2011b).

These estimates are necessarily also based on many assumptions, including extrapolation from purposively sampled (and often older) case studies, which may inadvertently zoom in on areas where PHL is largest. A representative picture of the diverse contemporary postharvest systems of durable crops such as cereals, which are the key staples and caloric providers in eastern and southern Africa, remains lacking (Stathers, Lamboll, and Mvumi, 2013). This paper has begun addressing this void using a completely reduced form approach, i.e. by drawing on farmers' reported estimates of their PHL of maize, collected in four comprehensive nationally representative LSMS-ISA household surveys from three countries of eastern and southern Africa (Uganda, Malawi and Tanzania).

It is estimated that on average between 1.4, 2.9-4.4, and 5.9 percent of the national maize harvest is lost in Malawi, Tanzania and Uganda respectively. These estimates are substantially lower than the 8 percent cereal loss from on-farm handling and storage in SSA (FAO, 2011), even though maize is more prone to post-harvest loss than the other cereals (World Bank, 2011b) and abstracting from the fact that the self-reported losses may also include losses incurred during marketing and field operations. Further analysis of the Tanzania experience shows that the self-reported estimates are broadly consistent with the key proximate determinants of PHL identified in the agronomic literature, pointing to internal consistency and providing confidence in this reduced-form approach. They are highest in Uganda (with warmer and more humid AEZs) and lowest in Malawi (where sub humid and semi-arid AEZs are equally represented). They also increase with storage duration and the harvest share marketed, are further exacerbated with the number of market visits (suggesting that they may also incorporate some losses during marketing), but decline with the use of improved storage technologies (even though not with the use of crop protection such as spraying or smoking, suggesting lower effectiveness of these techniques when applied by households in practice).

Yet as highlighted by Stathers, Lamboll, and Mvumi (2013), these aggregates hide a lot of heterogeneity. In effect, only a minority appears to be affected (only between 7 and 22 percent reports the occurrence of PHL of maize in Malawi, Tanzania and Uganda respectively), when affected, but they suffer substantial losses (between 21 and 27 percent of the harvest in Malawi, Tanzania and Uganda respectively). The estimates also fluctuate across years, with the national PHL estimate in Tanzania varying between 4.4 and 2.9 between 2008 and 2010, consistent with the observed changes in marketing behavior and the adoption of improved storage technologies.

More in-depth and causal multivariate analysis of the Tanzania 2008 experience shows that economic incentives, especially the seasonal price gap (and access to the market), substantially decrease the extent of PHL, while climatic factors (particularly the combination of heat and humidity) substantially increases it. PHL only decreases with post primary education (though not with primary education), though households' wealth position/poverty does not appear to affect it and female headed households tend to experience lower PHL. Some of these factors are likely to work through the adoption of improved storage technologies, an important area for further investigation.

These insights are important to incorporate in the planning, design and targeting of PHL interventions. First, attention is called to a proper contextualization of the widely quoted, high PHL estimates. These concern aggregate estimates of losses along the full chain, while the interventions discussed are typically concentrated on reducing on-farm post-harvest losses only. The latter are much smaller, also in the literature, but the current estimates are still quite high when compared with the self-reported estimates presented here (at least for maize). Yet the self-reported estimates are arguably the more relevant indicators of demand for better storage and handling techniques.

Second, as only a small (though annually changing) proportion of households report a loss, the findings further highlight that "one-size-fits-all" approaches are bound to fail (as highlighted 30 years ago by Lipton) and that solutions and interventions must be compatible with economic incentives.

Finally, by bringing out the granularity in PHL and storage behavior on the ground and enabling the calculation of nationally-representative estimates from the bottom up, the findings underscore the usefulness of nationally-representative household surveys such as those collected under the LSMS-ISA initiative in studying PHL. The data and insights generated from such surveys can furthermore be used to inform PHL information systems such as APHLIS, directly, to update their annual estimates and, indirectly, to help them fine-tune their underlying algorithms.

## References

- APHLIS, 2013. Database on post-harvest losses.
- Boxall, R.A., 1986. *A critical review of the methodology for assessing farm-level grain losses after-harvest*. Natural Resources Institute: Chatham, UK.
- , 2001. Post-harvest losses to insects – a world overview. *International Biodeterioration and Biodegradation* 48:137-52.
- De Groote, H., 2013. *Economic analysis of maize storage technologies in East and Southern Africa*, presentation at Agriculture and Food Security – Post-harvest Management (PHM) in Sub-Saharan Africa, Addis Ababa, October 29<sup>th</sup>.
- FAO, 1981. *Food loss prevention in perishable crops*. FAO Agricultural Services Bulletin: Rome, Italy.
- FAO, 1990. *Roots, tubers, plantains and bananas in human nutrition*. FAO: Rome, Italy.
- FAO, 2009. *Framework paper on postharvest loss reduction in Africa*. FAO: Rome, Italy
- FAO, 2011. *Global Food Losses and Food Waste-Extent, Causes and Prevention*. FAO: Rome, Italy.
- FAO, 2012. *National statistics on post-harvest losses and food waste*. FAO: Rome, Italy.
- Fuglie, K. O., 1995. Measuring Welfare Benefits from Improvements in Storage Technology with an Application to Tunesian Potatoes, *American Journal of Agricultural Economics* 77: 162-173.
- Greeley, M., 1982. Pinpointing post-harvest losses. *Ceres* 15 (1), 30-37.
- Greeley, M., 1986. Food technology and employment: the farm-level postharvest system in developing countries. *Journal of Agricultural Economics*, 37(3): 333–48.
- Grolleaud M., 1997. Post-Harvest Losses: Discovering the Full Story. FAO: Rome, Italy.
- Heckman, J., 1979. Sample selection bias as a specification error. *Econometrica* 47 (1): 153–61.
- Henkes, C., 1992. *Investigations into insect population dynamics, damage and losses of stored maize - an approach to IPM in small farms in Tanzania with special reference to Prostephanus truncatus (Horn)*. GTZ: Hamburg, Germany.
- Hodges, R., 2010. *Postharvest weight loss estimates for cereal supply calculations in East and Southern Africa*. Natural Resources Institute: Chatham, UK.
- IFPRI, Concern Worldwide and Welthungerhilfe, 2013. *Global Hunger Index – The Challenge of Hunger: Building Resilience to Achieve Food and Nutrition Security*. IFPRI, Concern World Wide and Welthungerhilfe: Washington DC, Dublin and Bonn.
- Kaminski, J., Christiaensen, L., Gilbert, C.L., and C.R. Udry, 2013. Is Seasonality Still Permeating African Agriculture? Presentation at the fourth International Conference of the African Association of Agricultural Economists, September 22-25, Hammamet, Tunisia.



- Kimenju, S.C., and H. De Groote. 2010. *Economic Analysis of Alternative Maize Storage Technologies in Kenya*. Paper presented at the Joint 3rd African Association of Agricultural Economists (AAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, Cape Town, South Africa.
- Lipinski, B., Hanson, C., Lomaw, J., Kitinoja, L., Waite, R., and T. Searchinger, 2013. *Reducing Food Loss and Waste*. Working Paper, Installment 2 of Creating a Sustainable Food Future. Washington, DC: World Resources Institute.
- Lipton, M., 1982. Post-harvest Technology and the Reduction of Hunger, *Institute of Development Studies Bulletin* 13-3: Brighton, Sussex.
- Park, A., 2006. Risk and Household Grain Management in Developing Countries. *The Economic Journal* 116:1088-1115.
- Sahn, D., and D?, Stifel, 2003. Exploring Alternative Measures of Welfare in the Absence of Expenditure Data, *Review of Income and Wealth* 49-4: 463-89.
- Stathers, T. E., M. Morris, W. Riwa, and B. M. Mvumi, 2004. *Farmers' livelihoods: What role for grain protection?* Chatham, UK: Natural Resources Institute.
- Stathers, T. E., R. I. Lamboll, and B. M. Mvumi, 2013. Postharvest agriculture in changing climates: its importance to African smallholder farmers. *Food Security* 5: 361-392
- Stephens, E., and C. B., Barrett, 2011. Incomplete Credit Markets and Commodity Marketing Behaviour. *Journal of Agricultural Economics* 62-1: 1-24.
- Wooldridge, J.M., 2002. *Econometric Analysis of Cross Section and Panel Data*. MIT Press: Cambridge, MA.
- World Bank, 2011a. *Responding to Global Food Price Volatility and Its Impact on Food Security*. Document prepared for the April 16, 2011 Development Committee Meeting by the staff of the World Bank.
- World Bank, 2011b. *Missing Food: The Case of Postharvest Losses in Sub-Saharan Africa*. Report No. 60371 – Africa Region, World Bank: Washington, DC.

Table 1: On-farm post-harvest loss of maize limited on average and concentrated among few.

| Proportions (%)  | Uganda 2009-10 |      | TZ 2010-11 |      | TZ 2008-09 |      | MWI 2010-11 |      |
|--|----------------|------|------------|------|------------|------|-------------|------|
|  | Mean           | SE   | Mean       | SE   | Mean       | SE   | Mean        | SE   |
| National PHL( 11 months adjusted)                                      | 5.9            | 11.9 | 2.9        | 5.0  | 4.4        | 9.5  | 1.4         | 6.0  |
| Household-level PHL<br>(11 months adjusted)                            | 3.9            | 11.3 | 1.9        | 5.4  | 3.8        | 8.9  | 2.9         | 10.7 |
| National probability of reporting PHL<br>(11 month adjusted, national) | 21.5           | 37.5 | 14.7       | 32.1 | 19.0       | 35.9 | 6.8         | 22.7 |
| National PHL among losers only<br>( 11 months adjusted)                | 27.4           |      | 19.7       |      | 23.1       |      | 20.6        |      |
| Number of observations<br>(maize-producing households)                 | 1,853          |      | 1,520      |      | 1,301      |      | 10,331      |      |

National numbers are household based estimates weighted by maize harvested.

Source: LSMS-ISA surveys (authors' own calculations)

Table 2: Basic post-harvest indicators and PHL estimates for LSMS-ISA surveys

| Storage and crop protection modalities among maize farmers (national) (%) | UG 2009-10 | TZ 2010-11 | TZ 2008-09 | MWI 2010-11 |
|---|------------|------------|------------|-------------|
| Traditional storage   | 1.4        | 24.8       | 19.2       | 17.9        |
| Improved storage  | 0.6        | 11.5       | 5.9        | 2.0         |
| Crop protection (spraying or smoking)                                     | 63.1       | 49.0       | 37.2       | 10.8        |
| Number of observations (maize-producing households)                       | 1,853      | 1,520      | 1,301      | 10,331      |

Notes: National numbers are household based estimates reweighted by maize harvested quantities. Improved storage refers to the use of airtight drums, modern store or metallic silos, or improved local infrastructures. Traditional and improved storage techniques are contrasted with “poor storage” that comprises in-house or ceiling storage, unprotected piles, and open drums and sacks.

Source: LSMS-ISA surveys (authors’ own calculations)

Table 3: Insects and rodents/pests (biotic factors) are responsible for the bulk of on-farm PHL of maize.

|                | Contribution of stated reasons for PHL to national self-reported maize PHL (%points) |                  |                  |                |
|----------------|--|------------------|------------------|----------------|
|                | Uganda 2009-10   | Tanzania 2010-11 | Tanzania 2008-09 | Malawi 2010-11 |
| Insects        | 1.77   | 0.56             | 2.29             | 0.27           |
| Rodents/pests  | 1.41   | 2.03             | 1.61             | 0.53           |
| Flood / rotten | 0.17   | 0.25             | 0.07             | 0.40           |
| Theft          | 0.31   | 0.07             | 0.35             | 0.04           |
| Other          | 2.23   | 0.00             | 0.03             | 0.15           |
| PHL (sum)      | 5.90   | 2.90             | 4.35             | 1.40           |

Notes: Household based estimates reweighted by maize harvested quantities.

Source: LSMS-ISA surveys (authors' own calculations)

Table 4: Reduced-form estimates of the determinants of self-reported PHLs of maize (magnitude and probability)

|  | Tobit PHL<br>(with selection correction) |        |     | Probit PHL reported<br>(yes/no)<br>(with selection correction) |       |     |
|--|--|--------|-----|--|-------|-----|
|  | Coef                                     | SE     |     | Coeff  | SE    |     |
| <b>Interview design features</b>         |  |        |     |  |       |     |
| Ln(months after harvest)                 | 0.158                                    | 0.052  | *** | 0.449  | 0.130 | *** |
| <b>Household characteristics</b>         |  |        |     |  |       |     |
| Male headed hh                           | 0.116                                    | 0.045  | **  | 0.226  | 0.130 | *   |
| Age of the hh head                       | 0.002                                    | 0.001  |     | 0.006  | 0.004 |     |
| Education of the hh head, base=none      |  |        |     |  |       |     |
| Primary incomplete                       | 0.04                                     | 0.047  |     | 0.208  | 0.139 |     |
| Primary complete                         | 0.006                                    | 0.055  |     | 0.100  | 0.148 |     |
| Secondary incomplete                     | -0.27                                    | 0.151  | *   | -0.697   | 0.423 | *   |
| Household size                           | -0.01                                    | 0.007  | *   | -0.046   | 0.022 | **  |
| Asset index                              | 0.005                                    | 0.022  |     | -0.001   | 0.061 |     |
| Rural household                          | -0.11                                    | 0.075  |     | -0.267   | 0.221 |     |
| <b>Economic environment</b>              |  |        |     |  |       |     |
| Wholesale maize seasonal price gap       | -0.07                                    | 0.039  | **  | -0.213   | 0.109 | **  |
| Retail maize seasonal price gap          | -0.05                                    | 0.024  | **  | -0.127   | 0.070 | *   |
| Distance to main population center       | 8E-04                                    | 6E-04  |     | 0.003  | 0.002 |     |
| Distance to main marketplace             | 9E-04                                    | 5E-04  | *   | 0.002  | 0.001 |     |
| <b>Agro-ecological environment</b>       |  |        |     |  |       |     |
| AEZ: warm semi-arid = base               |  |        |     |  |       |     |
| Warm sub-humid                           | 0.061                                    | 0.087  |     | 0.036  | 0.256 |     |
| Cool semi-arid                           | 0.083                                    | 0.111  |     | 0.219  | 0.295 |     |
| Cool sub-humid                           | 0.123                                    | 0.094  |     | 0.273  | 0.268 |     |
| Annual mean temperature                  | -0.01                                    | 0.007  |     | -0.045   | 0.021 | **  |
| Mean temperature of the wettest quarter  | 0.013                                    | 0.007  | *   | 0.053  | 0.021 | *** |
| Average total rainfalls                  | 6E-04                                    | 7E-04  |     | 0.002  | 0.002 |     |
| Average rainfalls of the wettest quarter | 2E-04                                    | 0.001  |     | -0.002   | 0.003 |     |
| Total rainfalls in july 2007-june 2008   | -0                                       | 5E-04  |     | -0.001   | 0.001 |     |
| Rainfall of the wettest q 2007-2008      | -0                                       | 6E-04  |     | 0.000  | 0.002 |     |
| Total rainfalls post-harvest 2008-09     | -0.001                                   | 5E-04  | *** | -0.003   | 0.001 | *** |
| Rainfall of the wettest quarter 2008-09  | 0.001                                    | 7E-04  | *** | 0.004  | 0.002 | **  |
| Regional dummies                         |  | Yes*** |     | No   |       |     |
| Month of the harvest dummies             |  | Yes*** |     | Yes***   |       |     |
| Inverse Mills Ratio                      | -0.12                                    | 0.114  |     | -0.414   | 0.259 | *   |
| Constant                                 | 2.118                                    | 1.796  |     | 4.940  | 5.426 |     |
| Estimated sigma (for tobit)              | 0.341                                    | 0.03   | *** |  |       |     |
| Observations                             |  | 1,185  |     |  | 1,185 |     |

Note: \* means statistical significance at the 10% level, \*\* at the 5% level, and \*\*\* at the 1% level

## Appendix

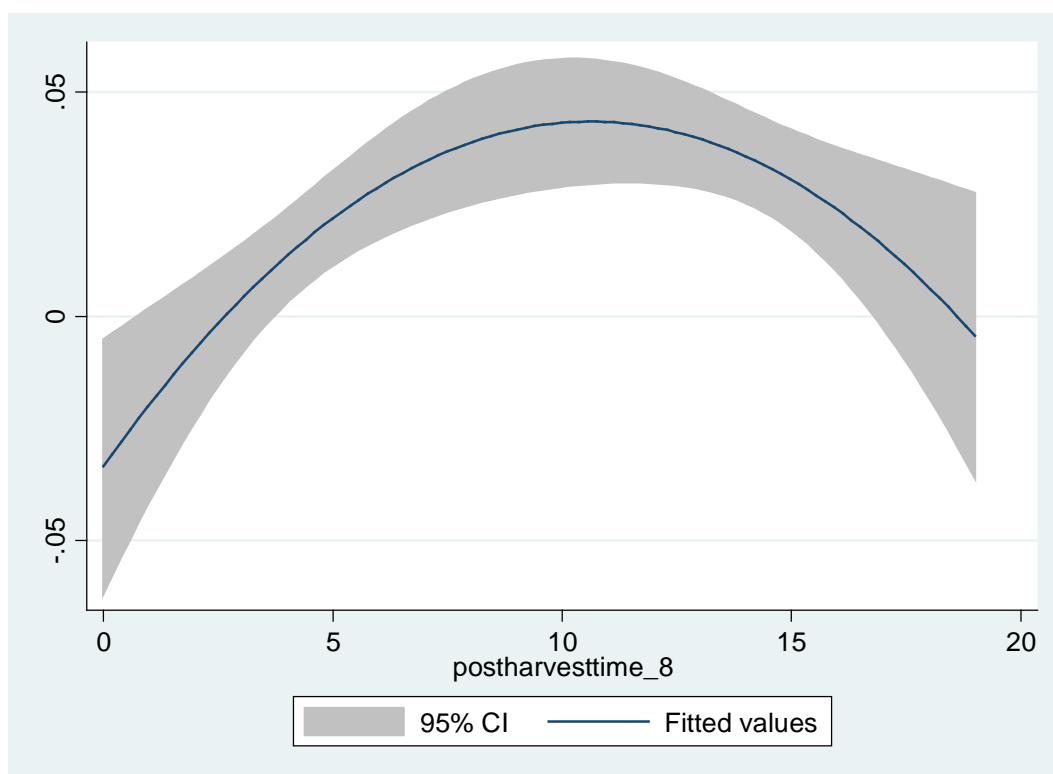
### A1. Adjustment procedure for the effect of interview timing on PHL estimates

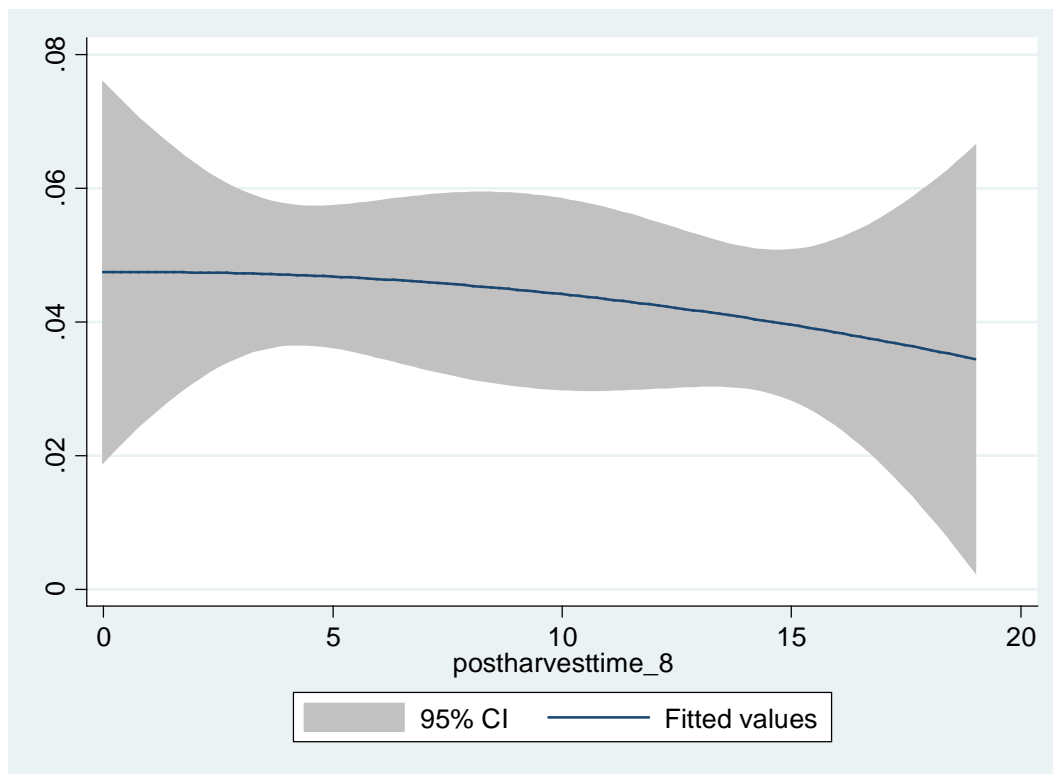
To correct for the amount of PHL which may have occurred after the date of the interview, the households declaring a strictly positive harvest of maize (our focus group) are split in two groups: 1) those reporting strictly positive maize PHL at the time of the interview and 2) those reporting no PHL at the time of the interview. The adjustment begins by estimating the effect of the number of months between the month of interview and the month of harvest completion on the proportion of PHL reported (using a Tobit regression) and the probability of reporting PHL (using a Probit regression). Other control variables in each regression included demographic characteristics of the household (household size, age, sex and education of household head), as well as indicators of the household's market accessibility and climatic conditions (average village-level rainfall and temperatures and their values the year before and during the survey, together with indicator variables of the agro-ecological zone of the household's residence, regional indicator variables and controls for the month of harvest) (as in Table 4).

The time lag between the month of interview and harvest completion was specified both as a quadratic and a logarithmic, with the former fitting the data best and the reported proportion (among losers) of PHL peaking at 11.22 months, and the reporting probability peaking at 11.64 months. Given the cumulative nature of PHL, those were taken as the cut-off points. By then the new harvest of the next agricultural season has come in and the decline in reported PHL for longer time lags is likely to follow from measurement bias due to interference of the new with the old harvest. Given the estimated effects of the time lag (from the quadratic specification) on reported PHL, the reported PHLs for all maize producers that reported a positive loss at the time of the interview were adjusted as follows: PHL adjusted at 11.22 month (for households with PHL>0 at interview)=Reported PHL+0.0144\*(11.22-interview-harvest time lag)-0.000641 (11.22<sup>2</sup>-interview-harvest time lag<sup>2</sup>). To obtain the annually adjusted PHL for those maize producers reporting no PHL

at the interview, the following adjustment procedure was followed. First, the probability of reporting a strictly positive PHL in the remaining period between the date of interview and the beginning of next harvest (proxied by the peak value of PHL probability, i.e. 11.64 months) was calculated: PHL probability adjusted at 11.64 months (for those with PHL=0 at interview) =  $0.03734 * (11.64 - \text{interview-harvest time lag}) - 0.001604 * (11.64^2 - \text{interview-harvest time lag}^2)$ . This adjusted probability was subsequently multiplied with the average amount of loss reported for that remaining period as indicated above, i.e. PHL adjusted at 11.64 months (for those with PHL=0 at interview) = [PHL probability adjusted at 11.64 months] \* [PHL adjusted at 11.22 month (PHL>0 at interview)].

#### Self-reported PHL before adjustment for interview time



**Self-reported after quadratic adjustment for interview time**



**A2. Correlation analysis of PHL proximate drivers for Tanzania 2008-9**

| PHL rate                           | Tobit 1 |              |     | Tobit 2 |              |     |
|------------------------------------|---------|--------------|-----|---------|--------------|-----|
|                                    | Coef.   | Std.<br>Err. |     | Coef.   | Std.<br>Err. |     |
| In(months after harvest)           | 0.1926  | 0.056        | *** | 0.2082  | 0.058        | *** |
| Storage depletion rate             | -0.0915 | 0.084        |     | 0.0118  | 0.126        |     |
| Share of marketed quantities       | 0.1475  | 0.08         | *   | 0.1308  | 0.082        | *   |
| Market share * trans. distance     | -1E-05  | 5E-05        |     | -1E-05  | 5E-05        |     |
| Market share * # sales             | 0.0691  | 0.032        | **  | 6.3E-02 | 3.0E-02      | **  |
| Harvested quantities               | 4.8E-06 | 7.6E-06      |     | 3.0E-06 | 7.8E-06      |     |
| Poor storage                       |         |              |     | 0.0939  | 0.067        |     |
| Traditional                        |         |              |     | -0.0832 | 0.108        |     |
| Improved                           |         |              |     | -0.097  | 0.154        |     |
| Spraying or smoking                |         |              |     | 0.0522  | 0.047        |     |
| AEZ: Warm semi-arid= base category |         |              |     |         |              |     |
| Warm sub-humid                     | -0.0531 | 0.082        |     | -0.0562 | 0.082        |     |
| Cool semi-arid                     | 0.058   | 0.1          |     | 0.0379  | 0.099        |     |
| Cool sub-humid                     | -0.0345 | 0.089        |     | -0.0394 | 0.089        |     |
| Month of harvest dummies           |         | Yes***       |     |         | Yes***       |     |
| Region dummies                     |         | Yes***       |     |         | Yes***       |     |
| Constant                           | -0.4466 | 0.245        | *   | -0.5747 | 0.284        | **  |
| Estimated sigma                    | 0.3596  | 0.033        | *** | 0.3566  | 0.032        | *** |
| Observations                       |         | 1,219        |     |         | 1,218        |     |

Note: \* means statistical significance at the 10% level, \*\* at the 5% level, and \*\*\* at the 1% level

**A3. Descriptive statistics of maize growers in the long rainy season, Tanzania 2008-9**

| Variables   | N    | MEAN    | SE      |
|---|------|---------|---------|
| PHL - hh-level average                                  | 1301 | 2.63%   | 8.91%   |
| National PHL  | 1301 | 3.18%   | 9.57%   |
| Post-harvest interview time (months)                    | 1301 | 10.03   | 4.09    |
| % reporting losses                                      | 1301 | 16.29%  | 36.93%  |
| % reporting losses - adjusted                           | 1301 | 19.05%  | 35.86%  |
| PHL adjusted hh average                                 | 1301 | 3.81%   | 8.90%   |
| PHL adjusted national PHL                               | 1301 | 4.35%   | 9.50%   |
| Storage depletion rate                                  | 1301 | 86.93%  | 23.59%  |
| Marketing rate qities                                   | 1301 | 19.08%  | 24.50%  |
| Marketing rate values                                   | 1301 | 24.11%  | 30.82%  |
| Number of sales   | 1301 | 0.462   | 1.333   |
| Number of sales of sellers only                         | 373  | 0.869   | 1.728   |
| Transportation distance (km)                            | 1301 | 172.147 | 618.208 |
| Transp. Distance for sellers only (km)                  | 373  | 323.472 | 818.040 |
| Distance to main population center (km)                 | 1220 | 56.083  | 36.562  |
| Distance to main marketplace (km)                       | 1220 | 81.598  | 54.154  |
| Wholesale price seasonal gap (%)                        | 1288 | 30.716  | 7.068   |
| Retail price seasonal gap (%)                           | 1288 | 27.351  | 8.551   |
| Male-headed households (prevalence)                     | 1301 | 86.35%  |         |
| Age of the household head                               | 1301 | 48.46   | 17.94   |
| Household head with post-primary education (prevalence) | 1281 | 5.8%    |         |
| Household size (number)                                 | 1301 | 5.91    | 3.51    |
| Asset index   | 1301 | -0.45   | 1.08    |
| Rural household (prevalence)                            | 1301 | 90.99%  |         |
| Annual mean temperature (°C) 1960-2000                  | 1218 | 21.71   | 2.36    |
| Mean temperature of the wettest quarter (°C) 1960-2000  | 1218 | 22.35   | 2.34    |
| Average total rainfalls (mm) 1960-2000                  | 1218 | 1002.5  | 292.5   |
| Average rainfalls of the wettest quarter (mm) 1960-2000 | 1218 | 536.4   | 159.5   |
| Total rainfalls in july 2007-june 2008 (mm)             | 1218 | 748.1   | 218.5   |
| Rainfall of the wettest quarter 2007-2008 (mm)          | 1218 | 501.5   | 139.2   |
| Total rainfalls post- harvest 2008-09 (mm)              | 1218 | 809.1   | 326.3   |
| Rainfall of the wettest quarter post-harvest (mm)       | 1218 | 520.9   | 210.1   |

Notes: Averages are household based estimates reweighted by maize harvested quantities..

Source: LSMS-ISA surveys (authors' own calculations)