Relating Rainfall Patterns to Agricultural Income: Implications for Rural Development in Mozambique

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ABSTRACT
Rural farmers in Mozambique rely on rain-fed agriculture for food and income, yet they experience high rainfall variability ranging from extreme drought to flooding rainfall from tropical cyclone systems. To explore linkages between rainfall and agriculture, the authors regress changes in annual household per capita agricultural income on reliance on staple food crops, agricultural and demographic characteristics, and rainfall patterns using longitudinal data for rural households for 2002 and 2005. They characterize rainfall patterns by defining nine rainfall zones using the percent of normal rainfall received in each month of three agricultural growing seasons and rainfall from two tropical cyclones that occurred during the study period. Results show that in a period where monthly rainfall seldom occurred in normal amounts, most households experienced decreases in agricultural income. Even after controlling for rainfall patterns, they find that greater household dependency on staple crop agriculture is associated with declining annual agricultural income. They also find that areas affected by both wet and dry rainfall extremes in the first year of the study had decreases in the well-being of rural households when measured two years later. Taken together, their findings suggest that antipoverty policies focused on increasing agricultural income seem likely to fail in countries characterized by highly variable rainfall and exposure to extreme events, particularly when coupled with high levels of poverty and widespread dependence on rain-fed agriculture.

1. Introduction
The endemic poverty of rural agriculturalists in many less developed countries (LDCs), together with growing evidence of climate change, has led to increasing interest in the effects of weather on the well-being of these populations. Since the 1960s, the dominant approach to rural development in low-income countries has focused on strengthening the small-farm agricultural sector in order to alleviate rural poverty (IFPRI 2002; Ellis and Biggs 2001; Ellis 2000). Yet, the agricultural sector across sub-Saharan Africa is highly vulnerable to climate variability and extremes (Easterling et al. 2007; Thomas et al. 2007; Parry et al. 2004; Rosenzweig and Parry 1994; Molua 2002) because of its high dependence on rain-fed agriculture.

Research suggests that the region will experience decreased annual rainfall and increased warming overall, and exposure to extreme weather events is predicted to increase locally (Easterling et al. 2007). A need exists to collectively examine rainfall patterns, dependence on crop agriculture, and rural well-being to inform policies aimed at mitigating climate vulnerability.

Mozambique provides an illustrative region to examine vulnerability to climate variability and extreme events in southern Africa. The country exemplifies many of the challenges facing LDCs, including extreme poverty, low levels of human and physical capital, heavy aid dependency, and limited capacity to cope with climate change. Mozambique is arguably one of the poorest nations in the world, and its low rankings on standard development indicators such as gross domestic product (GDP) per capita (ranked 209 out of 226 countries) and the Human Development Index (ranked 165 out of 169 countries) reveal that the vast majority of Mozambicans experience a very poor quality of life (Central Intelligence...
Agency 2013; United Nations Development Programme 2011). Nearly 70% of the population lives in rural areas and most households depend on rain-fed subsistence agriculture (Instituto Nacional de Estatística 2008; Mather et al. 2008). Thus, weather-related shocks to agricultural households have considerable potential to exacerbate existing poverty. A better understanding of how economic vulnerability of rural households is driven by agricultural dependency and how this varies across regions characterized by different rainfall patterns could have a direct impact on poverty reduction, improved food security, and the ability for rural people to maintain social norms and traditions that they have reason to value in developing countries such as Mozambique.

Recent empirical work finds that the weather is one of the most significant factors determining the well-being of rural Mozambican households. Mather (2012), Cunguara (2008), and Mather et al. (2008) find that a high number of drought days in the growing season have a strong, negative effect on agricultural income, primarily through decreases in maize and cassava production. Cunguara and Darnhofer (2011) find that the use of improved agricultural technologies by rural Mozambican farmers had no statistically significant impact on household income most likely because of drought conditions during their study period. However, these studies did not report on the effects of high rainfall events. Cunguara and Kelly (2009) find only minimal statistical significance for the majority of monthly rainfall totals during the growing season on successful outcomes for households farming maize. Their weather-related findings could be due to the fact that examining discreet monthly totals does not account for the complexity of the rainfall patterns over space and time. In addition, all four studies call for more in-depth research linking weather to agriculture.

The goal of our study is to relate distinctive rainfall patterns to changes in crop income for farmers in Mozambique by testing two main hypotheses. First, we hypothesize that the differing economic outcomes for rural agriculturalists will be explicable, in part, by the varying rainfall patterns that households experience over the study period. Second, we expect that higher dependency on income from staple food crops will be associated with declining agricultural incomes. We group households into zones based on intraseasonal rainfall patterns before we test the first hypothesis. This method allows us to consider both wet and dry events as well as identify households that experienced similar rainfall patterns. Using the most recently available longitudinal data on rural households from surveys conducted in 2002 and 2005, we utilize regression analysis to examine the effects of distinctive rainfall patterns on crop income while controlling for agricultural and demographic characteristics of households. After discussing the variability of rainfall throughout the study period, we demonstrate that both wet and dry events are associated with the largest negative changes in agricultural income across the study period. By measuring the effects of staple crop dependency on agricultural incomes in a period characterized by highly variable and extreme weather, this study also has implications regarding Mozambique’s current poverty reduction strategy.

2. Characteristics of the study region
There are marked differences between the northern, central, and southern regions of Mozambique with regard to poverty and development stemming from both the Portuguese colonial legacy and postindependence government policies (Isaacman 1996; Wuyts 1996, 2003; Pitcher 2002; Sheldon 2002). Colonial policies channeled development into the south of the country near the capital city Maputo. In addition, South African mining companies heavily recruited workers from the southern provinces, allowing households in this area more access to remittance income and financial capital to invest in farming (Hermele 1992). This trend of southern economic dominance has continued, in part because of infrastructure damage resulting from two protracting armed conflicts: the war for independence (1961–74) and the civil war (1977–92). Thus, the southern regions are characterized by higher household incomes, better market access, and greater linkages to the global economy (Silva 2007, 2008). The northern and central regions of the country have better agricultural potential than the south, but poor infrastructure and great distance limits farmers’ access to markets (Cunguara and Darnhofer 2011) and contributes to endemic poverty in those areas (Silva 2007).

In terms of climate, bad weather can occur in different parts of the country during the same year. For example, during the 3-yr period of this study, during which drought conditions have been documented (Reason and Phaladi 2005; Rouault and Richard 2005), two tropical cyclones made landfall in Mozambique and produced more than 150 mm of rainfall during their passage in different portions of the country (Matyas and Silva 2013). The coastline of Mozambique lies between 11° and 27°S latitude within the southern Indian Ocean basin, a latitudinal zone that favors the tracks of tropical cyclones (Ash and Matyas 2012: Fig. 1). Mozambique experiences approximately two landfalling storms every three

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1 The time period of each cyclone is discussed in detail in the section describing the study region.
years (Matyas and Silva 2013), which can result in flooding rainfall and wind-related damage.

Rainfall in Mozambique is highly variable from year to year (Washington and Preston 2006; Shongwe et al. 2009). On average, the northern and central regions receive 1000 and 1100 mm of rainfall, respectively, during the main growing season months of November–March, while only 600 mm is received during the October–March growing season near Maputo (FAO 2003). Multiday rainfall events occur when tropical temperature troughs (TTTs) develop over the region (Todd and Washington 1999; Usman and Reason 2004; Manhique et al. 2011), and the frequency and locations of these events often correspond with the phase of the El Niño–Southern Oscillation (ENSO). La Niña conditions are associated with high rainfall due to moisture advection from the south Indian Ocean and a stronger-than-normal Angola low, which leads to the development of the TTTs. Dry conditions occur in conjunction with El Niño events as convection shifts offshore east of Madagascar (Jury et al. 2004; Usman and Reason 2004; Reason et al. 2005; Alemaw and Chaoka 2006; Kruger 2007; Manhique et al. 2011). These weather patterns impact agricultural production by causing delays in planting, forcing crops to be replanted, decreasing crop yields, and forcing farmers to alter traditional agricultural practices in response to altered conditions (Silva et al. 2010). Previous studies have found Mozambican farmers to be highly vulnerable to such weather extremes because of, among other reasons, their limited use of irrigation and high levels of poverty (Arndt and Baçou 2000; Patt and Schröter 2008; Hahn et al. 2009; Sietz et al. 2011).

Because of the heavy reliance on rain-fed agriculture and high rainfall variability, this study analyzes rainfall patterns across Mozambique during the three summer growing seasons occurring between the National Agricultural Survey of Mozambique (Trabalho de Inquérito Agrícola (TIA)) surveys in 2002 and 2005. As few complete long-term rain gauge records exist for Mozambique, the paucity of ground-based measurements would lead to highly inaccurate interpolation at the household level. Instead, we utilize satellite-based estimates of monthly rainfall from the Tropical Rainfall Measuring Mission (TRMM) 3B43 product (Huffman et al. 2007). Adeyewa and Nakamura (2003) found that these TRMM estimates closely matched those of the rain gauges over southern Africa. One pixel spans 0.25° latitude and longitude so that 1075 pixels facilitate the analysis of mesoscale rainfall patterns over Mozambique. We obtain data from 1998 to 2009 using the National Aeronautics and Space Administration (NASA) Goddard Earth Sciences Data and Information Services Center (GES DISC) Interactive Online Visualization and Analysis Infrastructure (Giovanni). A GIS interpolates the data using ordinary spherical kriging across the area 9°–30°S and 26°–46°E. As locational coordinates are only available for villages, monthly rainfall totals are assigned to all households within each village and a 12-yr climatology is then calculated for each month. As monthly rainfall varies widely across the country, we calculate the percentage of the 12-yr normal rainfall received in each study month at each village and perform our analyses with these variables instead of the actual monthly rainfall totals. Thus, our study expands the rainfall time series utilized by Cunguara and Kelly (2009) that examined monthly rainfall totals over six years.

Our goal is to group households together that experienced similar rainfall patterns during the primary summer growing season months. Thus, we analyze data for November–March over the entire country and include October for the three southern provinces of Gaza, Inhambane, and Maputo, as their growing season typically begins in this month. Although some crops are harvested in April (FAO 2004), we omit rainfall from this month because of inaccuracies in the TRMM data (Matyas and Silva 2013). The growing seasons included in the current study are 1) October/November 2002 to March 2003, 2) October/November 2003 to March 2004,
and 3) October/November 2004 to March 2005. We also calculate storm-total rainfall from three tropical cyclones using the TRMM 3B42 daily rainfall product. Storm coordinates from the Joint Typhoon Warning Center (Joint Typhoon Warning Center 2003) are utilized to determine the days upon which any tropical cyclone could have produced rainfall over Mozambique. Daily rainfall was summed for 11–12 November for Cyclone Atang, 31 December 2002 to 6 January 2003 for Cyclone Delfina, and 1–5 March 2003 for Cyclone Japhet.

To measure the extent to which regional rainfall patterns can affect household income, we subdivide 536 villages into rainfall zones. Villages used in the analysis were included in both the 2002 and 2005 TIA surveys and had reliable GIS coordinates. This approach differs from those utilized by previous studies in that we identify patterns of rainfall ranging from extreme wet events to extremely dry periods so as to set each group of households apart from others across the country. Villages receiving at least 150 mm of rainfall from a tropical cyclone are placed into a “Delfina” or “Japhet” group, as these are the two most extreme wet events to affect at least 30 villages. Atang only produced high rainfall over 12 villages, making it too small of an event to warrant its own group. Two separate hierarchical cluster analyses emphasizing between-groups linkages are then performed with the remaining 402 villages. Fifteen study months are analyzed to produce four rainfall zones in the northern and central portions of the country, while 18 months are entered into the second analysis for 115 villages located in the three southern provinces. Three rainfall zones are identified in this region. Thus, we identify nine zones that characterize different patterns of intraseasonal rainfall variability.

a. Rainfall patterns

Our 12-yr climatology approximates the totals reported by the FAO (2003), showing that, on average, rainfall is highest in the central portion of the country, while areas in the south receive less than 600 mm during the growing season (Fig. 2a). Although previous research has identified all three seasons as drought years, rainfall deficits did not occur in every study month, and intraseasonal variability in rainfall was high throughout the country. As a result, none of the three seasons closely resembled the 12-yr average (Figs. 2b–d). Rainfall totals varied the most during season 1, as the three tropical cyclones and several multiday rainfall events during January not related to Delfina kept the northern and central regions above normal in terms of seasonal rainfall (Fig. 3a). In the south, however, rainfall was less than 50% of normal overall, and most locations did not receive rainfall that was above normal after October. Season 2 rainfall patterns were closer to normal, but many areas still experienced rainfall deficits (Fig. 3b). Season 3 started wetter than normal in the north and center of Mozambique, but by February, zone-averaged deficits ranged from 40% to 80% of normal nationwide, and these continued through March (Fig. 3c).

We next provide a brief description of the nine rainfall zones. We discuss the combined results of our TRMM-based analysis with data from the Food and Agriculture Organization (FAO) of the United Nations on rainfall patterns, main crops planted, and projected yields for each province (FAO 2003, 2004, 2005). In most cases our rainfall zones cross multiple provinces as the cluster analysis considered the percentage of normal monthly rainfall for each village without regard for administrative boundaries. Zones are numbered from north to south (Fig. 1).

Located in Cabo Delgado Province near the border with Tanzania, zone 1 is the third smallest zone and includes 33 villages. The most distinguishing rainfall characteristic for this zone was that Atang made landfall in Tanzania (Joint Typhoon Warning Center 2003) and brought more than 100 mm of rainfall to 12 villages during 11–12 November. Seventeen villages received more than 75% of their normal monthly rainfall from this tropical cyclone, which represents the most extreme rainfall event in the zone. Although total accumulated rainfall was lower than normal during season 2, due in large part to November 2003, good crop yields were reported in season 2 as well as in season 3, when the seasonal average was near normal. Cassava is the main crop planted within the fertile river valley soils, and cereal crop production is normally very high in this region.

Most zone 2 villages (66) are located in the provinces of Nampula (47%) and Cabo Delgado (45%). Some areas in Nampula received high rainfall from Delfina and suffered crop losses; however, yields were generally good in Cabo Delgado. Rainfall was near normal in the other months of season 1. Rainfall was below normal each month during season 2, but a steady distribution allowed for good crop yields similar to season 1. Above-normal rainfall during November and December 2004 allowed for a good yield in the first planting, but that fell to only 50% of normal by March. Maize and cassava are the main crops grown in zone 2.

The 63 villages in zone 3 are located within 100 km of Malawi in the higher-altitude regions of the Niassa (44%), Zambezia (17%), and Tete (38%) provinces. The most distinctive pattern for this zone was the contrast of seasons 1 and 3 (Fig. 3). A pattern of lower-than-normal totals during the first two months and higher-than-normal totals during the last three months for season 1 was reversed in season 3. Above-normal rainfall occurred in November of season 2, followed by
slightly below-normal conditions for the rest of this season. Crop yields were good for the first two years, but the irregular rains in season 3 favored crops that were planted early. Maize is the main crop planted.

The 104 villages receiving at least 150 mm of rainfall from Delfina comprise zone 4 and are located in Nampula (43%) and Zambezia (55%). Zone 4 extends from the coastline to 350 km inland and covers approximately 109,000 km², making it the third largest zone. The wettest of all months in all zones was January 2003, when an average of 550 mm of rainfall occurred during the passage of Delfina (Fig. 3). This represented more
than 200% of normal January rainfall. In no other month did the percentage of normal rainfall surpass 140%, and serious drought was not reported during any of the study months. In fact, this region, along with zone 5, experienced the most normal of rainfall patterns during season 2, while other zones experienced monthly averages below 50% of normal. Thus, Delfina’s passage brought the most extreme weather conditions to zone 4, where the majority of the country’s cassava crop was planted in each study year.

The cluster analysis determined that 125 villages within portions of the Zambezia (18%), Tete (23%), Manica (28%), and Sofala (31%) provinces had similar rainfall patterns. Zone 5 is approximately 280,000 km² spanning from the coast of the Mozambique Channel inland to the border with Zambia. Overall, the rainfall pattern here was the most similar to normal of the nine zones. The wettest month, at 168% of normal, was March 2003, when some areas received rainfall from Japhet, which the FAO reported to be beneficial to crops. Prior to Japhet’s rainfall, dry conditions were present in most months. The lowlands experienced irregular rainfall patterns and lower crop yields in season 2, but rainfall was more abundant in the interior highlands, so yields were mixed across the zone. Good yields were also reported in season 3. The majority crop in this region is maize, with these four provinces totaling about half of the maize planted nationwide.

Households within the 30 villages that received at least 150 mm of rainfall from Japhet comprise zone 6, which straddles the southern portions of the Manica (50%) and Sofala (50%) provinces. The second wettest month in the study was March 2003, when Japhet produced an average of 400 mm of rainfall over the region, bringing the monthly total to 230% of normal. In no other month did rainfall occur that was more than 110% of normal within zone 6. Early season droughts did occur during seasons 1 and 2, when rainfall was only 26% of normal in both Decembers. Beneficial rains from Japhet (Kadomura 2005; Joint Typhoon Warning Center 2003) allowed for crops damaged by early season drought to be replanted and eventually harvested. The current study does not include any villages located near the landfall location of Japhet, where strong winds were reported to cause damage (Kadomura 2005). Approximately 20% of Mozambique’s maize crop was planted within these two provinces each study year.

In zone 7, 89% of the 45 villages are located within the Inhambane province, and most are within 30 km of the coastline, where conditions are moister in general than farther inland. This zone has the highest percentage of villages located near the coast and because the TRMM 3B43 product is known to underestimate rainfall along the coast (Chen et al. 2013), rainfall totals could have been higher than our study shows. Although drought was the major weather extreme within all three rainfall zones in southern Mozambique during the study period, zone 7 was the least dry overall and received normal rainfall in two months of season 1. After receiving only 50% and 22% of normal rainfall in November and December of season 2, rainfall increased thereafter, and the FAO reports secondary harvests improved as some farmers planted cassava instead of maize. In season 3, the FAO noted that cassava production increased from previous years. This province features a mixture of crops with maize, ground nuts, and cassava comprising 30%, 22%, and 19% of the crops planted, respectively.

Because of their range of distances from the coastline, rainfall variability is higher among the 36 villages of zone 8 than zone 7. The majority of villages (94%) in
zone 8 are located in the Gaza province. The FAO reported severe drought and seeds lost during season 1, yet rainfall patterns were better suited for good yields in season 2. Our study shows that an average of 46% of normal rainfall was received during season 1, which increased to 74% in season 2. During season 3, four dry months followed the good rainfall in October, with March being the only other month when rainfall was more than 56% above normal. The FAO predicted a 45% reduction in maize harvest for season 3, which is the main crop planted in the zone.

Zone 9 is the smallest in the study, covering approximately 13,500 km², and all 34 villages are located within the Maputo province. Season 1 rainfall was less than 42% of normal in three of the six study months, and our finding that the lowest cumulative rainfall total for season 1 occurred here is confirmed by the FAO, which remarks that rainfall was the lowest in 50 years, resulting in a 50% reduction in maize crops from the previous year. We find that an extremely dry October–December was followed by a wet January and March, yielding a near-normal cumulative rainfall for season 2. Early maize crops failed, but later yields were twice as good as during the previous year. Although season 3 rainfall was approximately 75% of normal for all months, the FAO reported that after good rains in October, rainfall was erratic and not good for high crop yields throughout the rest of the season.

b. Socioeconomic characteristics

Now that we have described the nine distinctive rainfall patterns experienced across Mozambique in the study period, we examine socioeconomic characteristics across the zones. We use longitudinal household-level socioeconomic data from the TIA to calculate changes in annual crop income, participation in different crop types, income shares from different crop types, land area under cultivation, and other characteristics of households over the 2002–05 time period. The survey sample is nationally representative of small- and medium-scale farm households. After eliminating extreme outliers and households that did not receive any crop income in either 2002 or 2005, we use data from 3859 households located in 536 villages across the country.

Using the TIA dataset, Mather et al. (2008) and Cunguara (2008) do an extensive analysis of changing income source components by administrative provinces and by income quartiles. They find that income from staple food crops (grains, pulses, roots, and tubers) is particularly important for the most economically vulnerable households as it accounts for 68% or more of the income for the poorest 20% of rural Mozambican households. Since the vast majority of Mozambican small- and medium-scale farmers practice rain-fed agriculture and very few use agricultural inputs such as agricultural traction or irrigation (Walker et al. 2004; Mather et al. 2008; Cunguara and Kelly 2009), they are extremely vulnerable to bad weather. Their findings provide support for our study’s focus on crop income.

Since rural households acquire the bulk of their food from their own production, we calculate all crop income as the annual sum of all crop sales plus imputed income from food retained and consumed by the household. Thus, crop income includes the retained and sold value of staple crops and sales from cash crops, vegetables, fruits, cashews, and coconuts. Costs of seeds, fertilizers, and pesticides are subtracted from gross crop income. In the TIA dataset, the prices used to value retained quantities of food crops consumed by the household are the annual average retail price of each product from the nearest rural retail market as reported by the Mozambican Sistema de Informação de Mercados database (for more detail on the calculation of rural crop prices for 2002 and 2005, see Mather et al. 2008). The TIA uses the survey respondent’s reported value of sales from staple crops, cash crops, vegetables, fruits, cashews, and coconuts.

As evidenced by Table 1, median annual agricultural per capita incomes for rural households were extremely low in both 2002 and 2005. Our findings correspond to other accounts of poverty in the country, which report that 75% of Mozambicans lived on less than USD$1.25 per day in 2003 (World Bank 2013). These levels of poverty underscore the need for rapid policy interventions to improve rural incomes and overall well-being. In addition to examining median annual household per capita income from all agricultural sources, we also look at median income from staple crops, since most rural households derive the majority of their agricultural income from that source (Fig. 4). We find that median income for both staples and all crops declined between 2002 and 2005 in every area except zone 6 (Japhet). Also, decreases in median staple crop income were

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2 The TIA surveys were also conducted in 2006, 2008, and 2012, but the same households were not interviewed, thus preventing our longitudinal study from including these data.

3 Small farms consist of less than 10 ha, and medium-scale farms consist of 10–50 ha (World Bank 2006).

4 Table 1 provides a detailed account of crops categorized as staples and cash crops in the TIA dataset. The full TIA survey instruments for 2002 and 2005 can be accessed at http://fsg.afre.msu.edu/mozambique/survey/index.htm#minag.
Table 1. Median annual household per capita incomes (in 2002 USD) from staple food crops and all crop agriculture. Calculations include all 3859 households in the analysis that reported agricultural income for 2002 and 2005.

<table>
<thead>
<tr>
<th>Rainfall zones</th>
<th>1 (n = 205)</th>
<th>2 (n = 425)</th>
<th>3 (n = 455)</th>
<th>4 (n = 711)</th>
<th>5 (n = 882)</th>
<th>6 (n = 196)</th>
<th>7 (n = 347)</th>
<th>8 (n = 355)</th>
<th>9 (n = 283)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median household per capita income from staple crops¹</td>
<td>38.41</td>
<td>35.55</td>
<td>65.91</td>
<td>52.35</td>
<td>32.95</td>
<td>29.46</td>
<td>46.97</td>
<td>34.22</td>
<td>59.12</td>
</tr>
<tr>
<td>Median household per capita income from all crop agriculture²</td>
<td>35.52</td>
<td>30.94</td>
<td>43.29</td>
<td>23.52</td>
<td>25.93</td>
<td>36.15</td>
<td>39.15</td>
<td>17.89</td>
<td>23.94</td>
</tr>
<tr>
<td>Median % Δ in per capita income³</td>
<td>−3%</td>
<td>−23%</td>
<td>−23%</td>
<td>−53%</td>
<td>−23%</td>
<td>8%</td>
<td>−12%</td>
<td>−38%</td>
<td>−58%</td>
</tr>
</tbody>
</table>

¹ The total of annual staple crop income of households is calculated by summing all earnings from staple food crops minus the cost of seeds, pesticides, and fertilizers. Staple food crops consist of maize, rice, sorghum, millet, peanuts, butter beans, cowpeas, Bambara groundnuts, pigeon beans, Irish potatoes, cassava, and sweet potato. The total staple crop income is then divided by the number of household members to construct per capita values.

² New Mozambican Metical (MTN) in 2002 converted into 2002 USD, adjusted for purchasing power parity (PPP), using the World Bank PPP conversion factor for private household consumption.

³ MTN in 2005 first converted to 2002 MTN values using the International Monetary Fund’s inflation statistics for Mozambique. The figures are then converted into 2002 USD, adjusted for PPP, using the World Bank PPP conversion factor for private household consumption.

⁴ We report median percentage change in household per capita annual incomes.

⁵ Total crop income is calculated by adding the sum of crop sales plus imputed income from food retained and consumed by the household. Thus, crop income includes the retained and sold value of staple crops and sales from cash crops (i.e., cotton, tobacco, tea, sisal, soybeans, paprika, sunflower and sesame seeds, and ginger), vegetables, cashews, and coconuts. Costs of seeds, fertilizers, and pesticides are subtracted from gross crop income. Total crop income is then divided by the number of household members to construct per capita values.

either greater or almost equal to reductions in income from all crop agriculture.

Although southern Mozambique is widely acknowledged to be more economically developed than other parts of the country, we find that median incomes from staple crops or all crops did not follow any north–south geographic pattern in either year. Zones 4, 8, and 9 experienced the greatest declines in both types of agricultural income and, by 2005, were the poorest in absolute terms according to both our measures. Zone 9, our region with the most severe drought conditions, saw median agricultural incomes decline by more than 50%, and zone 4 (Delfina) experienced decreases of only a slightly lower magnitude. By 2005, zone 8, which also experienced drought conditions, had the lowest median crop incomes of all the zones. Zones 1 and 7 experienced the smallest declines in income from both staples and all crops, although some villages in zone 1 experienced an extreme wet event (Atang), and zone 7 was characterized by dry conditions (although coastal locations may have been less dry). Although zone 6 (Japhet) was the only region with an absolute increase in median agricultural incomes according to both measures, it was the poorest region, in absolute terms, at the start of the study period.

We next report the breakdown of crop types by rainfall zone (unlike previous studies that employed administrative districts) to regionally summarize the composition of crop types that comprise total crop income.

Staple food crops make up the largest single income source for agricultural income in every zone in both 2002, ranging from 78% to 96%, and 2005, ranging from 71% to 90% (Fig. 4). With the exception of zone 1, the percentage of income from staple crops decreased by an average of 7%. Zone 8 experienced the largest decline (19%) in share of staple crop income. In general, household participation in staple crop production decreased much less than agricultural income share (Table 2). For example, in zone 4, 100% of households grew staple crops in 2002, and that number declined by only 1% in 2005. This rate of initial participation and decrease was similar to that seen in zones 1, 2, 3, and 5. In contrast, zone 8 experienced the greatest decrease in households growing staple crops, dropping from 97% to 77%. Participation in staple crop agriculture also experienced substantial decreases in zones 7 and 9, the other two regions that experienced low rainfall, by 17% and 12%, respectively.

Increases in income share from agricultural sources that were not staple crops tended to be very small in all zones. For example, zone 3 experienced the greatest increase in cash crop income share, rising by 3%. Most zones did experience a slight increase in cash crop
income share, with the average being 1.2%. Zone 2 had the highest rate of households participating in cash crop production in both years (Table 2), and its income share from this source was also highest. Zones 3, 4, and 5 also had relatively high degrees of income coming from cash crops, although rates of household participation in this activity fell by 2%–4% in these zones. Zone 6 (Japhet) witnessed the greatest decrease in households participating

![Fig. 4. Composition of total agricultural income by source in 2002 and 2005 across nine rainfall zones.](image)

**Table 2. Percentage of households with income from each crop source in 2002 and 2005.**

<table>
<thead>
<tr>
<th>Rainfall zones</th>
<th>1 (n = 205)</th>
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<th>9 (n = 283)</th>
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<tbody>
<tr>
<td><strong>Staple crops</strong></td>
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<tr>
<td>In 2002</td>
<td>99%</td>
<td>99%</td>
<td>99%</td>
<td>100%</td>
<td>98%</td>
<td>99%</td>
<td>99%</td>
<td>97%</td>
<td>97%</td>
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<tr>
<td>In 2005</td>
<td>96%</td>
<td>97%</td>
<td>98%</td>
<td>98%</td>
<td>95%</td>
<td>91%</td>
<td>82%</td>
<td>77%</td>
<td>84%</td>
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<tr>
<td>Difference</td>
<td>−2%</td>
<td>−1%</td>
<td>−1%</td>
<td>−1%</td>
<td>−3%</td>
<td>−8%</td>
<td>−17%</td>
<td>−20%</td>
<td>−12%</td>
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<tr>
<td><strong>Cash crops</strong></td>
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<tr>
<td>In 2002</td>
<td>10%</td>
<td>42%</td>
<td>26%</td>
<td>18%</td>
<td>21%</td>
<td>27%</td>
<td>2%</td>
<td>1%</td>
<td>2%</td>
</tr>
<tr>
<td>In 2005</td>
<td>5%</td>
<td>35%</td>
<td>24%</td>
<td>16%</td>
<td>17%</td>
<td>10%</td>
<td>2%</td>
<td>3%</td>
<td>7%</td>
</tr>
<tr>
<td>Difference</td>
<td>−5%</td>
<td>−7%</td>
<td>−2%</td>
<td>−2%</td>
<td>−4%</td>
<td>−17%</td>
<td>0%</td>
<td>2%</td>
<td>5%</td>
</tr>
<tr>
<td><strong>Vegetables</strong></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In 2002</td>
<td>14%</td>
<td>14%</td>
<td>28%</td>
<td>13%</td>
<td>21%</td>
<td>16%</td>
<td>10%</td>
<td>8%</td>
<td>16%</td>
</tr>
<tr>
<td>In 2005</td>
<td>7%</td>
<td>5%</td>
<td>8%</td>
<td>8%</td>
<td>8%</td>
<td>7%</td>
<td>6%</td>
<td>9%</td>
<td>12%</td>
</tr>
<tr>
<td>Difference</td>
<td>−7%</td>
<td>−9%</td>
<td>−20%</td>
<td>−5%</td>
<td>−14%</td>
<td>−9%</td>
<td>−4%</td>
<td>2%</td>
<td>−4%</td>
</tr>
<tr>
<td><strong>Fruits</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In 2002</td>
<td>16%</td>
<td>16%</td>
<td>34%</td>
<td>17%</td>
<td>19%</td>
<td>23%</td>
<td>19%</td>
<td>10%</td>
<td>16%</td>
</tr>
<tr>
<td>In 2005</td>
<td>17%</td>
<td>17%</td>
<td>22%</td>
<td>20%</td>
<td>12%</td>
<td>20%</td>
<td>17%</td>
<td>13%</td>
<td>6%</td>
</tr>
<tr>
<td>Difference</td>
<td>1%</td>
<td>1%</td>
<td>−12%</td>
<td>3%</td>
<td>−7%</td>
<td>−3%</td>
<td>−3%</td>
<td>3%</td>
<td>−10%</td>
</tr>
<tr>
<td><strong>Cashews</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In 2002</td>
<td>24%</td>
<td>35%</td>
<td>1%</td>
<td>37%</td>
<td>7%</td>
<td>42%</td>
<td>54%</td>
<td>41%</td>
<td>15%</td>
</tr>
<tr>
<td>In 2005</td>
<td>27%</td>
<td>30%</td>
<td>0%</td>
<td>44%</td>
<td>7%</td>
<td>54%</td>
<td>59%</td>
<td>52%</td>
<td>25%</td>
</tr>
<tr>
<td>Difference</td>
<td>2%</td>
<td>−5%</td>
<td>0%</td>
<td>7%</td>
<td>−1%</td>
<td>11%</td>
<td>5%</td>
<td>12%</td>
<td>10%</td>
</tr>
<tr>
<td><strong>Coconuts</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In 2002</td>
<td>19%</td>
<td>5%</td>
<td>0%</td>
<td>11%</td>
<td>7%</td>
<td>8%</td>
<td>51%</td>
<td>8%</td>
<td>1%</td>
</tr>
<tr>
<td>In 2005</td>
<td>23%</td>
<td>6%</td>
<td>0%</td>
<td>13%</td>
<td>8%</td>
<td>11%</td>
<td>56%</td>
<td>9%</td>
<td>0%</td>
</tr>
<tr>
<td>Difference</td>
<td>5%</td>
<td>1%</td>
<td>0%</td>
<td>1%</td>
<td>1%</td>
<td>3%</td>
<td>5%</td>
<td>1%</td>
<td>0%</td>
</tr>
</tbody>
</table>
in cash crops (17%), but its income share from that source changed by less than 1%.

Income share from vegetables remained relatively steady in all zones, although participation levels decreased in all but zone 8. Vegetables accounted for less than 3% of total agricultural income in any zone. Participation rates in fruit crops were relatively similar across all zones, and income shares from this source changed less than 2%. One exception was zone 3, which had 34% of households participating in this activity in 2002, but saw the greatest participation decrease (12%). Fruit income share was highest in zone 6 in both years, and at least one-fifth of households participated in the activity.

There are two exceptions to the pattern of small changes in income composition noted above. One exception is the 17% increase in income from cashew groups in zone 8, which largely offset the declines in staple crop income share and contributed more than 20% to overall agricultural income in 2005. Across the other zones, cashew crop income share increased by 2.8%. Household participation in cashew production increased the most in zones 8 and 9, 12% and 10%, respectively. Zone 7 is unique in that more than 16% of its agricultural income is derived from coconut in 2002 and 2005, while no other zone exceeded 4%. The highest participation rates for coconut production were also in zone 7 in both years, 51% and 56%, respectively, more than double those in any other zone.

Taken together, our descriptive analysis illustrates that changes in household rates of participation in crop types rarely correspond to changes in income shares from those sources. Unfortunately, the TIA dataset does not provide information on the time households devote to any particular activity, so it is difficult to determine if the discrepancies between participation rates and income shares are the result of household labor allocation. But the case of staple crops, where income shares generally declined much more than household participation levels, suggests downward pressure on income from these crops. Cunguara and Kelly (2009) find that staple food crop prices were stable in Mozambique over the 2002–2005 period, with the exception of maize, which experienced a slight price hike in 2005. This suggests that the income declines associated with staple crop reliance are not due to a drop in prices and, as we hypothesize, can be attributed to weather-related factors, something we explore in our regression analysis.

In terms of our demographic variables, the zones are generally similar by several key measures (Table 3). Household size ranges roughly from 4–6 members and increased slightly in all zones over the study period. Per capita land under cultivation averaged 0.70 ha, with relatively small changes in the zones over time. On average, households in the three southern-most zones (7, 8, and 9) have older heads, higher levels of education, and higher shares of female-headed households. These three zones, as well as zone 1, had lower dependency ratios, averaging 0.72 as compared with 1.05 for the other zones. Except for zone 9, dependency ratios increased slightly in every zone. The percentage of households using fertilizer or pesticides tended to be low, with the exceptions of zones 2 and 3, and changes were generally small. All zones experienced a substantial increase in the share of households with at least one chronically ill member, ranging from 10% in zones 6 and 9 to 24% in zone 2.5

3. Regression analysis

In the following section, we extend our analysis by using a regression approach to examine the relationship between agricultural income change and complex rainfall patterns. This method allows us to control for initial levels of wealth, staple crop income share, and other household characteristics in a way that is not possible through the calculation of simple descriptive statistics.

The Mozambican government has increasingly encouraged small- and medium-scale farmers to produce export crops as a means of alleviating rural poverty (Government of Mozambique 2001, 2006; World Bank 2006; IMF 2007). Development policies aim to increase food security and foster economic growth by assisting all agricultural producers, ranging from agribusinesses to small-scale farmers, in exporting more higher-value agricultural goods (Government of Mozambique 2006). One might expect, in line with the government’s emphasis on agricultural exports, that farmers relying less on staple crops—and thus more on agricultural products for which an international market exists—would fare better economically. Thus, we hypothesize that higher dependency on income from staple food crops in the initial year of our study will be associated with declining total crop incomes.

We also hypothesize that the differing economic outcomes for rural agriculturists will be related to rainfall patterns. More specifically, we predict households experiencing extreme rainfall from a tropical cyclone that produces high rainfall over a large area will have negative

5 The very big differences in illness may be explained by a change in the wording of the questionnaire. In the 2002 TIA, the definition of serious illness was inability to work, while the question was phrased differently in the 2005 instrument. Thus, a higher percentage of sick children was likely captured in the TIA 2005 survey.

<table>
<thead>
<tr>
<th>Rainfall zone</th>
<th>1 (n = 205)</th>
<th>2 (n = 425)</th>
<th>3 (n = 455)</th>
<th>4 (n = 711)</th>
<th>5 (n = 882)</th>
<th>6 (n = 196)</th>
<th>7 (n = 347)</th>
<th>8 (n = 355)</th>
<th>9 (n = 283)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>02 05</td>
<td>02 05</td>
<td>02 05</td>
<td>02 05</td>
<td>02 05</td>
<td>02 05</td>
<td>02 05</td>
<td>02 05</td>
<td>02 05</td>
</tr>
<tr>
<td>Household size</td>
<td>4.23 4.78</td>
<td>4.59 4.97</td>
<td>4.98 5.39</td>
<td>4.49 4.87</td>
<td>5.39 5.86</td>
<td>6.04 6.51</td>
<td>5.45 5.85</td>
<td>5.76 6.15</td>
<td>5.55 5.85</td>
</tr>
<tr>
<td></td>
<td>0.19 0.19</td>
<td>0.11 0.12</td>
<td>0.13 0.16</td>
<td>0.08 0.09</td>
<td>0.12 0.15</td>
<td>0.31 0.30</td>
<td>0.22 0.27</td>
<td>0.25 0.32</td>
<td>0.24 0.27</td>
</tr>
<tr>
<td>Household head's age</td>
<td>43.3 46.4</td>
<td>39.6 42.6</td>
<td>41.1 44.9</td>
<td>39.2 42.4</td>
<td>40.9 43.3</td>
<td>45.9 49.0</td>
<td>49.4 49.9</td>
<td>49.6 52.4</td>
<td>47.1 49.9</td>
</tr>
<tr>
<td></td>
<td>1.52 1.34</td>
<td>0.71 0.66</td>
<td>0.92 0.80</td>
<td>0.56 0.56</td>
<td>0.62 0.59</td>
<td>1.42 1.40</td>
<td>1.05 1.14</td>
<td>1.11 1.09</td>
<td>1.25 1.14</td>
</tr>
<tr>
<td>Dependency ratio</td>
<td>0.72 0.73</td>
<td>1.08 1.10</td>
<td>1.04 1.09</td>
<td>0.99 1.09</td>
<td>1.03 1.02</td>
<td>0.98 1.11</td>
<td>0.77 0.86</td>
<td>0.64 0.73</td>
<td>0.77 0.73</td>
</tr>
<tr>
<td></td>
<td>0.07 0.06</td>
<td>0.04 0.05</td>
<td>0.06 0.06</td>
<td>0.03 0.04</td>
<td>0.04 0.03</td>
<td>0.08 0.06</td>
<td>0.05 0.06</td>
<td>0.05 0.05</td>
<td>0.05 0.05</td>
</tr>
<tr>
<td>Maximum education</td>
<td>2.57 3.31</td>
<td>3.09 3.75</td>
<td>2.99 3.81</td>
<td>3.12 3.77</td>
<td>3.70 4.56</td>
<td>3.45 4.09</td>
<td>4.07 5.26</td>
<td>3.86 4.65</td>
<td>4.30 5.26</td>
</tr>
<tr>
<td></td>
<td>0.23 0.25</td>
<td>0.16 0.17</td>
<td>0.18 0.19</td>
<td>0.13 0.14</td>
<td>0.14 0.17</td>
<td>0.24 0.28</td>
<td>0.25 0.28</td>
<td>0.22 0.25</td>
<td>0.28 0.28</td>
</tr>
<tr>
<td>Per capita cultivated land (ha)</td>
<td>0.75 0.66</td>
<td>0.63 0.71</td>
<td>0.71 0.75</td>
<td>0.70 0.66</td>
<td>0.68 0.62</td>
<td>0.65 0.74</td>
<td>0.71 0.67</td>
<td>0.80 0.77</td>
<td>0.70 0.67</td>
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<tr>
<td></td>
<td>0.07 0.03</td>
<td>0.03 0.04</td>
<td>0.03 0.03</td>
<td>0.05 0.02</td>
<td>0.04 0.03</td>
<td>0.04 0.05</td>
<td>0.05 0.05</td>
<td>0.05 0.06</td>
<td>0.08 0.05</td>
</tr>
<tr>
<td>Female headed (%)</td>
<td>21% 23%</td>
<td>27% 25%</td>
<td>26% 28%</td>
<td>18% 20%</td>
<td>25% 28%</td>
<td>17% 25%</td>
<td>29% 40%</td>
<td>32% 37%</td>
<td>35% 40%</td>
</tr>
<tr>
<td>Chronic illness (%)</td>
<td>4% 19%</td>
<td>3% 27%</td>
<td>5% 24%</td>
<td>6% 23%</td>
<td>6% 17%</td>
<td>6% 15%</td>
<td>8% 27%</td>
<td>10% 23%</td>
<td>5% 14%</td>
</tr>
<tr>
<td>Fertilizer or pesticides (%)</td>
<td>0% 0%</td>
<td>18% 15%</td>
<td>19% 14%</td>
<td>22% 8%</td>
<td>3% 4%</td>
<td>3% 0%</td>
<td>2% 5%</td>
<td>4% 1%</td>
<td>4% 1%</td>
</tr>
</tbody>
</table>

1. The dependency ratio in this analysis is calculated as the number of children under the age of 15 divided by the number of household members over the age of 15. We do not include the elderly (above age 64) as dependents in our measure. In Mozambique, due in part to the HIV/AIDS epidemic, the very elderly often head some households where there are no working-age adults.

2. The number of years of schooling of the most educated member of the household.

3. Chronic illness is defined as a household with one or more members (of any age) reported to be suffering from serious illness at the time of the survey or have suffered a serious illness for at least 3 of the preceding 12 months. The survey does not specify the type of illness.
agricultural outcomes, similar to those of households in regions experiencing prolonged dry conditions. We expect this because seasonal rainfall forecasts are regularly issued (Arndt and Baçou 2000) so that farmers may anticipate drought conditions. In contrast, rainfall from tropical cyclones is more difficult to predict (Langousis and Veneziano 2009), and farmers would not have enough lead times to adjust planting and harvesting schedules. In addition, tropical cyclones can seriously damage crops as well as the infrastructure necessary for farmers to access inputs or agricultural markets, as was the case with Cyclone Eline, which contributed to widespread flooding and damage in southern Mozambique in 2000 (Christie and Hanlon 2001).

a. Modeling approach

We estimate a generalized linear regression model using a generalized estimating equation (GEE) with an exchangeable working correlation matrix to explore the relationship between changes in rural household per capita agricultural income and rainfall patterns. This regression approach is commonly applied when using survey data with stratified sampling designs where the observations are clustered (Mathanga et al. 2010; Ghosh et al. 2008; Cole 2001; Wen and Yeh 2001; Zorn 2001). In the TIA data panel, multiple households were surveyed within each of the sampled villages, resulting in geographically clustered observations. However, even when clustered data observations are correlated, the GEE estimation generates regression coefficient estimates and empirically corrected standard errors that account for clustering and are robust to heteroscedasticity. This modeling approach allows us to pool all households in the sample in a single regression and control for geographical effects, such as elevation, soil types, and other unobservable characteristics that may be shared by households located in the same village. We then test for the effects of distinct rainfall patterns using dummy variables for each rainfall zone.

Table 4 includes details on the construction of each variable used in the analysis. The dependent variable ($\ln Y_i$) is the natural log of annual household per capita change in total crop income (including staple crops, cash crops, vegetables, fruits, cashews, and coconuts) between 2002 and 2005.

All independent variables are for the year 2002, thus measuring the initial conditions in the household before the rainfall patterns occurred and avoiding issues with possible endogeneity if measures of change are used as explanatory variables in the model. We include a variable ($\ln PCI_{i02}$) measuring annual per capita household total crop income, logged, in the regression to control for initial levels of wealth from all crop-related sources. We do this because poorer households will likely experience higher rates of income change given their lower initial income base (i.e., even small increases in income can result in high rates of change when initial incomes are very low). In contrast, wealthier households will likely have lower rates of increase (due to their higher initial income base).

Seven variables in our analysis measure agricultural characteristics of households. $\text{SFC}_{i02}$ is the percentage of total crop income derived from staple food crops. The majority of rural farmers earned some staple food crop income in 2002, allowing for this measure to be constructed as a continuous variable. We also include dummy variables that measure whether or not a household received any income from cash crops ($\text{DCC}_{i02}$), vegetables ($\text{DV}_{i02}$), fruits ($\text{DF}_{i02}$), cashews ($\text{DCA}_{i02}$), or coconuts ($\text{DCO}_{i02}$). We construct all five measures as dummy variables because of the limited number of observations for crops other than staples and high correlation between different types of agricultural production income. We include these crop variables to measure the effect of agricultural income composition on changes in agricultural income over time. As stated previously, we hypothesize that higher dependency on income from staple food crops will be associated with declining agricultural incomes for rural households. To control for the effects of farm size on income change, our model also includes a variable ($\ln PCLand_{i02}$) that measures the per capita land area cultivated by households, logged, to control for the effect of farm size on income change. We expect a positive relationship between farm size and crop income based on previous empirical studies (Mathier 2012).

We also include demographic variables in the analysis that theory and previous empirical evidence suggest will impact agricultural income. These variables are age of

6 One limitation of using the GEE approach is that it is not possible to calculate an $R^2$ for the model (since the estimating procedure does not use a likelihood function). We also estimated our model via ordinary least squares (OLS), and the signs and magnitude of regression parameter coefficients were all similar to the results of our GEE estimation (although the significance levels were much higher, most likely resulting from correlation among clustered observations). Because of space constraints, we only report the regression results from the GEE. Results from the OLS model are available from the lead author upon request.

7 We omit any measures of agricultural input use, such as fertilizer or pesticide, because of high correlation with cash cropping. In addition, we omit any measure for use of animal traction and irrigation, which is largely confined to southern regions of the country where the disease burdens on livestock are lower and some irrigation infrastructure is present.
Dependent
The change in total annual crop income is calculated by summing all earnings from staple food crops (sales plus value of produce retained for home consumption) and sales of cash crops, vegetables, fruits, cashews, and coconuts in 2002 and 2005. Costs of seeds, pesticides, and fertilizer are subtracted from the total. The 2005 incomes are converted to 2002 values using the IMF’s inflation statistics for Mozambique. The total household income is then divided by the number of household members to construct per capita values for each year. We take the natural log of our income figures to normalize the distribution. The change variable is the difference between the natural log of per capita household annual agricultural crop income in 2005 and 2002.1,2

Independents
Household per capita total crop income (lnPCI02)
Total annual crop income for households is calculated by summing all earnings from staple food crops (sales plus value of produce retained for home consumption) and sales of cash crops, vegetables, fruits, cashews, and coconuts in 2002. Costs of seeds, pesticides, and fertilizer are subtracted from the total. The total household income is then divided by the number of household members to construct per capita values. We take the natural log of our income figures to normalize the distribution.1

Share of total crop income from staple food crops (SFC02)
Percentage of household’s annual total crop income derived from staple crops (sales plus value of produced retained for home consumption) in 2002.

Household per capita land area under cultivation (lnPCLand02)
The total annual land area (measured in hectares) under cultivation by a household divided by the number of household members to construct per capita values in 2002. We take the natural log of our land area figures to normalize the distribution.1

Crop income dummy variables
- Cash crops (DCC02)
- Vegetables (DV02)
- Fruits (DF02)
- Cashews (DCA02)
- Coconuts (DCO02)
The dummy takes a value of 1 if a household reported any income from that crop type in 2002, and 0 otherwise. We constructed dummy variables for cash crops, vegetables, fruits, cashews, and coconuts, as these are the six agricultural categories specified in the TIA data.1

Age of household head (HAGE02)
The household head’s reported age in 2002.1

Chronically ill household members dummy (DILL02)
The dummy takes a value of 1 if the household has one or more members (of any age) that suffered from serious illness either at the time of the 2002 survey or for at least 3 of the preceding 12 months, and 0 otherwise. The survey does not specify the type of illness.1

Dependency ratio (HDR02)
The number of children under the age of 15 divided by the number of household members over 15 in 2002. The elderly (above age 64) are not considered dependents in our measure. In Mozambique, due in part to the HIV/AIDS epidemic, the very elderly often head some households where there are no working-age adults.1

Female-headed household dummy (DFEM02)
The dummy takes a value of 1 if the household is headed by a female in 2002, and 0 otherwise.1

Maximum educational attainment (EDU02)
The highest number of years of education of the most educated household member in 2002.1

Rainfall zone dummy variables zones 1, . . . , 9 (DZ102, . . . , DZ902)
The dummy takes a value of 1 if a household is located in the rainfall zone, and 0 otherwise. We construct dummy variables for all nine rainfall zones. The geographic coordinates of the village location of households is included in the TIA 2002 survey.1,3

1 Authors’ calculations using data from 2002 TIA (MADER 2002). All values are for the 12 months preceding the administration of the survey. The survey was administered before the 2002–2003 growing season.
2 Authors’ calculations using data from 2005 TIA (MADER 2005). All values are for the 12 months preceding the administration of the survey. The survey was administered after the 2004–2005 growing season.
3 Authors’ calculations for rainfall zones use TRMM climate data (Huffman et al. 2007) and geographic coordinates of villages from the TIA 2002 survey (MADER 2002).

Table 4. Construction of dependent and independent variables for regression analysis. Staple food crops consist of maize, rice, sorghum, millet, peanuts, butter beans, cowpeas, Bambara groundnuts, pigeon beans, Irish potatoes, cassava, and sweet potato. Cash crops consist of cotton, tobacco, tea, sunflowers, sesame, sisal, soybeans, paprika, and ginger.
can constrain labor endowments and reduce agricultural productivity. Households having more educated members are expected to experience better economic outcomes, since more schooling has been found to foster innovation among farmers in some rural African societies (Knight et al. 2003). Female-headed households should fare worse than those headed by males. For example, Walker et al. (2004) found that households that are headed by women are much poorer than are other Mozambican households, since women do not have equal access to land and other resources.

We include a series of categorical dummy variables to measure the effect of household location in a particular rainfall zone to test our hypothesis that the unique rainfall patterns had differing effects on household agricultural income (DZ1, DZ2, DZ3, DZ4, DZ5, DZ6, DZ7, DZ8, and DZ9). To avoid a situation with perfect multicollinearity, one categorical dummy variable must be excluded from the regression when an intercept is estimated. The omitted category becomes the reference group against which the effects of the other categories are assessed. The results of the parameter coefficients on the eight zone dummy variables included in the analysis are interpreted as the expected difference in mean of household income change in that particular zone as compared to the omitted category, holding all other predictors in the regression constant. Although both droughts and floods can negatively impact agriculture, farmers may have more time to adjust planting and harvesting schedules when climate forecasts warn of drought conditions. Thus, we choose to omit a cyclone-affected region, rather than the region most severely affected by the drought (zone 9). Although three tropical cyclones brought rainfall to Mozambique, we chose to omit Delfina (DZ4) over Atang or Japhet for two reasons. First, rainfall from Delfina was the most widespread and intense of the cyclone events. Second, previous research determined that the some areas were reported to be affected by Delfina.

b. Regression results

The parameter coefficients and the statistical test results of independent variables obtained from the regression analysis are presented in Table 5. The parameter coefficient on household per capita agricultural income in 2002 (lnPCI) is negative and significant. Thus, households with higher initial levels of agricultural income experience lower rates of income change than initially poorer households.

While variables measuring agricultural characteristics and regional rainfall patterns are significant, none of the parameter coefficients for the demographic variables are significant in the model. Regarding our agricultural variables, we find a negative and statistically significant relationship between income share from staple food crops (SFC) and income change. This indicates the more reliant a household was on staple food crop income in 2002, the worse it fared economically over the study period, supporting our second hypothesis. The parameter coefficient on household per capita land area under cultivation in 2002 (lnPCLand) is also positive and significant, suggesting that households that initially had larger farms or

### Table 5. Regression results. The regression is estimated as a general linear model using a generalized estimating equation with 3859 observations.

<table>
<thead>
<tr>
<th>Dependent: change in annual household per capita total crop income between 2002 and 2005, logged (lnY)</th>
<th>Estimate</th>
<th>Z score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>4.4698***</td>
<td>19.58</td>
</tr>
<tr>
<td>Annual household per capita total crop income, logged (lnPCI)</td>
<td>-0.6920***</td>
<td>-19.60</td>
</tr>
<tr>
<td>Share of total crop income from staple food crops (SFC)</td>
<td>-0.6429***</td>
<td>-3.69</td>
</tr>
<tr>
<td>Household per capita land area under cultivation, logged (lnPCLand)</td>
<td>0.3803***</td>
<td>5.83</td>
</tr>
<tr>
<td>Cash crops (DCC)</td>
<td>0.1350*</td>
<td>1.76</td>
</tr>
<tr>
<td>Vegetables (DV)</td>
<td>0.0124</td>
<td>0.18</td>
</tr>
<tr>
<td>Fruits (DF)</td>
<td>-0.0162</td>
<td>-0.24</td>
</tr>
<tr>
<td>Cashews (DCA)</td>
<td>0.0874</td>
<td>1.33</td>
</tr>
<tr>
<td>Coconuts (DCO)</td>
<td>0.1360</td>
<td>1.43</td>
</tr>
<tr>
<td>Age of household head (HAGE)</td>
<td>-0.0018</td>
<td>-1.01</td>
</tr>
<tr>
<td>Chronically ill household member(s) (DILL)</td>
<td>-0.1384</td>
<td>-1.33</td>
</tr>
<tr>
<td>Dependency ratio (HDR)</td>
<td>-0.0046</td>
<td>-0.13</td>
</tr>
<tr>
<td>Female-headed household (DFEM)</td>
<td>-0.0565</td>
<td>-0.95</td>
</tr>
<tr>
<td>Maximum educational attainment (EDU)</td>
<td>0.0004</td>
<td>0.04</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Zone</th>
<th>Estimate</th>
<th>Z score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1 (DZ1)</td>
<td>0.1217</td>
<td>0.70</td>
</tr>
<tr>
<td>Zone 2 (DZ2)</td>
<td>0.2263*</td>
<td>2.10</td>
</tr>
<tr>
<td>Zone 3 (DZ3)</td>
<td>0.6144***</td>
<td>5.61</td>
</tr>
<tr>
<td>Zone 5 (DZ5)</td>
<td>0.2071**</td>
<td>2.00</td>
</tr>
<tr>
<td>Zone 6 (DZ6)</td>
<td>0.3390***</td>
<td>3.18</td>
</tr>
<tr>
<td>Zone 7 (DZ7)</td>
<td>0.5654***</td>
<td>3.31</td>
</tr>
<tr>
<td>Zone 8 (DZ8)</td>
<td>-0.2250</td>
<td>-1.13</td>
</tr>
<tr>
<td>Zone 9 (DZ9)</td>
<td>-0.3358</td>
<td>-1.36</td>
</tr>
</tbody>
</table>

* Significant at p < 0.10 (two-tailed test).
** Significant at p < 0.05 (two-tailed test).
*** Significant at p < 0.01 (two-tailed test).

The variables included in the analysis have correlation coefficients of less than ±0.35, with the majority being correlated at less than ±0.10. The one exception is our coconut crop dummy and zone 7, which has a positive correlation of 0.40. However, the signs and significance of all parameter estimates do not change whether or not one variable is omitted; therefore, we leave both in the model. The variables included in the analysis have correlation coefficients of less than ±0.35, with the majority being correlated at less than ±0.10. The one exception is our coconut crop dummy and zone 7, which has a positive correlation of 0.40. However, the signs and significance of all parameter estimates do not change whether or not one variable is omitted; therefore, we leave both in the model.
more agricultural plots had better economic outcomes as measured by agricultural income change. Of all the crop dummy variables, only the parameter coefficient for households that engage in cash cropping in 2002 (DCC2002) is significant, and the relationship is positive. This indicates that a household having some form of cash crop income in 2002 is associated with more positive agricultural income change. 

Turning to our rainfall zone dummy variables, we find that the parameter coefficients on zones 1 (DZ1), 8 (DZ8), and 9 (DZ9) are insignificant. This suggests that households in these rainfall zones, after controlling for the agricultural and demographic characteristics included in the regression model, do no better in terms of agricultural income change than those located in zone 4, the area most impacted by Delfina. Both zones 8 and 9, as described earlier in the paper, experienced severe drought during the study period, particularly in season 1. Our findings for zones 8 and 9 also comport with those of Mather et al. (2008), who find that the number of drought days during the agricultural growing season is associated with lower incomes for Mozambican farmers, and Cunguara and Kelly (2009), who find that lower monthly rainfall totals during the growing seasons have detrimental effects on agricultural income in rural Mozambique. Importantly, our results show that the impacts on crop income from prolonged drought cannot be differentiated from those of cyclones producing widespread heavy rainfall. Future studies need to consider farmer responses to cyclones as well as drought to gain a better understanding of weather-related effects on rural agriculturalists.

The parameter coefficient for zone 1 was also insignificant. This area did not experience prolonged dry periods, and it is in the agriculturally productive area of northern Mozambique. The descriptive statistics on median income (Table 1) show that households experienced a 4% decrease in earnings from all crop sources, which is less than in other zones. This suggests that households in this region would fare better than those impacted by Delfina. It also points to limitations in using descriptive statistics to determine economic performance across rainfall zones and illustrates the benefits of using a regression-based approach that allows us to control for other variables in order to isolate the effects of rainfall patterns. As discussed previously, several villages in zone 1 received extreme rainfall from Atang in November 2002, and this could account for the insignificant parameter coefficient, indicating that households in this area, when controlling for other predictors in the model, did no better in terms of agricultural income than households in the Delfina region. To further investigate the impact of Atang on economic performance in this region, we correlated rainfall totals from Atang and agricultural income change. We find a significant, negative association between rainfall totals during the two-day event and change in household per capita agricultural income when performing a Spearman’s correlation coefficient, $r(203) = -0.14, p = .05$. This suggests that high rainfall from Atang had income-decreasing effects for households in zone 1. Given that Atang occurred in season 1 and the subsequent seasons were characterized by relatively normal rainfall patterns, our finding indicates that even such localized extreme events may have enduring effects on rural agricultural households.

The parameter coefficients for zone 2, 3, 5, 6, and 7 dummy variables (DZ2, DZ3, DZ5, DZ6, and DZ7) were positive and significant, indicating that, after controlling for the agricultural and demographic characteristics included in the regression model, households in these rainfall zones experienced more positive agricultural income change than households located in zone 4. As previously discussed, zones 2, 3, and 5 did not experience any extreme wet or dry events, although they did exhibit some month-to-month variability (Fig. 3). Thus, the positive and significant coefficient on these parameter estimates supports our hypothesis that regions with more stable weather would be characterized by better economic performance in terms of crop income, after controlling for other predictors in the model, as compared to the omitted area that experienced a tropical cyclone (zone 4).

The findings for zones 6 and 7 merit closer attention given that the rainfall patterns they represent each show signs of extremes. Zone 7 experienced drought conditions in seasons 1 and 2, yet they ended with normal or close-to-normal rainfall and may have allowed some households to replant crops that failed earlier in the season. This comports with FAO reports (2003, 2004, and 2005) that good rainfall at the end of the growing season may help farmers offset crop losses from or recover from earlier bad weather. In addition, many households in this zone are located near the coast, and the TRMM product tends to underestimate rainfall in coastal locations (Chen et al. 2013); thus, some households could have received more rainfall that our analysis showed. These explanations could account for the fact that households in this region did better relative to those in zone 4 while zones 8 and 9 did not. Our findings also indicate that the economic effects of low rainfall in coastal regions merits further study as better climate data become available for Mozambique.

The positive and significant parameter coefficient for zone 6 (Japhet) indicates that households in this region did better relative to households affected by Delfina, suggesting that rainfall from Japhet had positive effects
on household agricultural income. This finding comports with those of Matyas and Silva (2013) and Kadomura (2005), both of which use TRMM data, and with FAO (2003): all concluded that Japhet had beneficial effects on rural agricultural households because it brought late-season rain to areas that were previously experiencing drought. Moreover, seasons 2 and 3 had no extreme events and experienced better weather relative to other climate zones farther south. These factors may account for why positive effects from Japhet may still be evident over two years later.

To further test whether Japhet was indeed a drought-busting cyclone, as suggested by the significance of our zone dummy and the findings of previous empirical work, we correlate rainfall totals from days of the storm event and agricultural income change for all 861 households that received more than one-third of their March 2003 rainfall from Japhet. This enables us to investigate if Japhet rainfall benefited other nearby households with absolute totals less than 150 mm. We find that Japhet rainfall totals and change in all crop income are positively correlated, \( r(859) = 0.24, p = (<.01) \). This provides further support that Japhet was a drought-busting cyclone for households in our study and supports our interpretation of the zone 6 dummy parameter coefficient. However, we find that agricultural income became more unevenly distributed across households between 2002 and 2005, with a coefficient of variation of 23.4 and 30, respectively. This suggests that some households in the region were better positioned to take advantage of the benefits brought by Japhet. Although beyond the scope of this study, examining the characteristics that account for the differential benefits of drought-busting cyclones merits future research.

4. **Policy implications for rural development**

The core of Mozambique’s rural development strategy involves policies promoting greater production of agricultural exports by small- and medium-scale farmers (Government of Mozambique 2001, 2006). Examples of such policies include the provision of agricultural extension services for farmers producing internationally exportable nonstaple crops (Government of Mozambique 2001). The government’s focus on agricultural exports as a poverty reduction strategy has been widely criticized in the literature and associated with increasing rural poverty (Hanlon and Smart 2008; Cunguara and Hanlon 2010). Our findings indicate that farmers more reliant on staple crops fare worse economically, after controlling for initial wealth levels, distinctive rainfall patterns, and other agricultural and demographic characteristics. Moreover, we find evidence that households that earned some income from cash crops at the beginning of the study period fared better than households that did not. These findings lend some support to the idea that rural households can improve their economic position via the production of nonstaple crops. However, median household per capita agricultural income declined in most parts of the country and is extremely low. Thus, increasing the share of income from nonstaple crop production does not guarantee that households can adequately raise their incomes to a degree that improves standards of living.

Our weather-related findings suggest that households in cyclone-impacted areas generally have similar negative economic outcomes as those living in drought areas, which indicates that the majority of rural farmers operate in an extremely risky environment. Some researchers argue that rural farmers are increasingly facing limits to successful adaptation in the context of climate change (Eakin and Luers 2006; Eriksen and Silva 2009; Adger et al. 2009; Leichenko and O’Brien 2008; Silva et al. 2010). We find that median household incomes from all crops, and staple crops in particular, have decreased in most areas and that reliance on staple crops has an income-diminishing effect. This suggests that in a country already characterized by endemic poverty, rural households in this analysis may be confronting such limits. Given predictions that extreme events are likely to increase, the situation confronting farmers in countries like Mozambique makes climate mitigation and adaptation research increasingly important for poverty reduction policies.

The Mozambican case illustrates the difficulty in assessing whether development policy should focus on strengthening the small-farm agricultural sector or helping people move into nonfarm economic activities. Tschirley and Benfica (2001) advocate adopting a mixed approach. However, it is difficult to argue against prioritizing policies aimed at enhancing the resilience and profitability of the agricultural sector. The vast majority of rural households in Mozambique still engage in crop production. Policies that successfully increase agricultural productivity through advances such as improved efficiency, enhanced insurance mechanisms, and better access to markets would have a large economic impact because they are relevant to the majority of the rural population. However, as climate predictions suggest that conditions for rain-fed agriculturalists will continue to worsen, policies that stop short of irrigation infrastructure and state-sponsored crop insurance will likely lose their effectiveness over time.

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9 We would like to thank an anonymous reviewer for calling attention to this point.
We find households exposed to extreme wet events may experience comparable declines in agricultural income as those in drought-effect regions, which calls attention to the need for more research on the relationship between rainfall from tropical cyclones and agricultural outcomes for farmers. Moreover, although drought receives considerably more attention in the rural development literature, strategies focused on raising agricultural incomes also require policies that mitigate risks associated with extreme wet events. In the Mozambican context, the entire country is vulnerable to rainfall from tropical cyclones. In addition, some of the most drought-prone regions are in the south of the country, an area characterized by higher levels of economic development and stronger linkages to labor and commodity markets (INGC/UEM/FEWS NET MIND 2003; Silva 2007). However, areas in the northern and central regions of the country may, in fact, be the most in need of policies that foster an enabling environment for nonfarm start-up activities, improve abilities to trade, and increase mobility. More case studies of how households may take advantage of extreme events could help in the development of policies to help farmers capitalize on the aftermath of disasters when food supplies become limited and demand is high. Taken together, our findings suggest that development strategies relying primarily on extreme events when food supplies become limited and demand is high. Taken together, our findings suggest that development strategies relying primarily on increasing agricultural income face serious limitations in countries such as Mozambique, where endemic poverty and very low levels of infrastructure make it hard for farmers to access or compete in international commodity markets.

5. Concluding remarks

This study linked rainfall patterns to the economic well-being of rural agriculturalists in Mozambique, who mainly rely on rain-fed agriculture for food and income. We developed this link by dividing the study region into rainfall zones based on the percentage of normal rainfall received during the growing seasons and from two tropical cyclones at each of 536 villages. The rainfall analysis revealed that four of the nine rainfall zones experienced extreme wet or dry conditions, while high monthly and interannual variability in rainfall occurred throughout the country. We then developed a regression model utilizing measures of agricultural and demographic characteristics of households and controls for distinctive rainfall patterns to investigate the change in all crop income over the 3-yr study period. The agricultural variables attained a higher level of statistical significance than the socioeconomic variables that are not associated with the weather, and we find that rainfall patterns do have an important influence on economic well-being in Mozambique. We find that higher initial dependence on staple food crops within the study period is generally associated with declining per capita agricultural incomes for rural Mozambican households with small- and medium-size farms. We found this relationship regardless of whether or not households were in areas that had experienced extremely high or low rainfall over the time frame of the study. Our results also indicate that the extreme weather in season 1 is strongly associated with declining agricultural income. It is important to note that this is not only true for regions where all households are strongly impacted by a tropical cyclone in season 1 (zone 4, Delfina), but for those where there are a relatively small number of cyclone-affected households (zone 1, Atang). In addition, regions characterized by dry events (zones 8 and 9) fare no better than those impacted by tropical cyclones. However, some climate factors that are unobservable in this study (e.g., coastal rainfall) may improve agricultural outcomes, as could be the case with zone 7. The evidence of lingering negative effects of extreme weather in zones 1, 4, 8, and 9 suggest that coping and adaptation strategies of rural agriculturalists may not be sufficiently effective to halt the worsening economic position of farmers over time. The lingering positive effects of Japhet suggest that some tropical cyclones are beneficial to farmers, particularly if these events are followed by consecutive seasons of relatively normal rainfall.

In terms of policy implications, this study suggests that a continued attention to the rain-fed staple food crop sector remains important to rural livelihoods in Mozambique. Since reliance on staple crop income is associated with higher economic vulnerability, it follows that better provision of support services and inputs, as well as enactment of agricultural insurance schemes, would enhance coping and adaptation to variable climate conditions. Improving farmers’ access to climate forecasts would also strengthen the capacity of rural agriculturalists to mitigate the impacts of erratic or extreme weather. But agricultural strategies alone are unlikely to halt the declining economic position of rural agriculturalists, particularly given the climate predictions for the region. Thus, future research should examine best practices for improving access to nonagricultural types of activities that may be more effective in the long term in improving the well-being of rural households.

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form. We also thank Michael Lahr and Stewart Duncan for feedback on an earlier draft of the paper. Any errors or omissions are the sole responsibility of the authors.

REFERENCES


