Supplementary Material

Appendix 1. Empirical and theoretical differences with the study by Corno, Hildebrandt, and Voena (2016)

Although the Corno et al. study also uses DHS data it differs from ours in many important dimensions both empirically and theoretically. First, it does not use information on women's residence prior to marriage (e.g. while experiencing the shock), thus the authors make inference about the respondent's residence in adolescence based on her current residence. Given that migration related to marriage and/or a climatic shock is common in Africa, we do not assume that current residence reflects residence in adolescence and limit our sample to women whose adolescent residence is known. Second, the Corno et al. study uses rainfall to construct drought measures, whereas we use the SPEI measure which is a combination of different climate parameters including precipitation, but also evaporation. This is important because evaporation plays an important role in drought. Third, the Corno et al. study defines the shock as the calendar year rainfall below the 15% percentile of a long-run rainfall distribution (e.g. in the full year), whereas we focus on climatic conditions during the growing season. We do this because it is important to consider the specific period in which crops are actually growing to understand the nature of the shock. Fourth, the Corno et al. study considers marriage as the main outcome and conducts a cross-national analysis that spans multiple continents. We focus one case study and consider marriage in the context of young women's life course transitions, which we believe is contextually important given the fluid and processional nature of marriage in the sub-Saharan African context we study. In doing so, in addition to exploring the effects on marriage timing, we also examine the impacts on sequencing and partnership characteristics which are other key dimensions of young women's life course transitions. In part, this reflects differences in the goals of the paper: the Corno et al. study aims to explore the disparate effects of bride price versus dowry in influencing marriage timing under wealth shocks, while we strive to develop and test a more general framework about how weather shocks might influence young women's life course transitions.

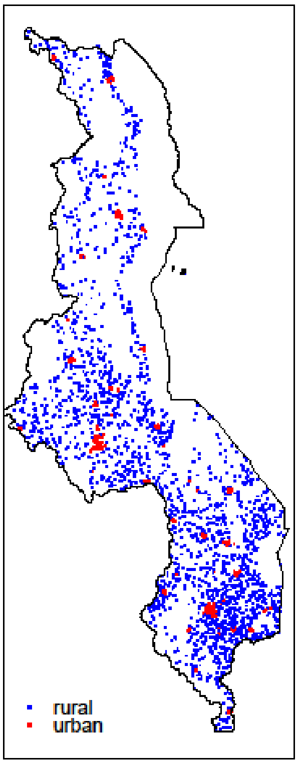
Appendix 2. Detailed discussion of sample creation

We combine data from three different sources in order to explore the effects of weather shocks on young adult women's transitions to adulthood in Malawi: (1) georeferenced individual-level data from the Malawi Demographic and Health Surveys 2000, 2004, 2010, 2015–16; (2) climate data on Malawi from the European Centre for Medium-Term Weather Forecasting (ECMWF); and (3) calendar crop data for Malawi from the Global Monthly Irrigated and Rainfed Crop Areas (MIRCA2000). Combing these data sources allows us to calculate a measure of drought shocks based on the SPEI index, and link this measure to young adult women's life course information (described in further detail in the section on treatment in the main text).

In what follows we describe each of the data sources used in our analysis in detail and also describe the climate parameters we take to create the SPEI index.

First, the individual-level data come from four Malawi Demographic and Health Surveys: 2000, 2004, 2010, 2015–16. The DHS is cross-sectional publicly available data that is nationally representative of women of reproductive age (e.g. 15–49), collected by ICF international in collaboration with host country governments. The DHS includes detailed information about union and family formation, reproductive health, fertility, and georeferenced information (i.e. latitude and longitude) on the woman's location (Fig. S1).

Fig. S1 Spatial distribution of the DHS cluster across Malawi by type of residence (rural/urban).



Because we are interested in union and family transitions in early adulthood, we focus our analysis on a sample of young adult women aged 15–24. The DHS uses a stratified random sampling design, where the primary geographic sampling unit is the cluster (also known as the primary sampling unit). We limit our sample to young adult women who report living in the same cluster since the age of 9 years old to ensure that we know where the woman was residing in early adulthood and thus have the correct spatial ordering between drought shocks and life course transitions. This is an important step since migration in response to a weather shock and/or marriage is common in Malawi (Beegle and Poulin 2012), thus women's current residence may not accurately reflect the location and climatic conditions of their adolescence prior to the shock. For example, women may have migrated in response to a weather shock or to marriage, so that based on their current location it appears that they were unaffected by weather shocks when in fact the reverse is true. This has been a limitation of other work on weather shocks and marriage, which have relied upon cross-sectional information about current location to assess the effect of exposure to droughts in adolescence on marital transitions (Corno and Voena 2016). We identify these women using a variable about how long the respondent has lived in the current cluster; this allows us to identify the childhood location of women who have never migrated, but does not provide information about residence in childhood for women who have migrated (who we drop from our analytical sample). Note that visitors, i.e. women surveyed but not resident in the household, are also excluded.

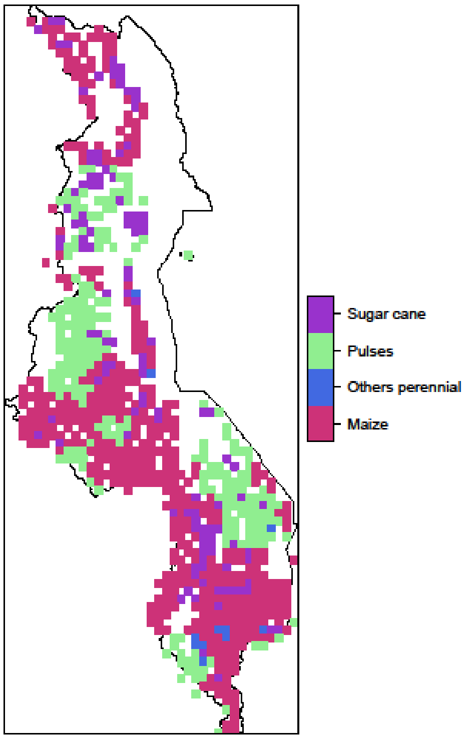
We take advantage of the fact that matrilineal lineage is common in Malawi (Peters 2010) which means that there are very high rates of young adult women still living in their natal communities. In total, 55.8% of young women aged 15–24 have been living in the same DHS cluster since the age of 9 years old, giving us a total sample of 17,033 women living in 2,680 clusters (Table 1 for summary statistics). Because bride price is less common in Malawi, this allows us to explore whether weather shocks impact young adult women's marital and life-course transitions even largely in the absence of bride price payments. Although existing studies have focused on bride price as the main reason weather shocks might impact transitions to marriage in Africa (Corno, Hildebrandt, and Voena 2016; Corno and Voena 2016; Hoogeveen, van der Klaauw, and van Lomwel 2011), weather shocks might still affect marriage because of the indirect financial gains from marriage. Given that the prevalence of bride price is highly heterogenous in Africa (Anderson 2007), there is a need for a broader understanding of how weather shocks impact young people's life course transitions even in the absence of bride price payments.

We construct two different types of datasets for our analysis. The first type of dataset is a panel dataset where the unit of analysis is person-years. This dataset is used for the Event History Analyses where the outcomes are related to timing of union formation and conception. We use 11 years of age as the data entry point, the age at first union and at first conception as the data exit point, and the survey month/year as the end of observation. In our sample, the minimum age at first union is 8 years old while that at first birth is 10 years old; however, most women report entering into a first union and having their first birth only after 10 and 11 years old, respectively. Thus, for consistency across models, we set 11 years old as the age when a woman is first at risk of entering into a union and childbearing. The data are right-censored because some women may not have experienced the event by the time of the survey, and are organized so that each woman contributes multiple person-years to the analysis. The second type of dataset is a cross sectional dataset where the unit of analysis is each individual respondent. This dataset is used to estimate linear probability models for outcomes related to partnership characteristics.

Second, the climate data is taken from the ERA-Interim archive produced by the European Centre for Medium-Term Weather Forecasting (ECMWF). Weather outcomes are available for every six hours from 1 January 1979 to 31 August 2016, on a global grid of parallels and meridians at a 0.75 × 0.75-degree resolution (Dee et al. 2011). We use data on monthly mean daily net solar radiation, daily maximum and minimum air temperature, monthly mean daily wind speeds at 10 m height, monthly mean daily dewpoint temperature, and elevation above sea level.

Third, calendar crop data is used to identify the growing-season months of the main crop grown (ranked by harvested area) in a given cell. We use the Global Monthly Irrigated and Rainfed Crop Areas (MIRCA2000), which is a data set of monthly growing seasons of 26 irrigated and rainfed crops at different latitudes and longitudes, with a spatial resolution of 5 arc-minute grids (Portmann, Siebert, and Döll 2010). We select the crop with the greatest value in each cell, in other words the main crop grown in the cell. The growing-seasons months are defined as those between the last month of the planting period and the first month of the harvesting period. Fig. S2 provides a full picture of the cultivation pattern across Malawi and shows variation in the crop spatial distribution. Using georeferenced data in the DHS, each woman in our sample is matched to the weather (ERA-I) and calendar crop (MIRCA) grid cell in which she resides.

Fig. S2 Spatial distribution of main crop across Malawi.



Appendix 3. Detailed discussion of creation of SPEI

Drought shocks have become one of the major manifestations of climate change in contemporary Malawi, with far reaching implications for livelihoods and population wellbeing. We measure drought exposure with the Standardised Precipitation Evapotranspiration Index (SPEI), which has been identified as the most complete and robust agricultural drought index in Africa (WMO 2012). The SPEI presents an improved measure of drought that includes climate indicators other than just precipitation. This is relevant because increases in evaporation from soil and vegetation—in addition to decreases in precipitation—play a role in droughts. Specifically, agricultural droughts are associated with a shortage of water for plant growth and are assessed as insufficient soil moisture to replace evapotranspirative losses (WMO 1975), which in turn affects crop yields and variability. The SPEI measures drought severity, intensity and duration, and allows for comparisons of drought severity through space and time (Vicente-Serrano, Beguería, and López-Moreno 2010). The SPEI at a 3 month-time scale reflects short and medium-term moisture conditions, thus providing a seasonal estimation of precipitation as it is relevant for agriculture.

A further benefit of our approach is that we focus on whether the drought occurred during the growing seasons—when crops are most vulnerable to drought—rather than using monthly or year rainfall averages as in Corno et al. (2016). The latter approach is problematic because it averages climatic conditions over a relatively long timeframe, which can mask important short-term shocks that are devastating to key crops. The SPEI index has been used to test the effects of agricultural shocks on conflict (Harari and La Ferrara 2018; von Uexkull et al. 2016) and the effects of drought shocks on child mortality (Andriano 2018), however our analysis represents the first time it is combined with data on young people's life course transitions.

For this analysis, we calculate the potential evapotranspiration (PET) – i.e. amount of water that could be evaporated and transpired if a sufficient water source were available – based on the FAO-56 Penman-Monteith estimation and the 3-month SPEI (SPEI3) for each cell and month from Jan 1979 to Aug 2016. SPEI3 is expressed in units of standard deviation from the cell average of SPEI and has mean 0 by construction. In accordance with the World Meteorological Organization (WMO), we designate a severe and extreme drought, which, for shorthand, we refer to as severe drought, when SPEI3 is smaller than –1.5 (WMO 2012). A drought is defined severe when SPEI ranges from –1.5 and –1.99 and extreme when SPEI is smaller than –2 (WMO 2012), thus SPEI ≤ –1.5 encompasses a severe and extreme drought. Then, for each cell g and woman w observed in month/year d we define the independent variable, severe growing-season drought (which is used interchangeably with growing-season drought), as the proportion of months during the last and second-to-last completed growing seasons in which a severe drought (i.e. SPEI3 below –1.5) occurs prior d. Then, we construct the growing-season drought variable as:

$$\mathrm{gs\_drought\_}ei_{\mathrm{g,d}} = \omega_{\mathrm{g,d}} * \mathrm{gs\_drought\_}ei_{1}^{\mathrm{g,d}} + \left(1 - \omega_{\mathrm{g,d}}\right) * \mathrm{gs\_drought\_}ei_{2}^{\mathrm{g,d}}, \text{ Eq. (S1)}$$

where $gs\_drought\_ei_1^{g,d}$ and $gs\_drought\_ei_2^{g,d}$ are the growing-season drought during the last and second-to-last completed growing seasons preceding date d for location g. Weight $\omega_{g,d}$ is given by $\omega_{g,d} = \frac{d-h^{g,d}}{12}$, where $h^{g,d}$ is the running month of the last harvest preceding date d in location g, and accounts for how many months in the year before the event a young woman was exposed to droughts. We demonstrate that our main results do not depend on the definition of $\omega_{g,d}$ (see Appendix 4 for further details). The growing-season drought variable is a [0;1] continuous variable where 0 indicates that the woman did not experience any drought event prior d and 1 indicates that the woman experienced droughts for the whole growing-season period prior d.

Appendix 4. Definition of $\omega_{g,t}$ in (Eq. (1)).

In Eq. (1) we average the last and second-to-last growing season drought using a pre-specified weighting variable that is proportional to the months between the end of the last growing-season and the date of the observation. This allows to capture that as the distance between the observation date and the most recent growing season gets longer, the drought in the previous growing season should be less relevant. In order to show that this weighting scheme is not affecting our results, we perform a series of robustness checks. First, we calculate the growing-season drought measure in Eq. (1) using our pre-specified weighting variable $\omega_{g,d}$ and calculate the mean value of this variable. Then, we estimate the discrete-time logit model of transition into first union in Eq. (2) to calculate the coefficient of growing-season drought on first union, its p-value, and the mean of fitted values of the model. We do the same exercise for different specifications of $\omega_{g,d}$ (as non-linear functions of time) and check if the mean value of growing season drought, the coefficient of growing season drought on first union, its p-value, and the mean fitted values of the model change. Table S1 shows that using different specifications of $\omega_{g,d}$ does not affect the results, which also validates the use of our pre-specified weighting variable in the definition of the growing season drought measure.

Table S1 Results from using different specifications of $\omega_{g,d}$ in (Eq. (1)).

Weight in Eq. (1)	Weighted mean of $gs\_drought\_ei_{it}$ in Eq. (1)	λ in Eq. (2)	P-value of λ	Mean fitted values
$\omega_{g,d}$	0.023	0.683	0.000	0.081
${\omega_{g,d}}^2$	0.024	0.537	0.001	0.081
$\sqrt{\omega_{g,d}}$	0.023	0.659	0.000	0.081
$\frac{\omega_{g,d}}{2}$	0.024	0.525	0.002	0.081
$\omega_{g,d} * 2$	0.022	0.372	0.002	0.081

Table S2 Discrete-time logit models of transition into first union and birth (log-odds ratios) – full sample.

	Union Model 1	Birth Model 2
Exposure to growing-season drought	0.39**	0.04
	(0.12)	(0.13)
Exposure to extremely wet growing season	-0.22	0.30
	(0.20)	(0.20)
Oldest	-0.002	-0.01
	(0.02)	(0.02)
Siblings (2,5]	0.02	-0.03
	(0.03)	(0.03)
Siblings (5,8]	0.03	-0.01
	(0.03)	(0.03)
Siblings 8+	0.0001	0.03
	(0.04)	(0.04)
Rural	-0.23***	-0.17***
	(0.03)	(0.03)
Years of education	-0.17***	-0.14***
	(0.003)	(0.003)
Muslim	0.18***	0.16***
	(0.05)	(0.05)
Other/None	0.21***	0.15***
	(0.02)	(0.03)
Protestant	-0.06*	-0.04
	(0.03)	(0.03)
Lomwe	0.24***	0.21***
	(0.04)	(0.04)
Ngoni	0.09**	0.17***
	(0.04)	(0.04)
Other	0.09*	0.08*
	(0.04)	(0.04)
Tumbuka	0.10*	0.11*
	(0.05)	(0.05)
Yao	0.05	0.03
	(0.05)	(0.05)
Person-Years of Observation	186,584	201,245
AIC	92,587.36	86,504.68

+p<.1; *p<.05; **p<.01; ***p<.001

Controls: age fixed effects, year of birth fixed effects, survey fixed effects, ERA-I cell fixed effects.

Appendix 5. More information about the supplementary analyses

As a supplement, we estimate our analyses on the *full* sample of women aged 15 to 24 (i.e., including both migrants and non-migrants) from the Malawi DHS and show that our main findings are similar to those generated using the full sample of DHS women (Table S2; results from Tables 4–7 are also robust and available upon request from the authors). This finding is consistent with the assumption that migration is local, that is women who migrate for marriage or other reasons are not migrating far from their childhood place of residence, and thus have the correct spatial ordering between drought shocks and life course transitions. Under this assumption, our results are generalizable to the whole population of Malawi.

As a further supplement, we examine if drought predicts the probability of marrying outside the location of residence during childhood. From the full sample of DHS partnered women, we exclude women who migrated after marriage as well as visitors and estimate the model in Eq. (4) where our dependent binary variable takes value 1 if the woman migrated at the same age as she got married or one year before and 0 otherwise to predict the effects of exposure to growing-season drought prior to the union onset on the probability of marrying outside the location of residence during childhood (results are robust to relaxing the sample restriction on excluding women who migrated after marriage and are available upon request). This finding is consistent with the (smaller) assumption that marriage is local, that is women who migrate for marriage are not migrating far from their childhood place of residence, and thus have the correct spatial ordering between drought shocks and life course transitions. We find that women's marriage-migration decreases with exposure to growing season droughts (Table S3, Supplementary Material) and this suggests that the women in our sample are less likely to marry out because of drought, thus indicating another way drought might influence women's marriage patterns.

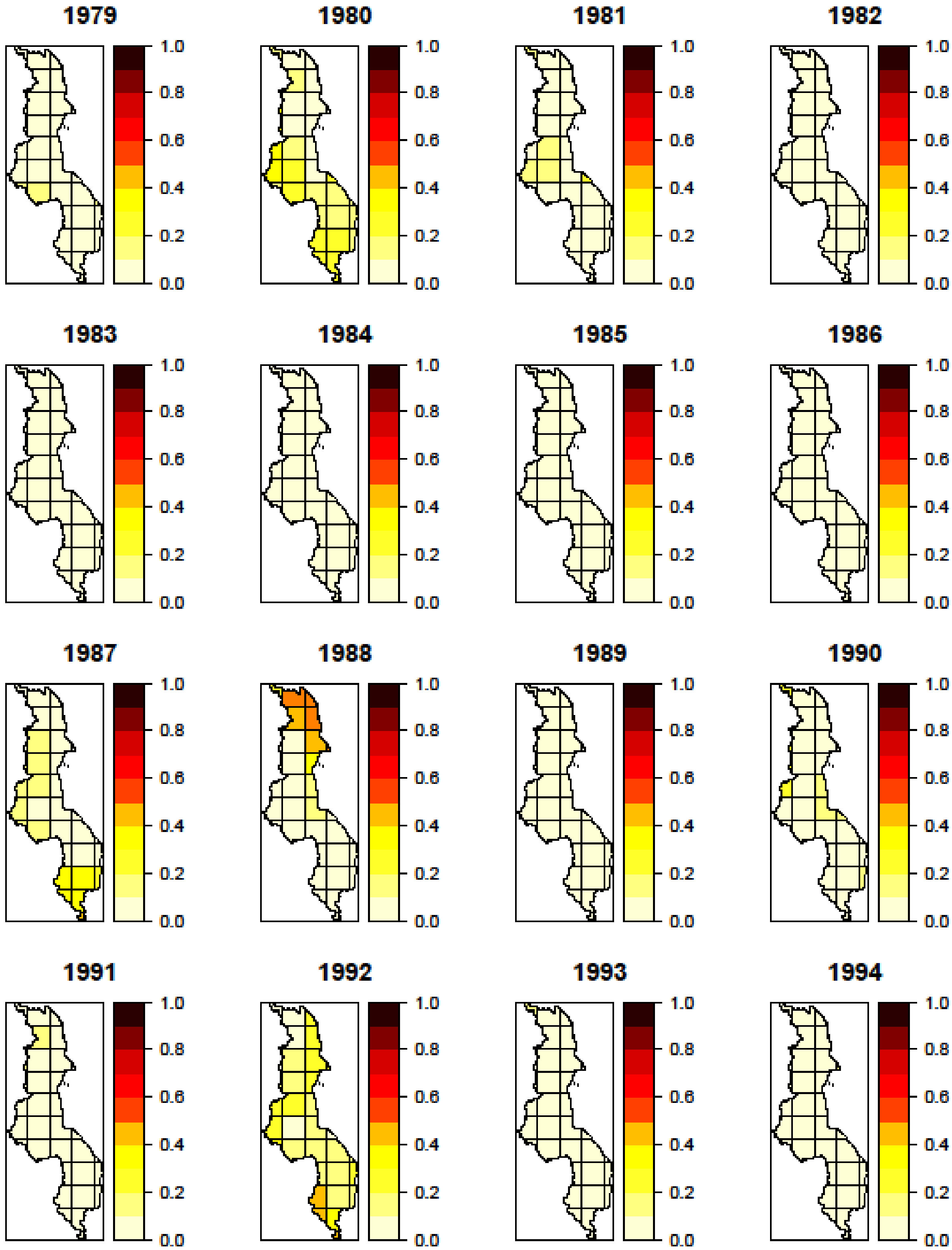
Table S3 Linear effects of droughts on marrying outside the location of residence during childhood.

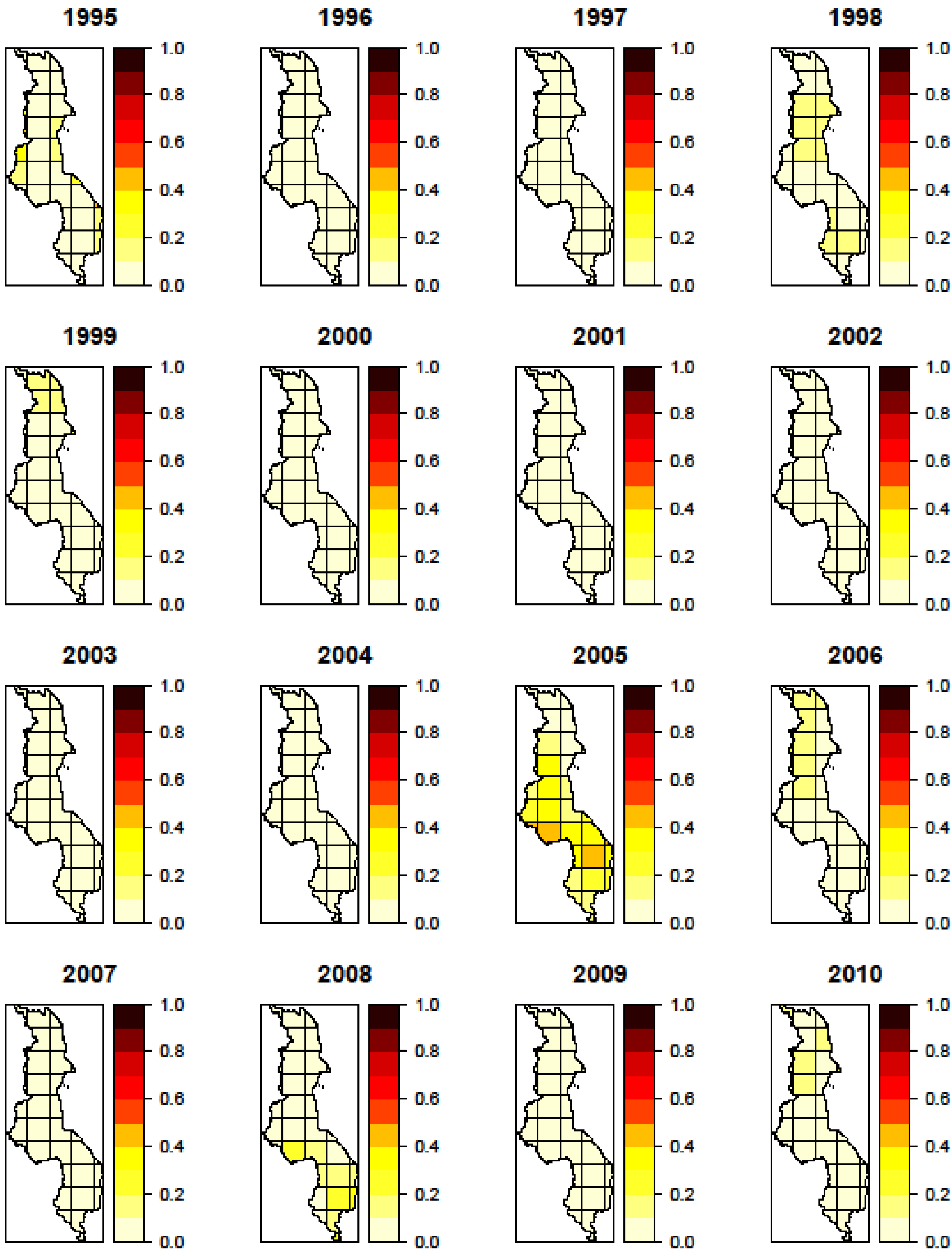
	Marrying outside
Exposure to growing season droughts	-0.16**
	(0.05)
Exposure to growing season wet events	-0.14+
	(0.07)
Oldest	-0.003
	(0.01)
Siblings (2,5]	0.02+
	(0.01)
Siblings (5,8]	0.02+
	(0.01)
Siblings 8+	0.002
	(0.02)
Rural	-0.13***
	(0.02)
Years of education	0.01***
	(0.001)
Muslim	-0.01
	(0.02)
Other/None	0.003
	(0.01)
Protestant	0.01
	(0.01)
Lomwe	-0.01
	(0.01)
Ngoni	0.02
	(0.02)
Other	0.05**
	(0.02)
Tumbuka	0.05*
	(0.03)
Yao	-0.01
	(0.02)
N	12,317
R^2	0.154

+p<.1; *p<.05; **p<.01; ***p<.001

Controls: year of birth fixed effects, survey fixed effects, ERA-I cell fixed effects. Standard errors are clustered by ERA-cell level and woman's year of birth.

Fig. S3 Spatial distribution of droughts across Malawi, 1979–2016.

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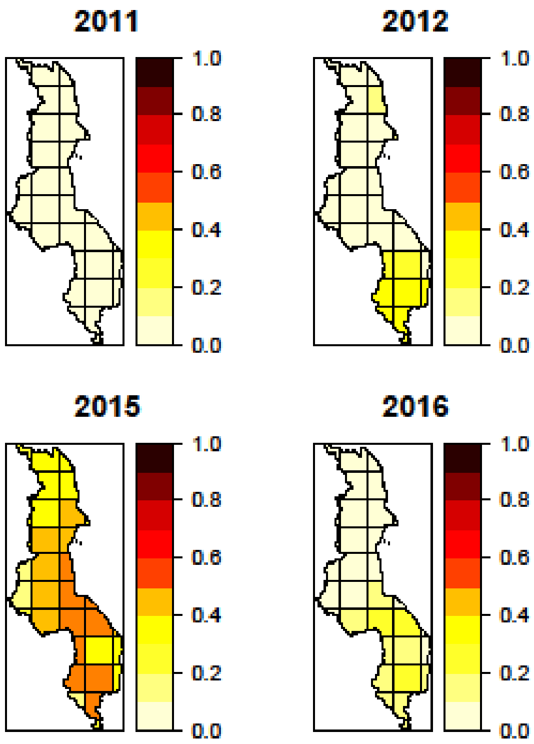
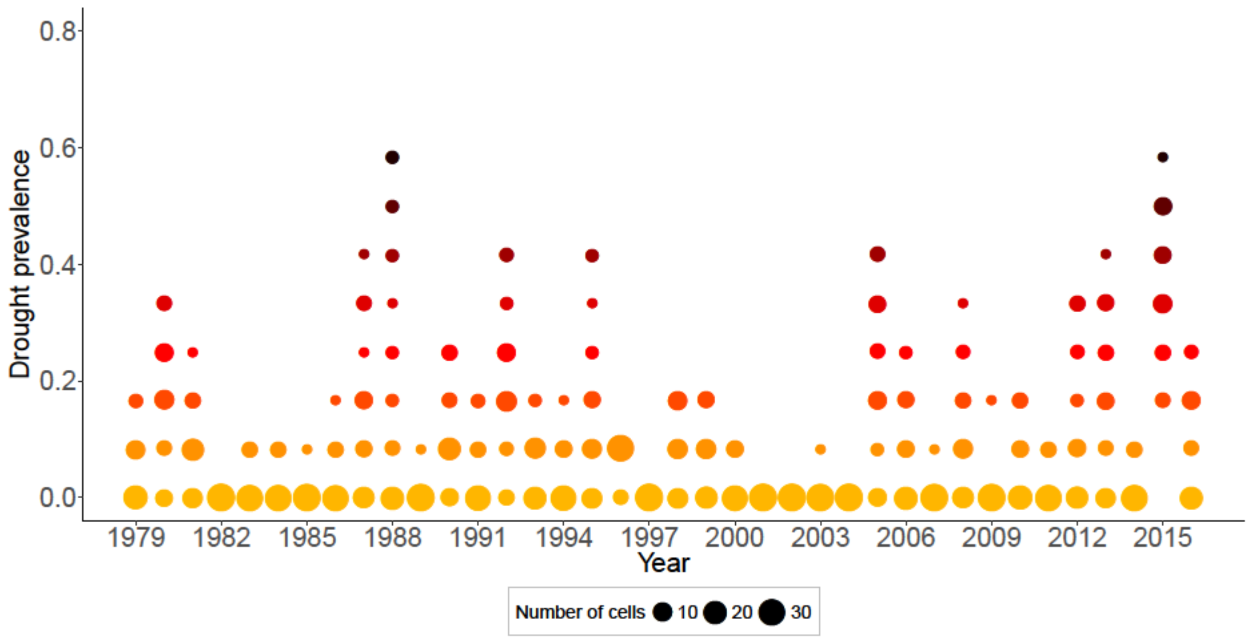


Note: For this analysis, we compute the drought measure in the calendar year (as opposed to the growing season) for two main reasons. First, in some spatial units the main crop's growing season starts in December and ends in April of the next year, which would make it infeasible to calculate a drought measure for each year. Second, the fact that the calendar data spatial resolution differs from the weather data spatial resolution prevents us from combining these data without aggregating the calendar crop data to larger spatial units.

Fig. S4 Drought prevalence in Malawi over time, 1979–2016.



Notes: Colour intensity varies with drought prevalence, the darker the colour the greater the prevalence of drought.

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