Women, Weather, and Woes: The Triangular Dynamics of Female-Headed Households, Economic Vulnerability, and Climate Variability in South Africa

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Abstract

Existing gender inequality is believed to be heightened as a result of weather events and climate-related disasters that are likely to become more common in the future. We show that an already marginalized group – female-headed households in South Africa – is differentially affected by relatively modest levels of variation in rainfall, which households experience on a year to year basis. Data from three waves of the National Income Dynamics Survey in South Africa allow us to follow incomes of 4,162 households from 2006-2012. By observing how household income is affected by variation in rainfall relative to what is normally experienced during the rainy season in each district, our study employs a series of naturally occurring experiments that allow us to identify causal effects. We find that households where a single head can be identified based on residency or work status are more vulnerable to climate variability than households headed by two adults. Single male-headed households are more vulnerable because of lower initial earnings and, to a lesser extent, other household characteristics that contribute to economic disadvantages. However, this can only explain some of the differential vulnerability of female-headed households. This suggests that there are traits specific to female-headed households, such as limited access to protective social networks or other coping strategies, which makes this an important dimension of marginalization to consider for further research and policy in South Africa and other national contexts. Households headed by widows, never-married women and women with a non-resident spouse (e.g., "left-behind" migrant households)

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are particularly vulnerable. We find vulnerable households only in districts where rainfall has a large effect on agricultural yields, and female-headed households remain vulnerable when accounting for dynamic impacts of rainfall on income.

Keywords: climate variability, economic vulnerability, female-headed household, poverty, South Africa

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1 Introduction

In the absence of additional mitigation efforts, climate change is predicted to "lead to high to very high risk of severe, widespread, and irreversible impacts globally" by the end of the century (IPCC, 2014a). While certain climate change scenarios suggest some benefits of global warming such as higher crop yields in world regions such as North America and Western Europe (Parry, Rosenzweig, Iglesias, Livermore, and Fischer, 2004), the widely projected increase in climate and weather variability and associated frequency and severity of extreme climate events is likely to have many adverse effects, particularly in less developed regions (Thornton, Ericksen, Herrero, and Challinor, 2014). Worse, the impacts of climate change are not distributed evenly across geographic regions, income levels, types of livelihood, or governance arrangements.

Non-climatic factors, including socioeconomic factors and institutional arrangements, can affect vulnerability to the risks of climate change. According to the definition given in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), vulnerability refers to "The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt." (IPCC, 2014a). We study economic vulnerability in a more narrow sense. In this paper, vulnerability refers to the degree to which household income is affected by variation in rainfall. Typically, people who are marginalized socially, economically, culturally, politically and institutionally are particularly vulnerable because they are less able to prepare for, respond to and cope with adverse effects of climate change. Accordingly, people who are disadvantaged in terms of socioeconomic resources (e.g., low-income groups, migrants and women) or physical mobility (e.g., children, the elderly and the disabled) are often considered to be the most vulnerable to climate change impacts (IPCC, 2014b). With limited access to land, formal employment, credit and insurance markets, female-headed households are obvious candidates for being one of the most disadvantaged groups (World Bank, 2012).

While studies of female-headed households and poverty are abundant across the globe, including South Africa (Buvinic and Gupta, 1997; Chant, 1997; Rogan, 2013), there have not been many studies that explicitly consider how they fare in the context of climate change (Terry, 2009). The IPCC confirms evidence that existing gender inequality is heightened as a result of weather events and climate-related disasters that are likely to become more common in the future (Olsson et al., 2014). However, most of the cited studies rely on research conducted after very extreme disasters such as Hurricane Katrina (David and Enarson, 2012) and/or have followed purposive sampling of particularly vulnerable areas or sub-groups of women (e.g., Rahman, 2013). Moreover, vulnerability studies often rely on either repeated cross-sectional data or sometimes just a single cross section, which do not allow for a proper comparison of how households fare before and after experiencing external shocks (Hoddinott and Quisumbing, 2003). As we are using exogenous and random variation in income stemming from rainfall variability and control for all unobserved time-invariant heterogeneity through household fixed effect regressions, our study is employing a series of naturally occurring experiments that allow us to identify causal effects. Furthermore, by using objective headship definitions rather than self-reported headship, we are able to clarify what types of household structures matter for economic vulnerability.

There are a small number of studies on the economic vulnerability of female-headed households that use panel data in other national contexts. The first study to use panel data to study the differential vulnerability of female-headed households was by Ligon and Schechter (2003) who found that the economic crisis in Bulgaria in the 1990s disproportionally affected female-headed households. Chudgar's (2011) study, which uses representative data from rural India, found that children's schooling outcomes were more sensitive to marginal changes in wealth in households headed by widows. Employing a difference-in-differences strategy, Kumar and Quisumbing (2013) found that the 2007-2008 food price crisis had a larger impact on female-headed households than male-headed households in rural Ethiopia, and that the former coped with the crisis to a larger extent by cutting down on immediate food consumption. Unlike these three studies, a study by Klasen, Lechtenfeld, and Povel (2014) found more mixed evidence of differential vulnerability. Using data from rural households in Thailand and Vietnam, they found that whether a female-headed household was differentially vulnerable to economic shocks depended on their economic situation, headship type and country context. Recognizing that weather events can provoke shocks to agricultural productivity, food security and income, these studies nevertheless did not include climate variability in the analyses. For South Africa there are two mainly qualitative case studies that have identified female-headed households as particularly vulnerable to climate variability, one from the Eastern Cape (Shackleton, Cobban, and Cundill, 2014) and one from Limpopo province (Vincent, 2007). These two studies also pointed to single male-headed households as being especially vulnerable. A recent study using panel data collected in rural north-eastern part of South Africa showed that both male- and female-headed households experienced consumption reduction following self-reported weather-related crop failure (Tibesigwa, Visser, Collinson, and Twine, 2015). However, de facto female-headed households appeared to be less vulnerable thanks to remittances from migrant husbands.

Our study is novel in using a sample of a whole population to assess how an already marginalized group – female-headed households – is differentially affected by relatively modest levels of variation in rainfall which households experience on a year to year basis. To this end, we use a relative measure of rainfall whereby each year's rainy season is scored according to its place in a gamma distribution of rainy seasons in 1980-2013 as our measure of climate variability. Relative measures of rainfall have frequently been used as sources of exogenous income variation in developing contexts (Paxson, 1992; Rose, 1999; Miguel, Satyanath, and Sergenti, 2004; Hidalgo, Naidu, Nichter, and Richardson, 2010; Kudamatsu, Persson, and Strömberg, 2012; Burke, Gong, and Jones, 2014; Flatø and Kotsadam, 2014). It is used in this study partly because it is independent of geographic characteristics, agricultural practices, and other factors that could potentially be correlated with household composition and income. Another crucial feature is that it is a measure that is important for livelihoods in the South African context, as we are able to show that it strongly affects local agricultural production. The analysis is also relevant for assessing impacts of climate change, which is causing both more variation in rainfall and less rainfall in large parts of southern Africa, as well as having other negative effects on agriculture with potentially similar distributional impacts (Niang et al., 2014). However, as our analysis only considers one aspect of climate change, it is by no means an analysis of the sum of complex changes that might come about.

The rest of the paper is organized as follows. After reviewing the existing literature, section two describes the mechanisms explaining why female-headed households might face economic disadvantages in the context of the changing climate. The third section discusses characteristics of female-headed households, their socioeconomic well-being, and the mechanisms underlying their vulnerability in the South African context. Section four discusses the definitions of headship and how it can influence the outcomes under study. The data used and empirical strategies employed are then described. Results on the impact of variability in rainfall on income by headship type are presented thereafter, and a number of robustness checks serve to verify these results. The final section discusses the findings and draws conclusions.

2 Female-headed households and climate vulnerability

Figure 1 displays the mechanisms explaining why female-headed households are assumed to face disadvantages under climatic shocks. The economic disadvantages of female-headed households are coined as "triple burden" for three main reasons (Rosenhouse, 1989). First, given that women have lower average earnings, fewer assets and less access to productive resources such as land, financial capital and technology than men, it follows that it is disadvantageous for a household to have a woman as the main earner. Second, lacking a male provider, female household heads are often the single earner and are consequently more likely to carry a higher dependency burden. These households often contain a higher ratio of non-workers to workers as displayed by a higher total dependency ratio comprising of both a higher proportion of dependent children (Mokomane, 2014) and a higher proportion of the elderly (Dungumaro, 2008). Third, women who are heads of households with no other adult help have to carry a "double day burden" where they have to fulfill both domestic duties and the breadwinner role. Consequently, female heads face greater time and mobility constraints and may have to work fewer hours or choose lower-paying jobs.

Gender disparities, particular disadvantages faced by certain household types, and disadvantages specific to female-headed households combine to make households headed by women economically vulnerable to climate-related shocks. These triple burdens influence households' access to resources and consequently their coping measures, which refers to responses by the household when facing different shocks with the aim of maintaining a smooth consumption flow. Examples of coping measures include selling assets, borrowing, using savings, skipping meals and migration.

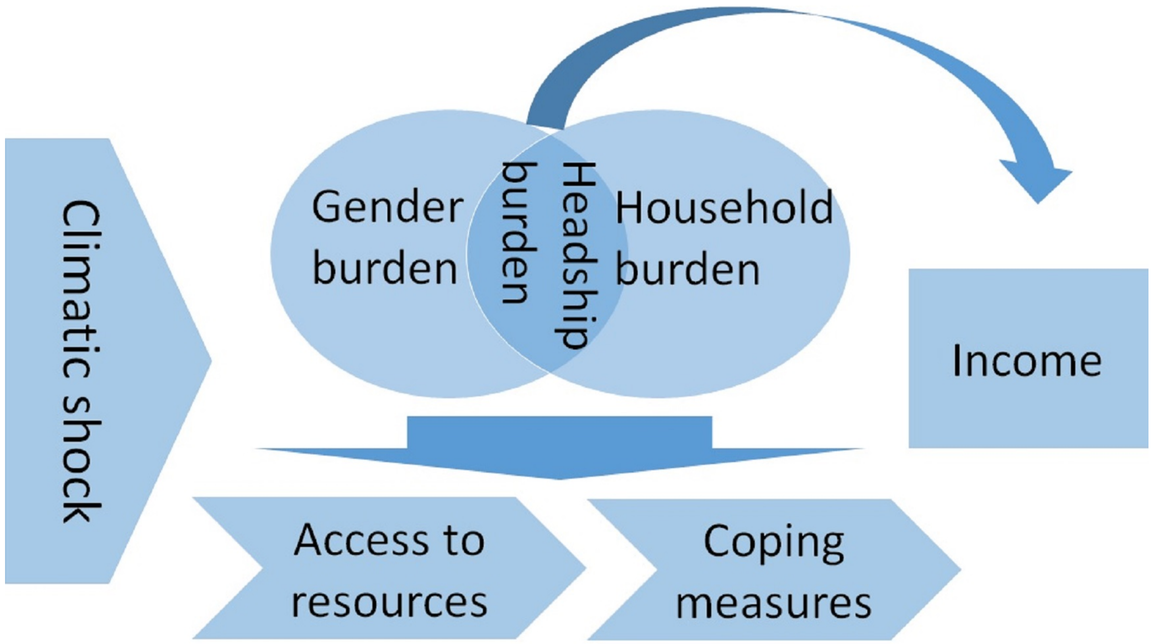


Figure 1: Diagram representing the mechanisms explaining economic vulnerability of female-headed households

With respect to the first type of disadvantage, it is evident that economic inequalities between males and females continue to persist, also in South Africa. There have been a number of developments in the post-apartheid period such as the introduction of need-based social grants to primary care givers of children under the age of 18 and progressive labor legislation, including extension of minimum wages for domestic workers; however, women still earn less than men (Posel and Rogan, 2012). Disparities between men and women range from labor market outcomes to limited access to formal credit markets, and to access to land. In terms of labor market disadvantages, a much larger proportion of women than men are engaged in childcare which partially explains lower labor market participation among women. Likewise, as a result of limited opportunities and resources in the formal employment sector, women, especially black women, are overrepresented in occupations with low pay and poor employment conditions such as domestic work (Hinks, 2002). Historically, limited access to education, the collapse of formal employment pushing women into poorly paid and highly unstable informal work and lack of access to resources such as housing and health services possibly explain the economic disadvantages of households headed by women in South Africa (Gilbert and Walker, 2002). Furthermore, women face various barriers in accessing finance, including lack of financial literacy, lack of financial confidence, limited use of networks as well as cultural prejudices and negative stereotyping towards women as entrepreneurs (Naidoo and Hilton, 2006). With respect to resource allocation and land ownership, customary land tenure and traditional management of land generally discourage allocation of land to unmarried women (McIntosh, Sibanda, Vaughan, and Xaba, 1996; Rangan and Gilmartin, 2002). Women's lack of access to and control over resources contribute to their socioeconomic disadvantages and make them more vulnerable to economic and climatic shocks.

Secondly, while the above evidence suggests that, individually, most women fare worse economically than men, such inequalities may increase when a household is headed by a woman. Indeed, there is consistent evidence that female-headed households in South Africa have lower income and are more likely to be in poverty than male-headed households (Bhorat and Van Der Westhuizen, 2012; Posel and Rogan, 2012; Rogan, 2013; Statistics South Africa [StatsSA], 2012a). In addition, a much larger proportion of female-headed households (50% vs. 24% of male-headed households in 2006) is composed of household members without employment (Posel and Rogan, 2009).

Although the three burdens are intertwined and not directly separable analytically, this study nevertheless aims to shed some light on which burden may be the most crucial to explain differences in climate vulnerability. If differences in vulnerability are mainly related to gender, we would expect female-headed households to be much more vulnerable than single male-headed households, and that single male-headed households and households with both male and female adults would have a somewhat similar vulnerability as the women's contribution to household income security is small. Differences in income levels and the number of workers should be important determinants of vulnerability. However, if household characteristics are crucial, then we expect that any differences we find between headship groups would be explained by differences in vulnerability along dimensions such as child dependency ratio, age composition and race, in addition to initial income and the number of workers. This is different from the third burden, which should reveal systematic differences in vulnerability between male and female-headed households which cannot be fully explained by other household characteristics.

3 Climate and household composition in South Africa

South Africa presents a unique setting for the study of female-headed households and vulnerability. Not only does the country have remarkably high rates of female headship, it is also particularly vulnerable to climate change – a key external factor exacerbating existing vulnerabilities. In terms of climate-related stressors, the whole African continent is projected to experience warming exceeding 2 °C by the last two decades of this century, greater than the global average under medium scenarios based on the projections described in the Fifth Assessment Report of the IPCC (Niang et al., 2014). In particular, high warming rates are projected for the semi-arid areas of South Africa, Botswana and Namibia. Over the last five decades the mean annual temperatures in South Africa increased by approximately 1.5 times the observed worldwide average of 0.65 °C for the period 1960-2010 (Department of Environmental Affairs, 2013). Likewise, the projected change in amount of rainfall – with western South Africa projected to be drier while southeastern areas are projected to be wetter – is likely to negatively influence crop yields. In fact, yield losses at mid-century range were estimated to be in excess of 30% (Schlenker and Lobell, 2010). A series of climate projections suggest that South Africa faces a considerably drier and warmer future by 2050 with projected rainfall decreases by more than 40mm per year for large parts of the interior for the 2080-2100 time-period (Department of Environmental Affairs, 2013). Studies of precipitation data report an increase in rainfall fluctuations in South Africa since 1960 (Fauchereau, Trzaska, Rouault, and Richard, 2003; Kane, 2009). Likewise, the trends in daily maximum and minimum extreme temperature observed between 1962-2009 reveal stronger increases in heat extremes in many regions (Kruger and Sekele, 2013). A higher frequency of flooding and drought extremes is also projected, with the range of extremes exacerbated significantly if global emissions are not constrained (Department of

Environmental Affairs, 2013). Predictably, the impacts of climate change will be more severe for the disadvantaged groups of the population. For instance, in 2015-2016 South Africa was suffering the worst drought since 1982, which resulted in a devastating drop in food production and rising prices of staples such as corn. This affected low-income households the most (Willemse, Strydom, and Venter, 2015).

Irrespective of climate change impacts, female-headed households have generated great interest since the 1970s, not only from a theoretical point of view, but also from economic and policy perspectives, given their rapid increase and widely perceived status as "vulnerable". The growing interest in female-headed households arises, in part, from the substantial increase in the number of such households in both developing and industrialized regions. Based on data from the Demographic and Health Survey (DHS) for 37 countries in Africa, the proportion of households headed by women was approximately 22% in the 1990s and rose to 28% at the turn of the century (ICF International, 2015). The DHS data also reveal a remarkably high proportion of female-headed households in southern Africa, ranging from 36.3% in Lesotho (2006), 43.9% in Namibia (2013) to 47.9% in Swaziland (2007).

In tandem with trends witnessed elsewhere in southern Africa and in other developing regions, the proportion of households headed by women in South Africa has been rising from 37.8% in 1996 to 41.2% in 2011 (StatsSA, 2012b). During this 15-year period, the total number of households headed by females increased by 73.6% – from 3.4 million in 1996 to almost 6 million in 2011. In comparison, during the same period the number of male-headed households rose by 50.9% – from 5.6 million in 1996 to 8.5 million in 2011 (StatsSA, 2004; 2012c). In fact, most of the growth in female-headed households appears to have happened between 1996 and 2001, i.e., soon after the dawn of the new political dispensation in 1994 that, among others, increased economic opportunities for women in the country (StatsSA, 2004; 2012c). The highest proportions of female-headed households are found in the predominantly rural provinces of Limpopo (49.2%), the Eastern Cape (44.7%) and KwaZulu-Natal (43.5%). The two most urbanized provinces (Gauteng and Western Cape) have the smallest percentage of female-headed households in the country, with approximately 30% each (StatsSA, 2012a).

Some of the reasons why South Africa ranks among the countries with the highest proportion of female-headed households in the world can be traced back to its unique history and distinctive social landscape. The rapid change in conventional household structures over the past few decades certainly cannot be ascribed to personal choice alone. Weight should also be given to a range of complex historical and societal dynamics, including the legacy of apartheid, urbanization and changes in urban lifestyle, labor migration, unemployment, the HIV/AIDS pandemic and premature mortality, as well as changing cultural norms (Wright, Noble, Ntshongwana, Barnes, and Neves, 2013). In other words, there is no single factor responsible for the formation of female-headed households, but rather a wide array of powerful drivers spread across the South African social landscape that have interacted to fuel cumulative change. These drivers include demographic, socio-political and economic antecedents.

With respect to demographic dynamics, one major driver is gender-specific migration that results in "left-behind" female heads in the sending area and the creation of households headed by women in the receiving area in the case of female out-migration. The migrant labor system that characterized the South African economy in the apartheid system is regarded as one of the most important factors that historically contributed to the rapid increase in female-headed households across southern Africa (O'laughlin, 1998). The recruitment of young men as laborers in South African mines across southern Africa and different areas in South Africa itself created thousands of disrupted and divided families that left rural women responsible for the care of their households.

Likewise, the legacy of apartheid is well-reflected in family disruptions. During the apartheid dispensation in South Africa, social policies and political pressures directly impacted household formation and family cohesion, and aggravated the negative impact of urbanization and industrialization on the family. One particular destructive legacy of apartheid on the family was the large number of single parent families, particularly among black women, that resulted largely from divorce and from pregnancy outside marriage (Bigombe and Khadiagala, 2004). As a large proportion of children were raised in female-headed families with little financial support, black families in apartheid South Africa suffered considerably more disintegration than families elsewhere in Africa.

Meanwhile, with the dawn of the new political dispensation in South Africa in 1994, which emphasized gender equity and the economic empowerment of women, large numbers of women entered the labor market as they embraced changes in educational and employment opportunities. The upward social and economic mobility associated with these changes, as well as the development of an urban lifestyle among young people and women, contributed to a significant increase in single and female-headed households (Bigombe and Khadiagala, 2004). In addition, the erosion of patriarchal norms and cultural tradition has fueled a new consciousness of independent living among the youth and single women, in particular. In the past 20 years, it has become increasingly acceptable for educated and better-off black single women and unmarried youth in South Africa to take up housing options on their own (Cross, Kok, O'Donovan, Mafukidze, and Wentzel, 2005). An enabling legal and policy environment after 1994 equipped South African women with greater economic freedom and social independence which, in turn, allowed them to remain unmarried or separate from or divorce their husbands.

Furthermore, the role of changing cultural values in the rise of female-headed households is closely linked to the system of lobola – a customary southern African ritual whereby the prospective groom pays a bride price to the family of his future wife for her hand in marriage. Changing economic circumstances that have led to down-scaling and job losses in many industries in recent times have made the payment of lobola unaffordable for thousands of prospective grooms. This contributes to a general decline in marriage rates among African women (Posel, Rudwick, and Casale, 2011; Rogan, 2013) and possibly to an increase in the number of single households since co-habiting partnerships are less stable. These conditions, in turn, triggered certain family dynamics, including an increased number of female-headed households, fragmented and unbundled households, out of wedlock births and a rapid rise in the number of households accompanied by a decline in household size (Pillay, 2008).

Likewise, the scars of apartheid are still well-reflected in the South African society, which remains highly unequal. Despite the decline in income inequality between races, the income gap between the black African and the white population remains large. In 2011, for instance, the average income for white households (R442,400 or US$35,691) was more than five times as much as the corresponding income for black households (R83,815 or US$6,762) (South African Institute for Race Relations, 2012). Furthermore, women continue to be distinctly disadvantaged in the labor market with a higher unemployment rate, lower average wages and higher likelihood to engage in unpaid labor (Casale and Posel, 2002; Leibbrandt, Levinsohn, and McCrary, 2005; Posel and Rogan, 2009). Subsequently, there is evidence of increasing economic disparities between male- and female-headed households over the period 1997-2006 (Rogan, 2013). Admittedly, the difference between these two groups in income and poverty incidence decreased somewhat in the subsequent period 2006-2011, in pace with the reduced inequality in South Africa due to the financial crisis (StatsSA, 2014a). These continuing disparities nevertheless provide reasonable grounds to assume that female-headed households are more vulnerable to economic or climatic shocks than male-headed households and other household types in the South African context.

4 Types of households and headship definitions

There are many sound reasons to assume that female-headed households are at a disadvantage, and a review of 61 studies conducted between 1978-1993 in Africa, Asia, Latin America and the Caribbean revealed that female-headed households are overrepresented among the poor based on a variety of poverty indicators (e.g., household income, consumption expenditures, access to services and ownership of land and assets) (Buvinic and Gupta, 1994). However, more recent studies have cast doubt on how generalizable the disadvantages of female headship are. Not only have inconsistencies been found regarding the relationship between female headship and poverty (Gammage, 1998; Lampietti and Stalker, 2000; Quisumbing, Haddad, and Peña, 2001), some empirical works have also shown no or even a negative association between female headship and poverty, that is, female-headed households are sometimes richer than households headed by men (Anyanwu, 2010; Djurfeldt, Djurfeldt, and Lodin, 2013; Klasen et al., 2014) There are a number of reasons for these discrepancies, including inconsistent definitions of headship (e.g., self-reported vs. demographic or economic-based measure), routes into female headship status (e.g., changes in marital status, migration, or non-marital household formation) and differences in how well-being and poverty are measured. To date, there is no universally accepted definition of headship and this in turn contributes to inconclusive results on female headship and poverty.

Given the diverse processes by which women become household heads, the social and economic well-being of such households can vary greatly. Correspondingly, international studies show that female-headed households are predominantly heterogeneous and whether they are poorer than other household types or not depends considerably upon routes into headship (Chant, 2004). It is therefore necessary to distinguish between different female headship types. In this regard, Fuwa (2000) classifies female-headed households into three broad typologies: self-reported, demographic and economic. Self-reported female-headed households are based on respondents' own perception in surveys and censuses while the demographic category refers to the temporary absence of the male partner in the household as well as households where the female head is never-married, divorced, separated or widowed. In this category a further distinction is sometimes made between de jure female-headed households (i.e., households headed by never-married, divorced, widowed or separated women) and de facto female-headed households (i.e., households in which the male partner is absent, but may still influence household decision-making) (Fuwa, 2000; Fafchamps and Quisumbing, 2007). In the case of South Africa, previous literature has shown that both de facto and de jure female-headed households face greater economic disadvantages as compared to other household types based on a variety of indicators, including lower likelihood of being in the labor market, lower earnings, and a lower number of employed members in a household (Rogan, 2013).

The headship of the household has traditionally been self-reported, meaning that a household resident (typically the oldest woman) is asked to name the head. This was essentially intended as a tool to avoid double counting. Yet, it has been widely used as an analytical category although not constructed for this purpose (Rogan, 2013). In addition to the somewhat arbitrary assignment, critics of the analytical usage of this term point out that female-headed and male-headed households are very heterogeneous groups, and that it precludes joint decision-making. Nevertheless, we believe that identifying household headship is useful, as it is an important marker of inequality and marginalization in South Africa (Posel, 2001). Hence, we follow Rogan (2013) and Fuwa (2000) in making use of alternative, objective definitions of headship. These alternative definitions are based either on the demographic composition of the household or the members' labor market attachment.

Using a demographic headship definition, a (fe)male-headed household is defined as having at least one and only (fe)male adult resident(s) while a dual-headed household is defined as having both male and female adult residents. The category of child-headed households form a separate group. Analogously, a working headship definition defines (fe)male-headed households as having at least one and only (fe)male adult workers, which can be compared to the two groups of dual and no workers. A third definition combines these two definitions and defines a (fe)male-headed household as a household fulfilling either the demographic or the working definition. The last definition is coined "combined headship".

5 Data and variables

In order to assess climate-induced economic vulnerability of female-headed households, we use longitudinal household-level data containing information on household economic conditions as well as time-series climate data.

5.1 Household-level data

The main source of data on household characteristics and income which we use are the first three waves of the National Income Dynamics Survey (NIDS), developed by the Southern Africa Labour and Development Research Unit (2014a; 2014b; 2014c). It is a nationally representative panel dataset with an initial 7,214 households being successfully interviewed in 2008 and then followed up in 2010/2011, and 2012. The data contain extensive information on demographic and socio-economic characteristics of individuals and households, including household composition and structure, labor market participation, economic activity, health, and education.

Economic vulnerability is measured by changes in household income. In each wave, a comprehensive income measure is obtained which includes all monetary incomes of all household members, the value of self-produced goods and gifts, remittances, and hypothetical rental income for owned houses. In the first round, participants were also asked about whether six types of positive economic events and eleven negative event types had occurred during the last two years, and to give an approximate value of the losses and gains that they experienced along with the month and year of its occurrence. They were also asked to report any other positive or negative event that was not mentioned. Some of the incurred losses and gains were reported per month and some were reported in total. We divide sums reported as totals by 12 and add and subtract all changes to the 2008 income from their month of occurrence to construct estimates of monthly incomes for the two preceding years. The next two waves only included questions about income at the time of survey and the timing of negative events. In cases where there were increases in incomes between the waves or no negative events were reported, we estimate monthly incomes by linear interpolation. If one negative event was reported and income decreased, the decrease is assigned from the reported month. Finally, if multiple negative events were reported and income decreased, the decline is divided between the events based on the relative size of the reported losses in the first wave. Monthly income is then deflated to reflect prices in December 2012 (StatsSA 2015).

From the first interview, we extracted information about all adult members' place of residence in February 2006 and added members who had deceased during the last two years. To re-construct households in 2006, we selected households who report that all adult members had the same place of residence in 2006. In total, we had 5,761 households that we were able to backtrack. Work and marital status was also traced back to 2006. If employed, self-empoyed or engaged in casual work or work on their plot in 2008, the respondent is coded as working in 2006 if any of these engagements started in 2006 or earlier. If not working, the respondent is coded as working in 2006 if the person stopped working less than a year ago, as not working in 2006 if stopped working more than 3 years ago, and with missing work status if he or she stopped working 1-3 years ago. Marital status in 2006 is re-coded to married if widowed, separated or divorced during the last two years, and as unknown if he or she got married or started living with a partner during the last two years. In subsequent rounds, we followed the oldest working member aged between 18 and 60 in 2006 if the household split.[1] In the second wave they managed to successfully re-interview 4,631 of these households. Our main sample consists of the 4,162 households for whom we also have data in the

[1] 60 years was chosen as it is the most common retirement age in South Africa. If all workers were older than 60 years old, we selected the youngest one. If no member was working, we selected the oldest member aged between 18 and 60 and otherwise the youngest member above 60. The oldest child was selected only if there was no adult resident in the household.

third wave.[2]

To ensure that the NIDS data are truly representative of the South African population, we compare the distribution of household types with other data sources. In addition to the second wave of the NIDS, there are two other larger datasets available that were collected in 2011. These are the General Household Survey (GHS) and the 10% sample of the 2011 Census, both produced by StatsSA (2012d; 2014b). In the first three columns of Table 1, we compare the weighted division of households based on the combined headship definition across these datasets. It shows that three of the groups – the male-headed, the female-headed, and the dual-headed households – each account for about one third of all households. Of the female-headed households, about half of them have never been married and more detailed data show that only about 10% of these have lived with a partner. The three columns also show that the 2010-2011 NIDS is fairly similar to the other two datasets although with a much smaller sample. The fourth column displays our sample with the headship status two years prior to the first survey, derived from retrospective questions. This is the sample which was successfully re-interviewed in all three survey rounds. The smaller sample size reflects that some households have split as well as attrition. The compositional difference is due to a number of factors such as the difficulty in tracing single male-headed households and that work status in 2006 is not traceable for all members. This difference may threaten the representativeness of the findings in this study, particularly for male-headed households. However, note that the composition of the female-headed households is quite similar to the other surveys, hence we believe that this group is quite representative of the population.

[2] In the second wave, they were asked about negative events since the last interview, whereas in the third wave they were asked about events during the last two years. 921 of these were re-interviewed more than two years after the second wave and hence they have a gap of 1-6 months without information on negative events. Results are very similar regardless of which sample is used, e.g., those interviewed once, twice, three times or three times without a gap in event recall history (see A).

Table 1: Households by headship groups

	(1) Census 2011	(2) GHS 2011	(3) NIDS 2010-11	(4) NIDS 2006
Male-headed households	**33.8**	**34.8**	**38.9**	**20.8**
Female-headed households	**29.7**	**32.0**	**27.2**	**35.5**
Non-working partner	*2.5*	*3.1*	*2.8*	*2.1*
Union dissolved	*2.1*	*2.7*	*2.2*	*2.3*
Widowed	*4.7*	*5.6*	*4.2*	*6.7*
Non-resident partner	*4.7*	*3.5*	*3.7*	*5.8*
Never married	*15.6*	*17.0*	*13.9*	*16.4*
Single, status unknown	*0.1*	*0.1*	*0.4*	*2.1*
Dual-headed households	**35.8**	**32.6**	**33.5**	**42.8**
Dual worker(s)	*15.6*	*19.1*	*15.0*	*12.7*
None work/unknown	*20.2*	*13.5*	*18.5*	*30.1*
No adult resident	**0.6**	**0.5**	**0.2**	**0.8**
Households in sample	1,158,452	25,086	9,023	4,162

Numbers are in percent of total. Columns 1-3 are weighted using the 2011 Census, column 4 is unweighted.

In Table 2, we compare the household groups along several dimensions and by different definitions. We observe that the household groups with adult residents are of relatively equal age, suggesting that female headship is not a phenomenon limited to a particular life phase. There are more workers in the dual-headed households than in the male-headed and female-headed households. By the combined and demographic definitions, there are also more workers in male-headed than in female-headed households. By the working headship definition, male and female-headed households have at least one adult worker by definition and dual-headed households have at least two. The last category consists of households without any adult workers or when we cannot determine which of the other groups the household belongs to because of missing information on work status, hence the smaller number of workers in this group. The shares participating in agriculture are more equal between the groups for all definitions, suggesting a larger share of the workers in female-headed households than in dual-headed households in agriculture. Female-headed households also have a higher child dependency ratio (defined as the number of children aged 15 and younger divided by the number of residents aged 16-60) than the other groups by all definitions and there are especially fewer children in the male-headed households. Female-headed households earn about half as much income as dual-headed households, with earnings of male-headed households lying in between the two groups. Education here is measured by educational level of the household member with the highest attainment and divided into having finished only grade 6 or below, having finished grade 7-9, and having any education above grade 9. By all definitions, the dual-headed households also have the highest education, followed by male-headed households and then female-headed households when using the combined definition, similar to income. By the demographic definition, male and female-headed households have about the same level of education. When considering the working definition, the ones with no or an unknown number of workers have the least education, followed by the male-headed households and then the female-headed households. Racial differences are most apparent between the dual-headed households and the other groups.

Table 2: Initial characteristics by household type

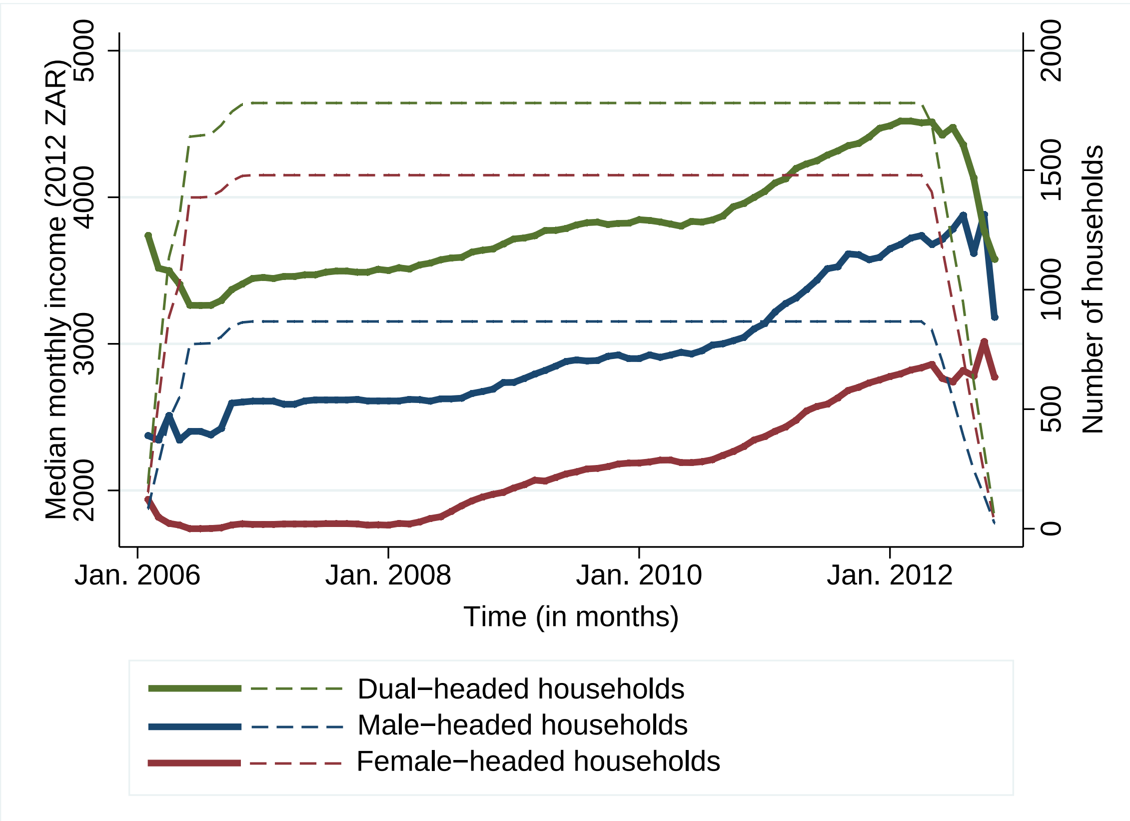
Headship definition	Combined headship			
Headship type	Dual	MHH	FHH	None / NA
Age of head/oldest member	42	39	42	16
Number of workers	1.01	0.80	0.54	0
Any agricultural activity	28 %	20 %	25 %	17 %
Child dependency	0.65	0.37	1.07	0.66
Income (mean)	6,482R	4,368R	2,959R	1,456R
Income (median)	3,454R	2,603R	1,774R	978R
Black majority	73 %	83 %	88 %	100 %
Highest educ. < grade 7	14 %	24 %	30 %	
Highest educ. = grade 7-9	20 %	23 %	21 %	
Highest educ. > grade 9	66 %	54 %	50 %	
Number of households	1,781	867	1,479	35

Headship definition	Demographic headship			
Headship type	Dual	MHH	FHH	None / NA
Age of head/oldest member	42	38	43	16
Number of workers	1.03	0.57	0.45	0
Any agricultural activity	28 %	16 %	23 %	17 %
Child dependency	0.66	0.14	1.13	0.66
Income (mean)	6,197R	3,453R	2,724R	1,456R
Income (median)	3,386R	1,788R	1,684R	978R
Black majority	74 %	90 %	89 %	100 %
Highest educ. < grade 7	14 %	31 %	32 %	
Highest educ. = grade 7-9	20 %	23 %	22 %	
Highest educ. > grade 9	66 %	47 %	47 %	
Number of households	2,333	498	1,296	35

Headship definition	Working headship			
Headship type	Dual	MHH	FHH	None / NA
Age of head/oldest member	43	40	41	41
Number of workers	2.28	1.08	1.12	0.26
Any agricultural activity	39 %	24 %	32 %	20 %
Child dependency	0.58	0.43	0.94	0.80
Income (mean)	9,248R	5,040R	4,035R	3,841R
Income (median)	5,320R	3,129R	2,378R	2,110R
Black majority	66 %	80 %	85 %	83 %
Highest educ. < grade 7	11 %	22 %	20 %	26 %
Highest educ. = grade 7-9	15 %	23 %	20 %	22 %
Highest educ. > grade 9	75 %	55 %	60 %	53 %
Number of households	529	646	710	2,277

Dual are dual-headed households, *MHH* are male-headed households, *FHH* are female-headed households, and *None / NA* are households without an adult head, without an adult worker, or where headship could not be determined. Child dependency ratio defined as members aged 0-14 years / members aged 15-60 years. Highest educational achievement is that of household members aged above 18 in 2006, recorded in 2008. All other variables are initial levels when entering the analysis in 2006.

It is also of interest to show how the incomes of households in these groups develop across time. In Figure 2, the median monthly income of each headship group by the combined definition is plotted across time along the solid lines by the left axis (in South African Rand at December 2012 prices). The right axis corresponds to the dashed lines which indicate the number of households in each group. We see that the lines are practically parallel and growing throughout the segments where we have information on all households.



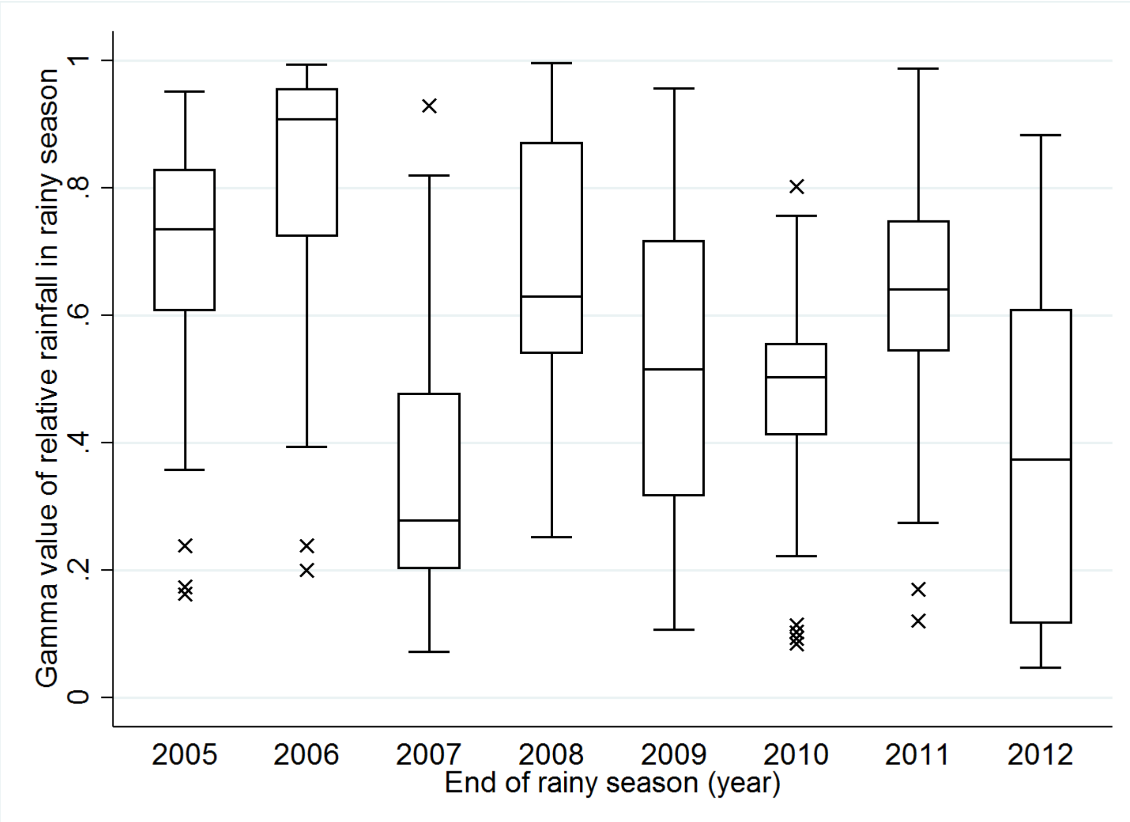
Time is measured in months. Thick lines represent median monthly income by combined headship group in South African Rand, PPP-adjusted to December 2012 prices (left axis). Dashed lines are the number of households by headship group (right axis).

Figure 2: Median income by combined headship group, 2006-2012

5.2 Climate data

In this paper, our focus is on effects of rainfall on household income, as rainfall is the most important source of climate variability for livelihoods. The demographic and income data are combined with a relative rainfall variable based on data from the ERA-Interim project (Dee et al., 2011) and further described in Flatø and Kotsadam (2014). Households and weather are matched based on 53 district councils following the geographical boundaries used in the 2001 Census. In each district, the grid with rainfall which is on a 0.75 x 0.75 degrees scale is weighted according to land coverage. The rainy season in each district is then identified as a continuous period with rainfall above average in each month (as suggested by Liebmann et al. (2012)). We use rainfall during the rainy season because this is when rainfall affects yields the most. The total rainfall is then summed for each season which ends between 1980 and 2013 and a cumulative gamma distribution is fitted to the time series (as suggested by Burke, Gong, and Jones (2014)). This means that in each year, each district receives a value which reflects the probability of experiencing rainfall at that level or below in that particular district. The level of relative rainfall in a given year is thus essentially random and independent of local characteristics.[3]

[3] Following Miguel (2005), a Moran's I test was conducted which did not show any significant correlation across districts (I-value 0.002, p-value 0.175).



Gamma value of rainfall during rainy season by year in which it ends, relative to the distribution of rainfall 1979-2013, for 53 districts. Box represents interquartile range, whiskers are 1.5 x IQR.

Figure 3: Box plot of relative rainfall, by season

Figure 3 shows box plots of the distribution of relative rainfall during the rainy season, by the year in which the season ended. The boxes represent the interquartile range of the values in the 53 districts, and the line within each box is the median. Whiskers show the highest and lowest values within 1.5 times the interquartile range from the bounds of the boxes. Outlying values are shown by crosses. We see that there is a large range of levels of relative rainfall in each year. There is no monotonic trend in the median values across the years.

6 Empirical strategy

The empirical strategy in this paper rests on the use of exogenous variation in rainfall which is random across time. By controlling for household fixed effects, we compare the same household in years when they were randomly exposed to more rainfall with years when they experienced relatively dry seasons. To study the differential effect across types of households, we interact our explanatory variable with headship status at the beginning of the time series in 2006. More specifically, we run the following regression:

$$\ln(Y_{it}) = \alpha_i + Rain_{dT} \times \alpha_H + t \times (\alpha_H + \alpha_P) + \epsilon_{it} \tag{1}$$

Where $\ln(Y_{it})$ is the logged monthly income of household i, α_i are household fixed effects, $Rain_{dT}$ is relative rainfall in district d in the last completed rainy season T, α_H is type of headship, t is a time trend which is squared in our baseline regression, and α_P is province. Standard errors are clustered at the district level.

In further specifications, we study how the differential vulnerability varies according to other characteristics in addition to headship status, and also allow for different time trends according to these characteristics. The specification is shown in the following equation:

$$\ln(Y_{it}) = \alpha_i + Rain_{dT} \times (\alpha_H + X_{2006}) + t \times (\alpha_H + \alpha_P + X_{2006}) + \epsilon_{it} \tag{2}$$

Where X_{2006} are socio-demographic characteristics measured in 2006 including income quintiles, years of education grouped in three-year intervals, number of workers, child dependency ratio, agricultural participation, and racial majority of the household.

7 Findings

Table 3 presents the impacts of variation in rainfall on household income by headship types. From Table 3, we see that the point estimates are positive for all groups across all definitions with only one exception, supporting our expectation that rainfall boosts agricultural yield and thereby increases income across the economy. Also as expected, the dual-headed households are the least vulnerable to climate variability. Column (1) reveals that a one standard deviation reduction in rainfall from the mean (which equals a reduction of 0.341 in the cumulative gamma distribution) reduces incomes only marginally with 0.2% for dual-headed households using the combined headship definition. Female-headed households are much more vulnerable than the dual-headed households according to this definition, with an estimated total impact of 1.7% loss in income from a similar shock. This difference is statistically significant at the 5% level. Male-headed households have a very similar vulnerability to rainfall variation as female-headed households, with a 1.6% decline in income from a one standard deviation reduction in rainfall from the mean. Breaking up the combined headship definition into demographic and working headship gives quite similar results. From column (3), we see that households without any adult workers are more vulnerable than households with workers of both genders, and have fairly equal vulnerability to households with worker(s) of only one gender.

Table 3: Vulnerability to relative rainfall variation, by headship groups

Headship definition	Combined	Demographic	Working
	(1)	(2)	(3)
Rain	0.006	0.006	-0.018
	(0.015)	(0.014)	(0.024)
$Rain \times MHH$	0.042**	0.060**	0.051*
	(0.019)	(0.029)	(0.030)
$Rain \times FHH$	0.045**	0.057***	0.052
	(0.018)	(0.018)	(0.033)
$Rain \times None/NA$	0.113	0.113	0.061**
	(0.185)	(0.185)	(0.028)
$Time \times Headship$	Yes	Yes	Yes
$Time \times Province$	Yes	Yes	Yes
R-squared	0.113	0.116	0.110
Number of households	4,162	4,162	4,162

Rain is the cumulative gamma distribution of relative rainfall. *MHH* are male-headed households, *FHH* are female-headed households, and *None / NA* are households without an adult head, without an adult worker, or where headship could not be determined. Reference group: Dual-headed households. All regressions include household fixed effects. Standard errors clustered at the district council level in brackets. Stars indicate significance of two-tailed tests. * significant at 10%, ** significant at 5%, *** significant at 1%.

7.1 Vulnerability by household characteristics

The finding that single-headed households (regardless of the gender of the household head) are more vulnerable to climate variability is likely to reflect a marginalization of this group along several dimensions. Here we explore whether income poverty and other socioeconomic dimensions such as low labor market attachment, differences in child dependency ratios, participation in agriculture, and race can explain this differential vulnerability. In columns 1-3 of Table 4, we include income quintiles in 2006 in the regression together with the fixed effects and time controls. The large increase in R-squared confirms that initial income can explain a lot of variation in the data, both in terms of trends across time and climate vulnerability. The lowest income quintile is much more vulnerable to climate variability than the other four quintiles and significantly different from them as a group, whereas the differences between the other four are small and not significant. Using the combined headship definition in column 1, we observe that the differential vulnerability of female-headed households is reduced by 20% compared to the specification without controls for initial income, but remains significant at the 5% level. The differential vulnerability of male-headed households is reduced to a third when controlling for initial income and it is no longer statistically significant. Male-headed households are thus more vulnerable mainly because they earn less than dual-headed households. Although lower income also explains some of the differential vulnerability of female-headed households, it explains much less than that of male-headed households and this group remains differentially vulnerable even when income is controlled for. In the last three columns, we include all the demographic variables measured in 2006 which are thought to be important for vulnerability as described earlier. Surprisingly, these variables do not explain much of the variation in income across time and we do not find any differential vulnerability to rainfall along these dimensions (not shown). R-squared remains almost unchanged and none of the additional interaction terms are significant. However, we see that the differential vulnerability of male-headed households has now completely vanished in all definitions of headship. This is different from that of female-headed households, where the vulnerability is reduced by 17% to become weakly significant at the 10% level based on the combined definition and is reduced by 8% and remains significant at the 5% level based on the demographic headship definition.

Table 4: Vulnerability by headship groups, controlling for income and demographic characteristics

	Combined (1)	Demographic (2)	Working (3)	Combined (4)	Demographic (5)	Working (6)
$Rain$	0.084**	0.075*	0.054	0.089**	0.072**	-0.010
	(0.040)	(0.041)	(0.046)	(0.035)	(0.036)	(0.050)
$Rain \times MHH$	0.014	0.027	0.038	-0.002	0.008	0.076
	(0.019)	(0.029)	(0.031)	(0.020)	(0.031)	(0.050)
$Rain \times FHH$	0.036**	0.052**	0.053*	0.030*	0.048**	0.101*
	(0.017)	(0.020)	(0.032)	(0.017)	(0.019)	(0.052)
$Rain \times None/NA$	0.101	0.109	0.060*	0.099	0.115	0.130***
	(0.176)	(0.176)	(0.031)	(0.168)	(0.168)	(0.042)
$Rain \times Income\,Q2_{2006}$	-0.096***	-0.094***	-0.099***	-0.098***	-0.096***	-0.104***
	(0.035)	(0.035)	(0.034)	(0.035)	(0.035)	(0.034)
$Rain \times Income\,Q3_{2006}$	-0.100***	-0.095**	-0.105***	-0.102***	-0.097**	-0.109***
	(0.037)	(0.038)	(0.036)	(0.038)	(0.038)	(0.037)
$Rain \times Income\,Q4_{2006}$	-0.068	-0.060	-0.073*	-0.070	-0.065	-0.080*
	(0.045)	(0.046)	(0.043)	(0.048)	(0.048)	(0.046)
$Rain \times Income\,Q5_{2006}$	-0.073*	-0.065	-0.072*	-0.071	-0.066	-0.081
	(0.042)	(0.043)	(0.041)	(0.051)	(0.051)	(0.049)
$Time \times Headship$	Yes	Yes	Yes	Yes	Yes	Yes
$Time \times Province$	Yes	Yes	Yes	Yes	Yes	Yes
$Time \times Income_{2006}$	Yes	Yes	Yes	Yes	Yes	Yes
$Rain \times X_{2006}$	No	No	No	Yes	Yes	Yes
$Time \times X_{2006}$	No	No	No	Yes	Yes	Yes
R-squared	0.255	0.256	0.254	0.267	0.267	0.265
Number of households	4,162	4,162	4,162	4,162	4,162	4,162

Rain is the cumulative gamma distribution of relative rainfall. *MHH* are male-headed households, *FHH* are female-headed households, and *None / NA* are households without an adult head, without an adult worker, or where headship could not be determined. Reference group: Dual-headed households. All regressions include household fixed effects. Standard errors clustered at the district council level in brackets. Stars indicate significance of two-tailed tests. * significant at 10%, ** significant at 5%, *** significant at 1%.

7.2 Vulnerability by routes into female headship

In Table 5, we have further divided the female-headed households by routes into the status of female headship. The group with a co-resident partner consists of households where the female works and has a male adult resident who does not work residing in the household. The subsequent female headship category listed consists of households without a male adult resident. Female-headed households labeled as “union dissolved” are households where the adult female is separated or divorced. The widowed form a separate group. The group with non-resident partners consists of married women who are not separated but have a spouse living elsewhere. The never married group that follows is by far the largest. Finally, there is a group of female-headed households that could not be categorized due to incomplete data. We observe that households with adults of both genders where the female works but the male does not work (i.e., co-resident partner) are not differentially vulnerable, nor are households headed by women who had been through a separation or divorce. The vulnerable female-headed groups are those headed by a widow, those with a non-resident partner, and households headed by never-married women.

Table 5: Vulnerability by headship groups and types of female-headed households

	Combined	Demographic	Working	Combined	Demographic	Working
	(1)	(2)	(3)	(4)	(5)	(6)
$Rain$	0.007	0.006	-0.017	0.081*	0.073*	0.054
	(0.015)	(0.014)	(0.024)	(0.041)	(0.041)	(0.046)
$Rain \times MHH$	0.042**	0.060**	0.051*	0.015	0.028	0.038
	(0.019)	(0.029)	(0.030)	(0.019)	(0.029)	(0.031)
$Rain \times Co-res.partner$	-0.024		0.001	-0.022		0.010
	(0.104)		(0.108)	(0.095)		(0.099)
$Rain \times Union\,dissolved$	-0.005	-0.012	-0.013	-0.032	-0.038	-0.047
	(0.035)	(0.037)	(0.043)	(0.037)	(0.039)	(0.050)
$Rain \times Widowed$	0.057**	0.061**	0.114**	0.040	0.046	0.010
	(0.028)	(0.028)	(0.055)	(0.029)	(0.029)	(0.063)
$Rain \times Non-res.partner$	0.090*	0.090*	0.093	0.076	0.081*	0.135
	(0.052)	(0.052)	(0.102)	(0.048)	(0.048)	(0.086)
$Rain \times Never\,married$	0.038**	0.050***	0.050	0.035*	0.052**	0.051
	(0.017)	(0.015)	(0.034)	(0.020)	(0.021)	(0.037)
$Rain \times uncategorised\,FHH$	0.115*	0.115	0.171	0.127*	0.144**	0.194*
	(0.068)	(0.071)	(0.108)	(0.069)	(0.069)	(0.102)
$Rain \times None/NA$	0.114	0.114	0.061**	0.104	0.112	0.061*
	(0.184)	(0.184)	(0.028)	(0.176)	(0.176)	(0.031)
$Time \times Headship$	Yes	Yes	Yes	Yes	Yes	Yes
$Time \times Province$	Yes	Yes	Yes	Yes	Yes	Yes
$Rain \times Income_{2006}$	No	No	No	Yes	Yes	Yes
$Time \times Income_{2006}$	No	No	No	Yes	Yes	Yes
$Rain \times X_{2006}$	No	No	No	No	No	No
$Time \times X_{2006}$	No	No	No	No	No	No
R-squared	0.116	0.118	0.112	0.257	0.257	0.255
Number of households	4,162	4,162	4,162	4,162	4,162	4,162

Rain is the cumulative gamma distribution of relative rainfall. *MHH* are male-headed households, *FHH* are female-headed households, and *None / NA* are households without an adult head, without an adult worker, or where headship could not be determined. Reference group: Dual-headed households. All regressions include household fixed effects. Standard errors clustered at the district council level in brackets. Stars indicate significance of two-tailed tests. * significant at 10%, ** significant at 5%, *** significant at 1%.

8 Robustness checks and extensions

8.1 Relevance of rainfall measure

To check the relevance of our rainfall measure as a source of variation in income, we combine it with the Agricultural Stress Index (ASI) (Rojas, Vrieling, and Rembold, 2011) obtained from the Food and Agriculture Organization of the United Nations. The index is an indicator of the percentage of cropland in each district that fails to produce a harvest in each agricultural season, presumably because of droughts. A greenness scale of satellite images and temperature were used in this assessment, but not rainfall data directly. We believe this is the most accurate measure of year to year variation in local agriculture available. Two regressions are carried out to examine the relationship between relative rainfall and ASI. In the first regression, all the years from 1984-2013 with available agricultural data are used, whereas in the second regression, we restrict the sample to the years 2005-2012. Both regressions include district council fixed effects and the results are shown in Table 6. It shows that a one standard deviation decrease in relative rainfall from the mean causes an increased crop loss of about 10% when using the whole time series (first regression) and 7% in the restricted time series (second regression). Both values are significantly different from zero at the 1% level. In Figure 4, we have plotted the residuals against the cumulative gamma distribution and fitted local polynomial smoothed averages. It shows that the relationship is decreasing across the distribution and that linear approximation is reasonable. From the confidence intervals, it is clear that even very minor variation in rainfall, such as that which can be expected over a three year period, leads to significantly different agricultural outputs.

Table 6: Effect of relative rainfall on the Agricultural Stress Index

DV: Agricultural Stress Index	(1)	(2)
Relative rainfall	-28.9***	-20.8***
	(1.89)	(2.64)
Years	1984-2013	2005-2012
District fixed effects	48	48
R-squared	0.144	0.156

Robust standard errors in brackets. Stars indicate significance of two-tailed tests. * significant at 10%, ** significant at 5%, *** significant at 1%.

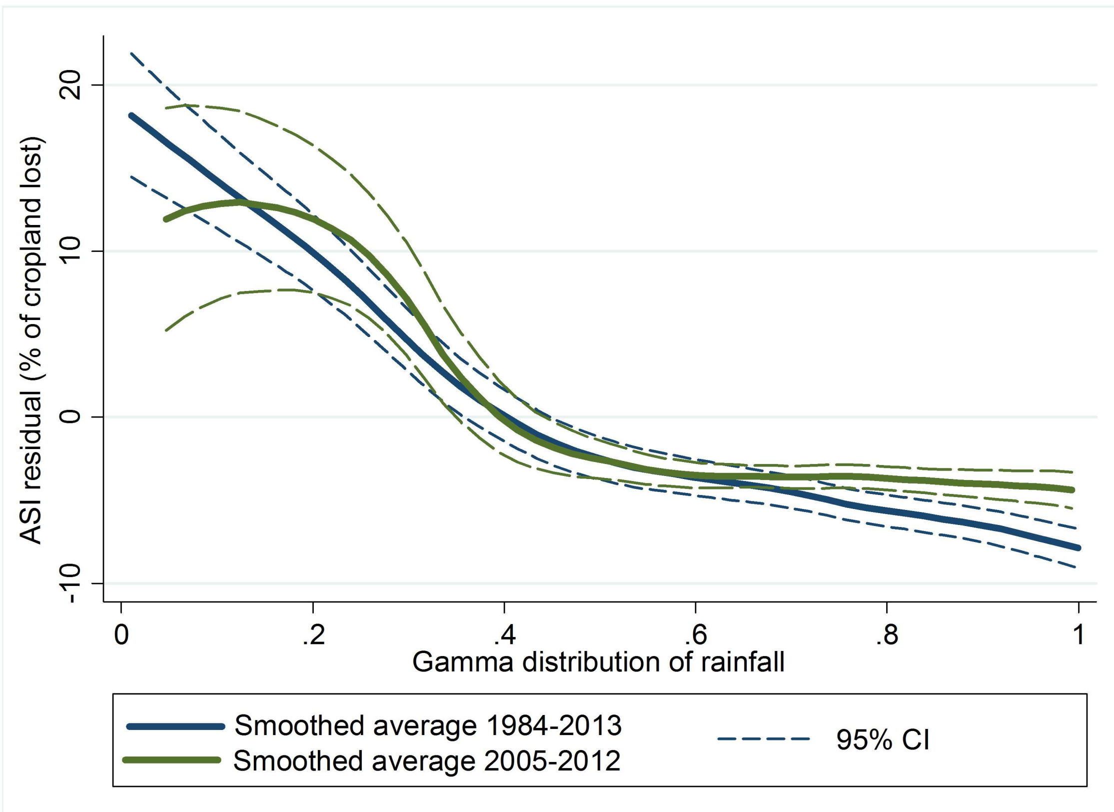


Figure 4: Residual plot from regression

As a robustness check, we examine whether the places where rainfall affects incomes and differentially so across household groups are the same areas where rainfall affects agricultural yields.[4] Hence, we split the districts into two samples, one where the effect of rainfall on agriculture was above the median, and one where the effect of rainfall on agriculture was below the median based on the regression of rainfall on the ASI using the 2005-2012 seasons. The results are presented in Table 7. The first three columns, representing the districts where the effect of rainfall on agriculture was below the median, show that none of the household groups in these districts display any vulnerability to climate variability, as the coefficients are very close to zero. There is also no differential vulnerability by headship type. However, when we consider the districts where rainfall has a larger effect on local agriculture as presented in the last three columns, both male-headed households and female-headed households are significantly affected according to the first two definitions, and the effects are larger than in the baseline regression. There is also significant differential vulnerability of female-headed households compared to dual-headed households when using the demographic headship definition.

[4]Due to changes in district councils, we spatially matched each of the 53 districts for which we have household information with 48 districts where we have the ASI using Global Administrative Unit Layers (Food and Agriculture Organization [FAO], 2014).

Table 7: Vulnerability by headship groups and effect of rainfall on agriculture

Rain impact on ASI	< median			> median		
Headship definition	Combined	Demographic	Working	Combined	Demographic	Working
	(1)	(2)	(3)	(4)	(5)	(6)
Rain	-0.014	-0.013	-0.010	0.026	0.024	-0.028
	(0.022)	(0.025)	(0.035)	(0.018)	(0.014)	(0.032)
$Rain \times MHH$	0.034	0.007	0.001	0.031	0.054	0.088**
	(0.027)	(0.052)	(0.043)	(0.029)	(0.043)	(0.035)
$Rain \times FHH$	0.001	0.013	-0.013	0.051*	0.064**	0.075
	(0.025)	(0.029)	(0.059)	(0.026)	(0.024)	(0.048)
$Rain \times None/NA$	0.092	0.093	0.010	0.359	0.360	0.101***
	(0.259)	(0.261)	(0.049)	(0.250)	(0.249)	(0.031)
$Time \times Headship$	Yes	Yes	Yes	Yes	Yes	Yes
$Time \times Province$	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.110	0.111	0.112	0.134	0.138	0.114
Number of households	2,162	2,162	2,162	2,059	2,059	2,059

Sampled districts divided by whether the impact of rainfall on the Agricultural Stress Index was above or below the median in 2005-2012. *Rain* is the cumulative gamma distribution of relative rainfall. *MHH* are male-headed households, *FHH* are female-headed households, and *None / NA* are households without an adult head, without an adult worker, or where headship could not be determined. Reference group: Dual-headed households. All regressions include household fixed effects. Standard errors clustered at the district council level in brackets. Stars indicate significance of two-tailed tests. * significant at 10%, ** significant at 5%, *** significant at 1%.

8.2 Timing of rainfall

In this paper, we considered the effect of rainfall during the last completed rainy season on income in a given month. Our results prove that rainfall in the last season indeed affects income levels. However, there may also be effects of rainfall during other seasons, in particular the penultimate season and the immediate and partially incomplete season, which is considered in this section. More specifically, this section deals with possible ways in which a different timing of the impact of rainfall on income may influence our results.

As we follow the same households throughout a six year period, income in one period is likely to affect income in the next period. Rainfall during one rainy season may thus affect income not only during the next 12 months, but also start dynamic processes which will affect income in the next period as well. Given these dynamics, it is possible that our analysis has underestimated the full effect of rainfall since we have not taken into account that income in a given month is affected by rainfall several years back. It could also be the case that our model is mis-specified if it is the immediate rainfall which is impacting income rather than rainfall during the last completed rainy season, and we might only be picking up a lag of that effect. In this section, we will thus include both a lead and several lagged seasons of rainfall.[5]

Table 8 shows that the point estimates of the differential vulnerability do not change much from the baseline regression. When one lead and one lag are entered one at a time into the combined definition regressions of Table 8, the differential vulnerability remains significant at the 5% and 10% level for male- and female-headed households respectively when rainfall during an unfinished or upcoming rainy season is controlled for (column 1), and significantly different at the 5% level for female-headed households when one lag is controlled for (column 4). By the demographic definition, female-headed households are significantly more vulnerable at the 5% level when including the lead (column 2) and 1% level when including the lag (column 5). Similar coefficients were also obtained when entering more lagged terms (see B). As expected, relative rainfall of several other seasons is negatively correlated with income as they are negatively correlated with relative rainfall during the last rainy season by construction. This, for instance, is the case with the lead terms in columns 1-3. Columns 4-6 in Table 8 show mostly positive yet insignificant coefficients of relative rainfall during the penultimate rainy season. In sum, we conclude that there are no other rainy seasons around the time of income imputation that exert a strong influence on the differential vulnerabilities of interest.

[5]A related issue is that autocorrelation in the dependent variable may lead to an inconsistent fixed effects estimator even if the explanatory variable is exogenous as in our case (Söderbom, Teal, Eberhardt, Quinn, and Zeitlin, 2014). We show that female-headed households remain vulnerable to rainfall when including auto-regressive variables in C.

Table 8: Vulnerability to rainfall during various rainy seasons, by headship groups

	Combined (1)	Demographic (2)	Working (3)	Combined (4)	Demographic (5)	Working (6)
$Rain_T$	-0.016	-0.015	-0.027	0.011	0.008	-0.026
	(0.019)	(0.018)	(0.0282)	(0.022)	(0.021)	(0.030)
$Rain_T \times MHH$	0.051**	0.055	0.051	0.039	0.062*	0.061
	(0.022)	(0.037)	(0.033)	(0.027)	(0.036)	(0.037)
$Rain_T \times FHH$	0.043*	0.057**	0.040	0.047**	0.066***	0.064
	(0.023)	(0.024)	(0.040)	(0.022)	(0.022)	(0.039)
$Rain_T \times None/NA$	-0.089	-0.091	0.041	0.144	0.148	0.081**
	(0.216)	(0.217)	(0.035)	(0.214)	(0.215)	(0.035)
$Rain_{T+1}$	-0.052**	-0.046**	-0.010			
	(0.023)	(0.020)	(0.039)			
$Rain_{T+1} \times MHH$	0.037	-0.005	0.001			
	(0.042)	(0.061)	(0.043)			
$Rain_{T+1} \times FHH$	-0.002	0.004	-0.037			
	(0.031)	(0.035)	(0.059)			
$Rain_{T+1} \times None/NA$	-0.852***	-0.859***	-0.064			
	(0.310)	(0.311)	(0.047)			
$Rain_{T-1}$				0.013	0.002	-0.031
				(0.025)	(0.022)	(0.034)
$Rain_{T-1} \times MHH$				-0.010	0.006	0.033
				(0.037)	(0.040)	(0.043)
$Rain_{T-1} \times FHH$				0.001	0.027	0.038
				(0.023)	(0.025)	(0.034)
$Rain_{T-1} \times None/NA$				0.097	0.109	0.060
				(0.238)	(0.239)	(0.037)
$Time \times Headship$	Yes	Yes	Yes	Yes	Yes	Yes
$Time \times Province$	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.113	0.116	0.110	0.115	0.117	0.110
Number of households	4,162	4,162	4,162	4,162	4,162	4,162

Rain is the cumulative gamma distribution of relative rainfall. *MHH* are male-headed households, *FHH* are female-headed households, and *None / NA* are households without an adult head, without an adult worker, or where headship could not be determined. Reference group: Dual-headed households. All regressions include household fixed effects. Standard errors clustered at the district council level in brackets. Stars indicate significance of two-tailed tests. * significant at 10%, ** significant at 5%, *** significant at 1%.

9 Discussion and conclusions

Much of the vulnerability to poverty literature is troubled by being unable to distinguish differential vulnerability of female-headed households from heterogeneity which not only makes this group worse off, but may also create a different income trajectory over time, and which may have contributed to establishing the household as female-headed in the first place. In this study, we are able to control for all observable and unobservable characteristics of the household through fixed effects and also take into account that different headship groups may have diverging time trends. As we observe all household characteristics and most notably headship at the start of our time series in 2006, our analysis is not troubled by the potential reverse causality problem in which an income shock leads to a change in household structure. Finally, this study does not make use of income shocks that depend on factors that are a function of household characteristics, nor are we relying on income shocks that households may self-select into experiencing. Rather, we are using rainfall as an exogenous variation in income, and by adopting relative deviations in this variable we ensure that the variation is random and unrelated to geographic characteristics. In sum, this empirical strategy allows us to measure the causal effect of climate variability on incomes of various types of households.

We find that in South Africa, female-headed households are indeed vulnerable to climate variability. Using the ASI at the district level in South Africa, we are able to show that precipitation variability is significantly associated with variation in agricultural outputs across time within a district. Consequently, we also find the greatest impacts of rainfall on incomes and the largest differentials by headship groups in the districts where it causes the greatest loss in yields. Even though less than one-third of the households in the sample are engaged in agriculture, crop losses in a district can indirectly affect food and livelihood security and, consequently, also household income through surges in food prices and shortfalls in local demand. Indeed, it has been shown in the Ethiopian context that female-headed households are more vulnerable to rising food price than male-headed households, particularly due to their limited resources and networks (Kumar and Quisumbing, 2013). Likewise, with women being proportionately more engaged in the informal economy than men, women's employment may be more susceptible to climatic shocks than those of men.

9.1 Possible causes of differential vulnerability

Women's position in the labor market and society in general is one of the burdens which may cause differential vulnerability. These are partially unobserved factors such as gendered inequalities in bargaining power in the community, labor market and legal institutions (Chant, 2007). However, this study shows that the disadvantage is likely not only caused by the inferior situation experienced by women regardless of household structure. A very apparent indication of this is that the large difference in vulnerability that we find is between dual-headed households and single-headed households, both male and female.

This points to the second "household" burden as a potentially important channel, by which female-headed households are vulnerable because of household characteristics rather than gender per se. The difference in vulnerability between male-headed households and dual-headed households is largely explained by the first group's lower income, hence economic poverty seems to be a relevant household characteristic. Initial earnings is also a contributing factor to female-headed households being more vulnerable. However, we find that the child dependency ratio and the number of workers do not explain differences in vulnerability between households. Furthermore, even after controlling for initial income and other characteristics, there remains a substantial and significant relationship between female headship when an adult male resident is absent and economic vulnerability. This draws our attention to the possible presence of unobserved sources of differential vulnerability as well as features particular to female-headed households. For instance, it is likely that the social networks and access to social capital of female heads are smaller. This is attributed to their lack of ties with ex-partners' relatives (Willis, 1993), and being "time-poor" as a result of multiple responsibilities (Fuwa, 2000). Female heads may also refrain from seeking help from others since they are not able to meet reciprocal demands for assistance in return (De La Rocha, 1994). Limitations and unequal access to and/or use of social capital of female-headed households possibly explain the remaining inequality in vulnerability after accounting for initial income. In sum, these results suggest that disadvantages specific to female-headed households contribute to their vulnerability in the face of climate variability.

Supporting this theory, a further analysis suggests that not all types of female-headed households are vulnerable to rainfall variation. Dividing female-headed households by routes into female headship shows that widows, women with a non-resident spouse (e.g., left-behind migrant households), and never-married female heads are more likely to suffer from economic vulnerability due to climate variability. Of these, the never-married female-headed households is the largest group as they make up 46% of the female-headed households in our sample based on the combined headship definition, compared to 19% (widowed) and 16% (non-resident partner) in the other two groups. Unmarried women are particularly disadvantaged because they lack access to some of the resources which are available to married women. For instance, under official customary law, communal land is generally allocated to men by traditional leaders for purposes of cultivation, building homes, or both, on the basis that this will be used to support other family members. Despite the Communal Land Rights Act of 2004, which states that a woman is entitled to the same legally secure tenure to land, in practice, women's access to land remain limited (Curran and Bonthuys, 2005). Without rights to land which is fundamental to basic livelihoods, economic security is consequently compromised. Furthermore, there could be a negative selection of never-married women. Studies in North America and Europe commonly associate this household type with negatively observed and unobserved characteristics that explain their lower likelihood of being in a marital relationship (Buchel and Engelhardt, 2003; McKeever and Wolfinger, 2011). This could also be the case in South Africa. In addition, it is argued that government subsidies may unintentionally encourage the separation of households. Cross et al. (2005) explained that subsidies for services such as housing, water and electricity are defined in a way that encourage households to unbundle into smaller units in order to maximize the family's benefit from these subsidies. Likewise, some social grants, despite being proven to be one key instrument in reducing income inequalities, may create perverse incentives such as increasing teenage pregnancies in order to qualify for the Child Support Grant. However, there has been no reliable scientific evidence supporting this argument (Patel, 2013).

9.2 Further implications

The number of female-headed households is on the rise in South Africa and the frequency and intensity of abnormal weather events is increasing because of climate change. Under both wetter and drier climate futures, significant socio-economic implications are expected for vulnerable groups and communities in South Africa, including female-headed households. These implications will largely manifest through impacts on water resources and a higher frequency of natural disasters (flooding and drought) with cross-sectoral implications for household income, consumption, and food security (Tibesigwa, Visser, Collinson, and Twine, 2015). There is little doubt that such implications call for strong, coordinated interventions by various ministries and government departments, specifically those in the social, economic, and environmental sectors.

The need for such a concerted intervention is, in fact, central to the multi-sectoral, integrated and interdisciplinary approach in designing and implementing programs that is advocated by the Population Policy for South Africa (Department of Social Development, 1998). The policy identifies a number of major national population concerns at the intersection of population and development, some of which are likely to be disproportionately impacted by future climate changes in the country. Among these count the high incidence of poverty in both urban and rural areas, as well as the marked gender inequities in development opportunities that reflect the low status and vulnerability of women (Department of Social Development, 1998). When it comes to policy making and intervention, a gender-sensitive approach requires more than an analysis of disaggregated data showing the differential impacts of climate variability on men and women. In the South African context, in particular, it requires an understanding of past and existing inequalities and how such inequalities can aggravate the effects of climate change for all vulnerable sectors, at both the individual and household level. Hence, understanding the causes of female headship and specifically why many women establish a household without entering marriage or co-habitation may help explain why they are more vulnerable to climatic shocks than other headship types and help design policies addressing the root cause of vulnerability.

One limitation of this study is that we only consider effects on household income. Hence, we cannot draw any direct conclusions on how climate variability affects consumption patterns of different types of households. If households are able to borrow and save money without friction and are forward-looking in their consumption behaviour, expenditures will not change with temporary income fluctuations, according to the Permanent Income Hypothesis (Friedman, 1957; Hall, 1978). Furthermore, symmetric income fluctuations such as those created by year-to-year variation in rainfall will not affect household welfare levels in the long run if this hypothesis holds. There are, however, several reasons why we would expect that expenditures and welfare are also affected by climate variability in South Africa. Using South African panel data, Berg (2013) finds that household expenditure responds to anticipated changes in household income, which violates the permanent income hypothesis. He points to credit constraints as the most likely cause, and furthermore finds consumption effects regardless of whether the recipient is male or female. Credit constraints may be worse when facing an unanticipated negative change in income whereas positive income shocks may be more likely to be saved if unanticipated and irregular (Paxson, 1992). Differential access to credit and saving institutions by household types may cause even larger differences in expenditures and welfare impacts of climate variability than the differences in income which we have documented, and would indeed be an interesting issue for further research.

Another interesting further avenue for research would be to explore whether climate variability and other income shocks affect the break-up and formation of households. For instance, in order to cope with income loss from climatic shocks, migration is one common strategy used by households whereby men, in particular, migrate to seek employment elsewhere leaving women to take charge of household activities and strategic decisions (Adoho and Wodon, 2014; Sugden et al., 2014). Male out-migration due to climatic shocks can therefore lead to an increase in female headship. Moreover, climate variability can add stress and tension to households resulting in increased gender-based violence as reported in Australia, the United States and Bangladesh (Fisher, 2010; Schumacher et al., 2010; Whittenbury, 2013). This may consequently lead to separation or divorce. Studying how climate variability influences household structure is, however, beyond the scope of this paper. Given limited evidence on the relationship between climate variability and household formation, this calls for future research on the issue.

Exploiting the nationally representative longitudinal surveys of households in South Africa and district-level rainfall data, we are able to assess how female-headed households fare economically when facing variation in rainfall, with implications for vulnerability in the context of a changing climate. The further analysis of which female headship type is more vulnerable to climate variability revealed that the group of never-married female household heads is the largest of the particularly vulnerable groups, for whom a specially targeted policy is perhaps required. Although it is not necessarily possible to generalize from our results whether female-headed households are more economically vulnerable to aspects of climate change in other national contexts, we show that it is important to clearly distinguish the causes of female headship and consider heterogeneity between different types of female-headed households in vulnerability analyses.

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Appendix

A Different samples

As mentioned in Section 5.1, our sample consists of households that have been successfully re-interviewed three times. Table 9 shows that exactly the same results can be obtained if also including the households that have been interviewed once or twice. Furthermore, since the questions about previous negative events were asked about the last two years rather than since the last interview in wave 3, 921 households had gaps in their recall history of 1-6 months. Excluding these households also yields very similar results.

Table 9: Vulnerability by headship groups, different samples

Sample	Wave 1 or more			Wave 2 or more		
Headship definition	Combined	Demographic	Working	Combined	Demographic	Working
	(1)	(2)	(3)	(4)	(5)	(6)
Rain	0.009	0.009	-0.016	0.007	0.007	-0.016
	(0.012)	(0.012)	(0.021)	(0.013)	(0.013)	(0.023)
$Rain \times MHH$	0.034*	0.050*	0.043	0.048**	0.069**	0.049
	(0.020)	(0.029)	(0.028)	(0.021)	(0.030)	(0.031)
$Rain \times FHH$	0.041**	0.050***	0.061*	0.048**	0.059***	0.063*
	(0.017)	(0.018)	(0.033)	(0.019)	(0.019)	(0.037)
$Rain \times None/NA$	0.173	0.173	0.058**	0.150	0.150	0.062**
	(0.147)	(0.147)	(0.026)	(0.162)	(0.163)	(0.028)
$Time \times Headship$	Yes	Yes	Yes	Yes	Yes	Yes
$Time \times Province$	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.103	0.106	0.098	0.107	0.110	0.102
Number of households	5,761	5,761	5,761	4,631	4,631	4,631
Sample	Wave 3, ignoring gaps (baseline)			Wave 3, without gaps		
Headship definition	Combined	Demographic	Working	Combined	Demographic	Working
	(7)	(8)	(9)	(10)	(11)	(12)
Rain	0.006	0.006	-0.018	0.00002	0.002	-0.021
	(0.015)	(0.014)	(0.024)	(0.014)	(0.013)	(0.022)
$Rain \times MHH$	0.042**	0.060**	0.051*	0.049**	0.065*	0.060*
	(0.019)	(0.029)	(0.030)	(0.024)	(0.039)	(0.032)
$Rain \times FHH$	0.045**	0.057***	0.052	0.048**	0.055***	0.060
	(0.018)	(0.018)	(0.033)	(0.020)	(0.019)	(0.037)
$Rain \times None/NA$	0.113	0.113	0.061**	0.108	0.105	0.055*
	(0.185)	(0.185)	(0.028)	(0.239)	(0.240)	(0.028)
$Time \times Headship$	Yes	Yes	Yes	Yes	Yes	Yes
$Time \times Province$	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.113	0.116	0.110	0.113	0.116	0.107
Number of households	4,162	4,162	4,162	3,241	3,241	3,241

Rain is the cumulative gamma distribution of relative rainfall. *MHH* are male-headed households, *FHH* are female-headed households, and *None / NA* are households without an adult head, without an adult worker, or where headship could not be determined. Reference group: Dual-headed households. All regressions include household fixed effects.Standard errors clustered at the district council level in brackets. Stars indicate significance of two-tailed tests. * significant at 10%, ** significant at 5%, *** significant at 1%.

B Timing of rainfall (contd.)

In Section 8.2, we showed that the results are robust to including a lead and a lag one at the time. This section shows that also other specifications give similar coefficients.

In Table 10, the lead and lagged terms are entered simultaneously in columns 1-3, and two lags are included in columns 4-6. By the combined definition, the significance drops when lead and lags are entered simultaneously, yet by the demographic definition, the differential vulnerability of female-headed households from rainfall during the last season remains significant at the 5% level through all the specifications. That differential vulnerability is also very similar and significant at the 10% level when including lead and two lags, and drops somewhat when lead and three lags are included (not shown).

Table 10: Vulnerability to rainfall during various rainy seasons, continued

	Combined (7)	Demographic (8)	Working (9)	Combined (10)	Demographic (11)	Working (12)
$Rain_{dT}$	-0.018	-0.020	-0.042	0.014	0.006	-0.031
	(0.029)	(0.029)	(0.037)	(0.026)	(0.024)	(0.031)
$Rain_{dT} \times MHH$	0.049*	0.055	0.062	0.012	0.030	0.051
	(0.027)	(0.043)	(0.041)	(0.033)	(0.043)	(0.038)
$Rain_{dT} \times FHH$	0.043	0.066**	0.050	0.036	0.058**	0.053
	(0.028)	(0.029)	(0.048)	(0.024)	(0.025)	(0.036)
$Rain_{dT} \times None/NA$	-0.085	-0.082	0.058	0.256	0.264	0.087**
	(0.252)	(0.253)	(0.045)	(0.239)	(0.240)	(0.034)
$Rain_{d,T+1}$	-0.053**	-0.049**	-0.018			
	(0.025)	(0.024)	(0.041)			
$Rain_{d,T+1} \times MHH$	0.034	-0.005	0.008			
	(0.039)	(0.060)	(0.043)			
$Rain_{d,T+1} \times FHH$	-0.003	0.008	-0.030			
	(0.032)	(0.035)	(0.061)			
$Rain_{d,T+1} \times None/NA$	-0.851***	-0.855***	-0.055			
	(0.311)	(0.312)	(0.049)			
$Rain_{d,T-1}$	-0.003	-0.014	-0.040	0.014	-0.002	-0.038
	(0.027)	(0.025)	(0.034)	(0.033)	(0.031)	(0.041)
$Rain_{d,T-1} \times MHH$	-0.005	0.003	0.034	-0.048	-0.044	0.017
	(0.033)	(0.038)	(0.042)	(0.049)	(0.056)	(0.049)
$Rain_{d,T-1} \times FHH$	0.0002	0.026	0.031	-0.013	0.016	0.022
	(0.023)	(0.026)	(0.036)	(0.029)	(0.034)	(0.040)
$Rain_{d,T-1} \times None/NA$	0.014	0.025	0.048	0.286	0.303	0.067
	(0.257)	(0.258)	(0.040)	(0.324)	(0.325)	(0.043)
$Rain_{d,T-2}$				0.012	-0.003	-0.018
				(0.026)	(0.024)	(0.037)
$Rain_{d,T-2} \times MHH$				-0.094**	-0.103*	-0.036
				(0.044)	(0.052)	(0.042)
$Rain_{d,T-2} \times FHH$				-0.040	-0.028	-0.035
				(0.027)	(0.032)	(0.048)
$Rain_{d,T-2} \times None/NA$				0.441	0.457	0.025
				(0.331)	(0.331)	(0.042)
$Time \times Headship$	Yes	Yes	Yes	Yes	Yes	Yes
$Time \times Province$	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.116	0.119	0.111	0.115	0.118	0.111
Number of households	4,162	4,162	4,162	4,162	4,162	4,162

Rain is the cumulative gamma distribution of relative rainfall. *MHH* are male-headed households, *FHH* are female-headed households, and *None / NA* are households without an adult head, without an adult worker, or where headship could not be determined. Reference group: Dual-headed households. All regressions include household fixed effects. Standard errors clustered at the district council level in brackets. Stars indicate significance of two-tailed tests. * significant at 10%, ** significant at 5%, *** significant at 1%.

C Auto-regressive model

Autocorrelation in the dependent variable may lead to an inconsistent fixed effects estimator even if the explanatory variable is exogenous as in our case (Söderbom, Teal, Eberhardt, Quinn, and Zeitlin, 2014). Intuitively, what happens is that a season with shortage of rain that has dynamic effects on income beyond the first year will reduce the fixed effect estimate and thus bias our estimator. In this section, we show that female-headed households remain vulnerable to rainfall when including auto-regressive variables.

To that end, we first have to re-organize the time series to consider agricultural years, since that is the level at which we have variation in the independent variable. We thus ran the following model:

$$\bar{Y}_{iT'} = \alpha_i + Rain_{dT} + \alpha_{PT'} + \epsilon_{iT'} \tag{3}$$

Where T' is one of eight agricultural years, defined as the 12 months following the end of rainy season T, and $\bar{Y}_{iT'}$ is the average of the logged monthly incomes in the period. The regression was run separately for each household group. Results are shown in Table 11. Some signficance is lost as we are not exploiting all the available time information, yet female-headed households remain vulnerable according to the combined and demographic definitions at the 10% and 5% significance levels respectively.

Table 11: Vulnerability by headship groups, agricultural year averages

	Combined headship			
	Dual	MHH	FHH	None / NA
	(1)	(2)	(3)	(4)
Rain	-0.039	0.015	0.064*	-0.346
	(0.032)	(0.051)	(0.037)	(0.444)
$Year \times Province$	Yes	Yes	Yes	Yes
R-squared	0.086	0.129	0.164	0.615
Number of households	1,781	867	1,479	35
	Demographic headship			
	Dual	MHH	FHH	None / NA
	(5)	(6)	(7)	(8)
Rain	-0.038	0.063	0.081**	-0.346
	(0.036)	(0.082)	(0.038)	(0.444)
$Year \times Province$	Yes	Yes	Yes	Yes
R-squared	0.086	0.167	0.171	0.615
Number of households	2,333	498	1,296	35
	Working headship			
	Dual	MHH	FHH	None / NA
	(1)	(2)	(3)	(4)
Rain	-0.076	-0.013	0.045	0.007
	(0.046)	(0.040)	(0.053)	(0.037)
$Year \times Province$	Yes	Yes	Yes	Yes
R-squared	0.110	0.102	0.164	0.146
Number of households	529	646	710	2,277

Rain is the cumulative gamma distribution of relative rainfall. *MHH* are male-headed households, *FHH* are female-headed households, and *None / NA* are households without an adult head, without an adult worker, or where headship could not be determined. All regressions include household fixed effects. Standard errors clustered at the district council level in brackets. Stars indicate significance of two-tailed tests. * significant at 10%, ** significant at 5%, *** significant at 1%.

The next step is to insert a lagged dependent variable. For that, we reformulate the equation to difference form and estimate the following equation:

$$\Delta \bar{Y}_{iT'} = \Delta \bar{Y}_{i,T'-1} + \Delta Rain_{dT} + \Delta \alpha_{PT} + \Delta \epsilon_{iT} \qquad (4)$$

Where Δ is a change from the previous period. Following Anderson and Hsiao (1982), we instrument the lagged difference in the dependent variable by its level in period $T' - 2$. This was again done separately for every household type, except for the child-headed households since the sample size is too small to be analyzed with a credible instrument.[6]

We see from Table 12 that there is strong serial correlation in the data, with significant values of the lagged dependent variables in all regressions. Even when this is controlled for, female-headed households display significant vulnerability for changes in relative rainfall by the combined and the demographic definitions, at 10% and 5% significance levels respectively. There are also large point estimates for the vulnerability of male-headed households by the demographic definition and female-headed households by the working definition, although not significant.

[6]We also used more moments by applying the difference GMM method of Arellano and Bond (1991) and the system GMM method of Blundell and Bond (1998) using the program of Roodman (2009), yet these specifications were overidentified in most of the twelve regressions. The levels and significance of the rainfall variable were similar.

Table 12: Vulnerability by headship groups, Anderson and Hsiao method

	Combined headship		
	Dual	MHH	FHH
Dep. var: $\Delta\bar{Y}_{iT'}$	(1)	(2)	(3)
$\Delta Y_{i,T'-1}$	1.455***	1.241***	1.233***
	(0.096)	(0.079)	(0.115)
$\Delta Rain_{dT}$	0.018	0.010	0.046*
	(0.021)	(0.034)	(0.023)
$Year \times Province$	Yes	Yes	Yes
First-stage F-test	16.09	12.86	16.01
Number of households	1,781	867	1,479

	Demographic headship		
	Dual	MHH	FHH
Dep. var: $\Delta\bar{Y}_{iT'}$	(1)	(2)	(3)
$\Delta Y_{i,T'-1}$	1.395***	1.167***	1.287***
	(0.110)	(0.086)	(0.134)
$\Delta Rain_{dT}$	0.017	0.046	0.044**
	(0.020)	(0.060)	(0.022)
$Year \times Province$	Yes	Yes	Yes
First-stage F-test	21.46	10.15	15.87
Number of households	2,333	498	1,296

	Working headship			
	Dual	MHH	FHH	None / NA
Dep. var: $\Delta\bar{Y}_{iT'}$	(1)	(2)	(3)	(4)
$\Delta Y_{i,T'-1}$	1.508***	1.336***	1.072***	1.352***
	(0.345)	(0.190)	(0.149)	(0.072)
$\Delta Rain_{dT}$	0.005	0.015	0.046	0.009
	(0.043)	(0.029)	(0.034)	(0.025)
$Year \times Province$	Yes	Yes	Yes	Yes
First-stage F-test	4.95	8.57	9.63	21.68
Number of households	529	646	710	2,277

Rain is the cumulative gamma distribution of relative rainfall. *MHH* are male-headed households, *FHH* are female-headed households, and *None / NA* are households without an adult head, without an adult worker, or where headship could not be determined. Standard errors clustered at the district council level in brackets. Stars indicate significance of two-tailed tests. * significant at 10%, ** significant at 5%, *** significant at 1%.