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Climate Change, Agrarian Distress, and the Feminization of Agriculture in South Asia*

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Abstract Agrarian distress—the experience wherein sustaining an agricultural livelihood becomes increasingly challenging—is well documented in South Asia. Another regional trend is the feminization of agriculture or an increase in women's work and decision-making in agriculture. Scholars have recently linked these two phenomena, demonstrating that agrarian distress results in the movement of men out of agriculture, driving women into the sector. Yet what remains underexplored is the relationship between climate change, a contributor to agrarian distress, and the feminization of agriculture. To examine this, we link socioeconomic and demographic data from India, Bangladesh, and Nepal to high-resolution gridded climate data. We then estimate a set of multivariate regression models to explore linkages between recent temperature and precipitation variability from historical norms and the likelihood that a woman works in agriculture. Results suggest that hotter-than-normal conditions in the year prior to the survey are associated with an increased likelihood of working in agriculture among women. This relationship is particularly strong among married women and women with less than primary education. While more research is needed to fully understand the mechanisms between climate change and the feminization of agriculture, our findings suggest a need for gender-sensitive climate change adaptation strategies.

Introduction

The feminization of agriculture has been a subject of interest since the parallel phenomenon of the feminization of poverty was recognized as a priority in the 1970s (Boserup 1970; Jiggins 1998). Broadly described

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as an increase in women's participation and decision-making in agricultural work, the feminization of agriculture can be demonstrated through increased percentages of women's employment in agriculture or increased women's time use in agricultural activities, especially when compared to men (Jiggins 1998; de Schutter 2013). While globally men are more likely than women to report working in agriculture, nearly half of the world's economically active women work in the agricultural sector (Doss 2014). Moreover, rates of women in agriculture are likely much higher given that women's participation in agriculture is known to be underreported due to gender discrimination in perceptions of what forms of work count as "work" (Doss 2014; Pattnaik and Lahiri-dutt 2021). The feminization of agriculture is an important topic of study, with a breadth of literature seeking to understand its mechanisms, causes, and effects (e.g., Adhikari and Hobley 2015; Gartaula, Niehof, and Visser 2010; McEvoy et al. 2012; Pattnaik, Lahiri-dutt, et al. 2018; de Schutter 2013; Zuo 2004). In this paper, we argue that the feminization of agriculture can be seen as a feminization of agrarian distress, wherein women are increasingly pushed into agricultural employment due to the sector's growing precarity. Precarity in the agricultural context of South Asia refers to the risks farmers and farmworkers must undertake with few safety nets, increased privatization and corporate power over inputs leading to indebtedness, instability of and lack of control over global crop markets, low income derived from agricultural work, and informality and lack of worker power in waged farm work (Barah and Sirohi 2011; Mishra 2020; Srivastava and Srivastava 2010). Contributing to this precarity is climate change, which makes agricultural livelihoods more unpredictable and generally decreases crop yields (Hatfield et al. 2011; Morton 2007).

To examine this, we link socioeconomic and demographic data from multiple rounds of the India Employment Survey, the Bangladesh Population and Housing Census, and the Nepal Population Census to high-resolution gridded climate data to understand the extent to which recent temperature and precipitation variability from historical norms is associated with a woman's likelihood of working in agriculture and to identify whether certain sub-populations are more vulnerable to climate-induced agricultural work. Climate projections for South Asia include increases in temperature, greater heterogeneity in rainfall, more extreme weather events, and increases in soil salinity (Lin et al. 2014; Sivakumar and Stefanski 2011; Teh and Koh 2016). Climate change is expected to negatively impact yields of crops including rice and wheat, likely leading to a decline in GDP in countries across the region (Bandara and Cai 2014). This paper offers novel insights into the gendered impacts of climate change in South Asia and can contribute to policy development with the goals of promoting gender equity and poverty reduction in the face of climate change.

Mechanisms, Causes, and Effects of the Feminization of Agriculture

Among employed individuals in South Asia, a greater proportion of women than men work in agriculture. In Nepal, India, and Bangladesh, 74, 55, and 58 percent of employed women work in agriculture, respectively, compared to 52, 40, and 30 percent of employed men (World Bank 2019). These statistics demonstrate the critical role women play in formal agricultural production, though it is important to note that women have historically also been central to agriculture in the informal sector, often as key contributors to subsistence production (Agarwal 1994; Boserup 1970). Though the feminization of agriculture speaks broadly to the increasingly important role of women in agriculture, within the literature, there are three separate yet closely related mechanisms through which feminization occurs.

The first conceptualization of the feminization of agriculture is that in subsistence agriculture in the Global South, women are increasingly responsible for farm work, taking on new tasks and roles previously gendered as men's (Jiggins 1998; de Schutter 2013). This can occur as men migrate for wage labor, leaving women to care for the home and family farm independently (de Brauw et al. 2013; Lyon, Bezaury, et al. 2010; McEvoy et al. 2012; de Schutter 2013). It can also occur without male out-migration if men shift to local wage labor or cash-cropping on the family farm, leaving women to manage subsistence agricultural production (Jiggins 1998; de Schutter 2013). Both of these paradigms can lead to increased visibility and recognition of women as employed in agriculture.

The second conceptualization is women increasingly shifting from subsistence production to more commercialized agriculture. This challenges traditional notions of women in agriculture, as female farmers may seek titles to the land under cultivation and be incorporated into markets, forcing communities and markets to recognize women as farmers in ways they had not been previously (Lyon, Bezaury, et al. 2010; de Schutter 2013). This shift may include greater decision-making on the farm for women, management of laborers, and participation in community farming groups—duties often incongruent with perceptions of women's appropriate role in agriculture (McEvoy et al. 2012).

The third mechanism is that women are increasingly being hired to perform wage labor in agriculture (Lowthers 2018; Mannon et al. 2011; Patel-Campillo 2012; Preibisch and Encalada Grez 2010).

While women's employment as agricultural wage laborers has been associated with gender-based violence (Lowthers 2018; Patel-Campillo 2012) and a presumed subservient nature inherent to women (Mannon et al. 2011), Bieri's (2014) review provides a more nuanced perspective of women's increased role in commercial agriculture, including findings that link women's waged employment in agriculture to increases in women's agency. These three mechanisms capture how the feminization of agriculture is happening through numerous channels and in small- and large-scale agricultural production.

Turning to causes, research has identified numerous interplaying push and pull factors that increase women's participation in agriculture. These include greater economic precarity in agriculture, especially for smallholders (Deere 2005; McMichael 2006a). As smallholders have been increasingly forced to compete in global markets through neoliberal globalization, they have been faced with challenges such as price controls, overproduction in the Global North, and dumping of the surplus products by Global North actors into the Global South (McMichael 2006a). Thus, smallholder farming has become a less viable livelihood, causing many households to adapt through livelihood diversification (Deere 2005). Related is an increase in male migration as men seek non-agricultural work, facing fewer mobility constraints than women (Lyon et al. 2010; McEvoy et al. 2012; de Schutter 2013).

Women's economic precarity under global patriarchy is another contributing factor (Jiggins 1998), as are labor and migration regimes that strategically recruit women due to their economic vulnerability (Chuang 2016; Deere 2005; Mannon et al. 2011; Preibisch 2005). As Kabeer (2012) notes, "evidence from a wide range of developing countries show widespread and increasing entry of women into work on a temporary, casual, seasonal or part-time basis" (15). Thus, women tend to have less stable and reliable employment compared to men, consequential to their (lack of) ability to organize for better working conditions (Deere 2005). Women's economic vulnerability is compounded by reproductive labor expectations and the related gender asset gap, or women's comparative lack of tangible and intangible assets (Deere 2005; FAO 2011).

The logic behind the feminization of agrarian distress hypothesis is that a key cause of the feminization of agriculture is the increasing tendency for male heads of households to temporarily migrate out of rural areas to seek new income opportunities as agricultural incomes prove inadequate (Pattnaik et al. 2018; de Schutter 2013). As Jiggins (1998) notes, "the intensity of women's dependence upon agriculture increases with the level of poverty" (252). Similarly, Pattnaik et al. (2018) argue that in India, the feminization of agriculture would "better be described as the feminization of agrarian distress" (138). While men are often able to find wage work outside of agriculture, women globally tend to have less access to outside wage work, and as described above, that work tends to be lower quality. When agriculture becomes a less viable livelihood, men migrate in search of alternative livelihoods, while women, with fewer opportunities to do so, are left behind to farm (Pattnaik et al. 2018). Thus, the feminization of agriculture can be seen as a joint expression of women's marginal economic status and agriculture's decreased viability as an economically sustainable livelihood.

There is an ongoing discourse as to whether the feminization of agriculture is a positive trend for women, leading to greater decision-making power and land-ownership, or whether it is a negative trend, wherein the burden of agricultural labor is falling onto women's shoulders. While some research shows an increase in women's decision-making power and ownership of assets as a result of the feminization of agriculture (Gartaula et al. 2010; Lyon et al. 2010), other research suggests that changes may be short-lived and insignificant and that the feminization of agriculture adds stress to already overburdened women (Adhikari and Hobley 2015; Daoud and Karama 2012; Gioli et al. 2014; McEvoy et al. 2012).

Research from South Asia suggests nuanced effects of the feminization of agriculture on women, complicated by differences in the mechanism of feminization, household status, and socioeconomic status. Studies demonstrate that women—particularly poor women—are bearing the brunt of the heavy workloads, instability, risk, and psychological stress of agricultural livelihoods, without radical or sustained increases in agency and empowerment (Adhikari and Hobley 2015; Bhandari and Chinnappa Reddy 2015; Garikipati and Pfaffenzeller 2012). Women entering agricultural wage work generally lack resources and opportunities to pursue alternative livelihoods, largely due to limited formal education, and these jobs have not only low pay but also low status (Garikipati 2008; Pattnaik et al. 2018; Srivastava and Srivastava 2010). Further, women's increased participation in agriculture causes increased demands on their time, contributing to mental distress (Adhikari and Hobley 2015; Bhandari and Chinnappa Reddy 2015).

However, this intensification of women's work has not necessarily been associated with parallel improvements in ownership of agricultural land, control over income, or the ability to make major household decisions (Adhikari and Hobley 2015; Arun 2012; Gartaula et al. 2010; Kanchi 2010; Pattnaik and Lahiri-Dutt 2020; Spangler and Christie 2020; Srivastava and Srivastava 2010). In smallholder circumstances, women may have minor decision-making power during a spouse's migration, yet lack major decision-making power, and might find their gains in the agency to be lost upon a husband's return (Adhikari and Hobley 2015). These findings are complicated, however, by the makeup and dynamics of the household (be it female-headed or headed by paternal in-laws), community, and type of agricultural work. Spangler and Christie (2020), Gartaula et al. (2010), and Pattnaik and Lahiri-Dutt (2020) all note heterogeneity in the effects of feminization on women, with some household, community, cultural, and work circumstances allowing for increased agency and power for women. For women agricultural wage workers, findings are less encouraging. Findings suggest agricultural work does not increase women's status due to the low status of the work itself, and due to low pay, and women's lack of control over income (Garikipati 2008; Srivastava and Srivastava 2010). Thus, while effects are diverse for individual women, overall feminization of agriculture in South Asia speaks less to women having increased power in agriculture, but more to poor rural women, a marginalized group, being forced to make livelihoods in a sector itself marginalized in the region's economy due to its low pay, low skill, and low-status nature.

Climate Change and the Feminization of Agrarian Distress

The feminization of agriculture in South Asia can further be seen as disempowering when taking into account agrarian distress and the growing effects of climate change on agricultural livelihoods. Framing the feminization of agriculture as demonstrative of women's lack of alternative livelihood opportunities rather than as an indicator of women's increasing empowerment, Pattnaik et al. (2018) link agrarian distress in India to the feminization of agriculture there. Agrarian distress can be defined as the increasingly precarious nature of smallholder farming due to agricultural competition in global markets, threats of land-grabbing and dispossession, and decreased sovereignty through corporate control of input markets (Barah and Sirohi 2011; McMichael 2006a, 2006b). Agrarian distress thus occurs as agriculture is progressively globalized, commercialized, and consolidated.

The literature on agrarian distress largely focuses on political, economic, and social factors affecting farmers (Barah and Sirohi 2011; McMichael 2006b). Climate change additionally intensifies agrarian distress in South Asia, as smallholder farmers depend on the natural environment for their subsistence (Morton 2007). Negative impacts on agricultural production in South Asia have been linked to changes in average temperatures (Isaac and Isaac 2017; Mall et al. 2006), changes in the timing and duration of rainfall particularly during the monsoon season (Isaac and Isaac 2017; Mall et al. 2006), increased CO_2 levels

(Mall et al. 2006), and major weather events such as droughts and floods (Mall et al. 2006). Increased heat in particular is a significant factor in decreasing crop yields and profits (Aggarwal 2008; Cai et al. 2016; Dell, Jones, and Olken 2008, 2009). Major crops in South Asia including various cultivars of rice, wheat, and maize have been shown to be highly vulnerable to irregularities in temperature (Hatfield et al. 2011; Rao et al. 2015; Ruhul Amin, Zhang, and Yang 2015).

Farmers have adopted a variety of adaptation strategies to cope with climate change. These include livelihood diversification, often entailing earning non-agricultural income, such as through men's migration for wage labor (Jha et al. 2018; Surie and Sharma 2019). This adaptation strategy could thus contribute to the feminization of agrarian distress. Globally, climate change is projected to increase migration in low- and middle-income countries, primarily through impacts on agricultural production (Falco et al., 2019). Climate-related migration has been well-documented in South Asia. Heat is associated with increased male migration in Pakistan (Mueller et al., 2014) and Bangladesh (Call et al., 2017) and rainfall variability is associated with increased male migration in Nepal, Bangladesh, and India (Bhatta et al. 2015). Dry spells are associated with an increase in male household head internal and international migration in Bangladesh (Carrico and Donato 2019).

Hypotheses

Our key research questions examine whether adverse climatic conditions contribute to women's employment in agriculture and whether certain sub-populations of women are most affected. We build off the theory that the feminization of agriculture is a result of agrarian distress and that agrarian distress is being exacerbated by climate change to test three hypotheses:

Hypothesis 1 When temperatures in the past year are higher than historic averages, women will have a greater likelihood of working in agriculture.

Hypothesis 2 When precipitation in the past year is drier or wetter than historic averages, women will have a greater likelihood of working in agriculture.

Hypothesis 3 The relationship between climatic conditions and the likelihood of working in agriculture will vary by a woman's level of education and marital status.

Methods

Data

To answer these questions we utilize socioeconomic and demographic data from the Integrated Public Use Microdata Series, International (IPUMS-I) (IPUMS 2019). IPUMS provides harmonized survey and census data to facilitate analyses across space and time. Datasets used in the analyses include the India Employment Survey from 1987, 1999, 2004, and 2009; the Bangladesh Population and Housing Census from 1991, 2001, and 2011, and the Nepal Population Census from 2001 and 2011. Each dataset contains information on women's employment in agriculture, individual- and household-level socioeconomic indicators, and district of residence. Other countries in the region were excluded from our sample due to the lack of data availability. We restrict our sample to respondents who identified as female, lived in rural areas, and were between the ages of 14–60 at the time of enumeration, based on legal retirement and working ages in all three countries.

Climate data were obtained from the Climatic Research Unit Time-Series (CRU) version 4.04 (Harris et al. 2020). CRU provides near-global monthly gridded data on average maximum daily temperature (°C) and total precipitation (mm) at a resolution of 0.5° latitude by 0.5° longitude. The CRU data were created by interpolating weather station data from over 4,000 stations using angular distance weighting. We extract spatial means of rainfall and temperature at the district level using time-stable geographic boundaries created by IPUMS-I. District boundaries correspond to second-level subnational administrative units in each country (called *zila* in India and Bangladesh and *jilla* in Nepal). Included in our analysis are women from 437 districts in India, 64 in Bangladesh, and 72 in Nepal. See Figure 1 for a map of the study countries including district boundaries.

From the monthly data, we calculate the average maximum temperature and total precipitation at the district-year scale and then transform these data into *z*-scores relative to a 30-year baseline period covering 1982–2011. A temperature *z*-score of two would therefore indicate that the temperature in year t in district k was two standard deviations hotter than the long-term average annual temperature for that district. Finally, we link the climate data to the survey/census data using the year of survey and a woman's district of residence.

Measures

Our outcome variable is a binary indicator of whether or not a woman reports working in agriculture at the time of the census/survey. It is worth

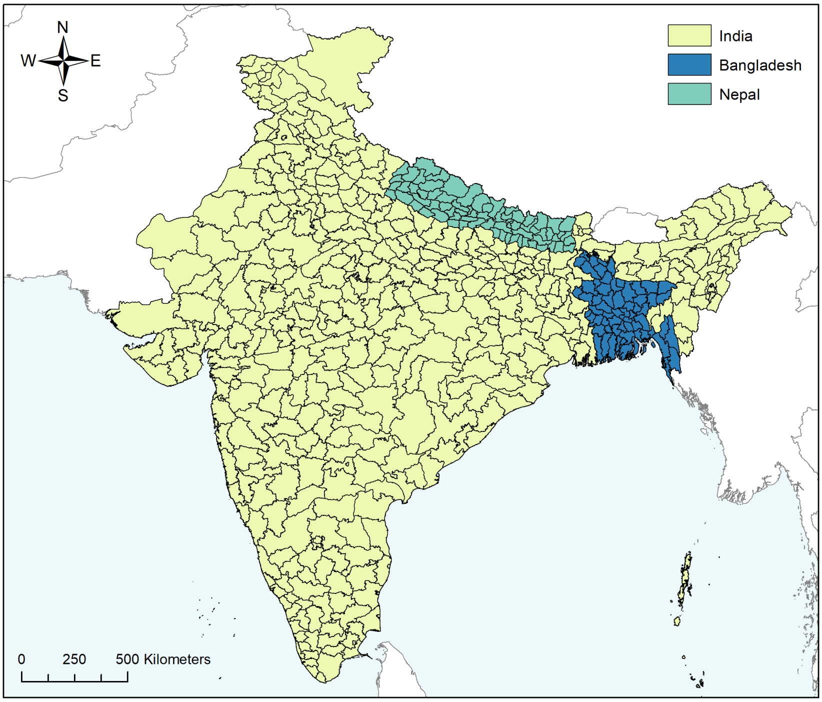

Figure 1. Map of Study Countries Including Administrative District Boundaries.

noting that the outcome variable is an imperfect proxy for the feminization of agriculture, as it measures a woman's employment in agriculture at a single time point rather than changing the participation of women in agriculture over time. Women are included in the sample regardless of if they are considered economically active or not. Our main predictor variables are temperature and precipitation *z*-scores for the year prior to the survey year. This enables us to examine the extent to which recent weather conditions are associated with the likelihood that a woman works in agriculture.

To account for additional factors that could influence a woman's employment in agriculture, we include a set of control variables at the individual, household, and district level: age, whether or not a woman has a young child under the age of five, religion (Hindu, Muslim, other), marital status (unmarried, married), educational attainment (less than primary completed, primary, or greater), household type (single person or single parent, nuclear family, multi-generational family, other), historical total annual precipitation, and historical mean maximum daily temperature.

We control for religion to account for differences in gendered expectations of women's mobility and participation in agriculture (Agarwal 1994). Marital status is included because male out-migration may lead to greater participation in agriculture among wives. Education is used as a proxy for socioeconomic status, as less educated women may have fewer economic opportunities compared to more educated women (Garikipati 2008; Srivastava and Srivastava 2010). Household type is used to determine whether those living in multi-generational households have different experiences related to the feminization of agriculture compared to those in one generation households, as previously demonstrated (Adhikari and Hobley 2015; Gartaula et al. 2010; Spangler and Christie 2020). We control for historical average temperature and precipitation to account for differences in climatic conditions and associated agricultural productivity across the nearly 600 districts in the three countries.

Analysis

To examine the linkages between climatic conditions and women's participation in agriculture, we estimate a set of binary logistic models predicting the likelihood that a woman reports working in agriculture based on recent temperature and precipitation conditions. We include quadratic specifications for temperature and precipitation including both linear and squared terms to account for potential non-linearities in the relationship between climatic conditions and participation in agriculture. To account for underlying differences in women's participation in agriculture between regions and across time, we include fixed effects for first-level administrative units (state in India, division in Bangladesh, and zone in Nepal) and decade (1980s, 1990s, 2000s, and 2010s). These fixed effects account for all time-invariant factors at the state/division/zone level and all time-varying factors at the national level as long as these effects are linear. We cluster standard errors at the district level to account for non-independence among women residing in the same district. Lastly, we include sampling weights so that our results are representative at the national level. Our analytic sample includes 8,341,850 women, and the weighted data are representative of 675,947,774 women.

To examine the extent to which the relationship between recent climatic conditions and women's participation in agriculture varies across sub-populations, we estimate two additional models in which temperature and precipitation are interacted with education and marital status. The first interaction model enables us to examine whether less-educated women are more likely to work in agriculture after adverse climatic conditions due to lower socioeconomic status and limited access to other economic opportunities. The second interaction model allows us to examine whether married women may be more affected by the feminization of agriculture due in part to their spouse's migration or engagement in alternate local employment opportunities, following the feminization of agrarian distress hypothesis.

Results

Descriptive statistics for the analytic sample are provided in Table 1. Approximately, 29 percent of women reported employment in agriculture. The average age is 32 years and approximately 29 percent of women have a young child under the age of five. The majority—about 75 percent—of women are Hindu, followed by 20 percent Muslim, and 5 percent other religions. Approximately 76 percent of women are married and most have a low level of formal education, with 70 percent not having completed full primary education and 30 percent with primary education or more. Women live in a variety of household arrangements: 43 percent live in a nuclear family, 45 percent live in a multi-generation household, 5 percent live alone in or in a single-parent household, and 7 percent live in other arrangements. There is a large variation in historical average precipitation and temperature conditions, demonstrating the variety of ecological zones on the Indian sub-continent. Mean precipitation is 1,310 mm per year, ranging from 175 to 4,005 mm, corresponding to climatic zones ranging from arid to monsoonal. The mean monthly maximum temperature is approximately 31°C and ranges from 3.7 to 34.5°C, representing climates ranging from hot deserts to the high-altitude Himalayas. Climate variability in the year prior to the survey/census round ranges greatly as well, with temperature *z*-scores ranging from −1.51 to 3.21 and precipitation *z*-scores ranging from −2.01 to 2.08.

Table 2 presents results from a binary logistic regression model of the relationship between recent temperature and precipitation variability and the likelihood that a woman works in agriculture. Consistent with our first prediction, there is a significant positive non-linear relationship between temperature *z*-score and the odds of working in agriculture. This suggests women who experienced hotter-than-normal temperatures during the year prior to the survey are more likely to report working in agriculture than those who experienced normal or cooler-than-normal temperatures. Contrary to our second prediction, however, we do not find a significant association between precipitation variability and the likelihood that a woman works in agriculture. Examining the control variables, we find the likelihood of working in agriculture increases with a woman's age and for married women. Women with young children are less likely to work in agriculture, as are women with primary

Table 1. Descriptive Statistics of Study Sample

	Mean	SD	Min	Max
Outcome variable				
Woman works in agriculture	0.29		0	1
Climate variables				
Temperature variation (*z*-score)	0.3	0.98	−1.52	3.21
Precipitation variation (*z*-score)	0.17	0.76	−2.01	2.08
Woman's characteristics				
Age	32.23	12.80	14	60
Has young child (under the age of 5)	0.29		0	1
Religion				
Hindu	0.75		0	1
Muslim	0.20		0	1
Other	0.05		0	1
Marital status			0	1
Not married	0.24		0	1
Married	0.76		0	1
Educational attainment				
Less than primary	0.70		0	1
Primary or more	0.30		0	1
Household type				
Single parent	0.05		0	1
One generation	0.43		0	1
Multi-generation	0.45		0	1
Other	0.07		0	1
Additional controls				
Historic mean annual precipitation (mm)	1,310.39	630.22	175.17	4,005.12
Historic mean annual temperature (°C)	31.18	2.90	3.72	34.53
Decade				
1980s	0.23		0	1
1990s	0.33		0	1
2000s	0.38		0	1
2010s	0.06		0	1
N	8,341,850			
Weighted *N*	675,974,774			

or greater education. Compared to women who live in nuclear family households, those living in single-parent households are more likely to work in agriculture, while those living in multi-generational households are less likely. Lastly, Muslim women are less likely to work in agriculture compared to Hindu women.

To examine whether the relationship between temperature and the likelihood of working in agriculture varies by a woman's education and marital status, we perform a set of interaction models. Table 3 presents results from both the climate-education interactions (Model 2) and climate-marital status interactions (Model 3). Results indicate that

Table 2. Binary Logistic Regression Model Predicting the Odds of Women Working in Agriculture Based on Recent Temperature and Precipitation Conditions

	Model 1	
	Odds Ratio	Std. Err.
Climate variables		
Temperature	1.32***	0.08
Temperature Squared	0.91***	0.02
Precipitation	0.96	0.04
Precipitation Squared	0.96	0.03
Woman's characteristics		
Age	1.01***	0.0007
Has young child	0.95**	0.02
Household type (reference: nuclear household)		
One-generation household	1.79***	0.06
Multi-generation household	0.09***	0.02
Other	1.35***	0.04
Married	1.55***	0.04
Religion (reference: Hindu)		
Other	1.18*	0.08
Muslim	0.41***	0.02
Educational attainment		
Primary or more	0.36***	0.01
Other controls		
Historic mean temperature	0.93***	0.01
Historic mean precipitation	1.0004*	0.0001
Decade (reference: 1980s)		
1990s	1.15*	0.08
2000s	1.26**	0.09
2010s	0.57**	0.10
Pseudo R^2	.17	
N	8,341,850	
Weighted N	675,974,774	

Note: Models also include fixed effects for first-level administrative units. Standard errors are clustered at the district level.

*$p < .05$; **$p < .01$; ***$p < .001$.

significant interactions exist between temperature and both education and marital status. Again, we find no significant relationship between precipitation and the likelihood of working in agriculture.

To examine the magnitude of the relationships between temperature and women's employment in agriculture, we calculate predicted probabilities of working in agriculture at a range of temperature *z*-scores, holding all other variables at their means. The top left panel of Figure 2 displays predicted probabilities for the full sample. We see that the

Table 3. Binary Logistic Regression Models Predicting the Odds of Women Working in Agriculture Based on Recent Temperature and Precipitation Conditions, Including Interactions Demonstrating Sub-population Differences

	Model 2	
	Odds Ratio	Std. Err.
Climate-education interactions		
Temperature	1.36***	0.08
Temperature × primary or more	1.15*	0.06
Temperature squared	0.91***	0.02
Temperature squared × primary or more	0.92***	0.02
Precipitation	0.997	0.04
Precipitation × primary or more	1.02	0.04
Precipitation squared	0.95	0.03
Precipitation squared × primary or more	1.05	0.03
	Model 3	
Climate-marital status interactions		
Temperature	1.16*	0.07
Temperature × married	1.36***	0.08
Temperature squared	0.95*	0.02
Temperature squared × married	0.9***	0.02
Precipitation	1.06	0.04
Precipitation × married	0.98	0.04
Precipitation squared	0.94	0.03
Precipitation squared × married	0.96	0.03

Note: Models also include control variables and fixed effects for first-level administrative units. Standard errors are clustered at the district level.

*$p < .05$; ***$p < .001$.

probability of working in agriculture is lowest following cooler-than-normal years and rises with increasingly hot recent weather. For example, at a *z*-score of –1, a woman has a 17 percent predicted probability of working in agriculture, while at a *z*-score of 2 the probability increases to 26 percent.

The top right panel of Figure 2 displays predicted probabilities from the temperature-education interaction model. First, we see that women with less than primary education have a significantly higher probability of working in agriculture at all temperature levels. In addition, we find a strong positive relationship between temperature *z*-score and the probability of working in agriculture, but only among less-educated women. For those with less than primary education, a *z*-score of 2 is associated with a 12-percentage-point higher probability of working in agriculture than a *z*-score of –1 (33 percent compared to 21 percent).

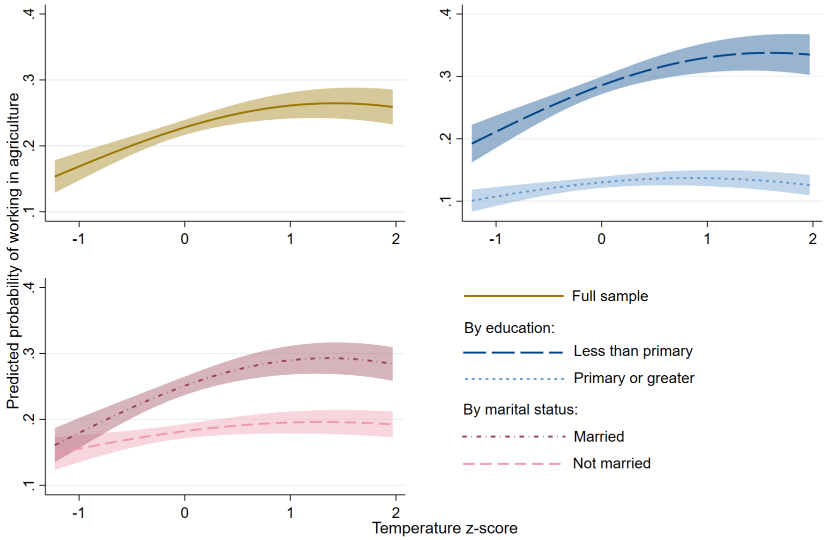

Figure 2. Predicted Probabilities of Working in Agriculture Based on Temperature *z*-scores, Including 95 Percent Confidence Intervals.

The bottom left panel of Figure 2 shows predicted probabilities from the temperature-marital status interaction model. Among individuals who experienced a cooler-than-normal year prior to the survey (*z*-score of −1), the predicted probability of working in agriculture is not significantly different between married and unmarried women (18 percent vs. 15 percent, respectively). However, there is a strong positive relationship between temperature and the probability of working in agriculture for married women, and only a weak (and marginally significant) positive relationship among unmarried women. For married women, the predicted probability increases by 10 percentage points to 28 percent at a *z*-score of 2, while for unmarried women it increases by just four percentage points to 19 percent. Taken together, these results suggest temperature variability is a key driver of women's participation in agricultural work in rural South Asia, and that married women and those with less formal education are particularly sensitive to the livelihood and time use impacts of heat.

Lastly, as a supplementary analysis, we estimate models separately for each country that predict a women's likelihood of working in agriculture based on recent climatic conditions. Appendix Table A1 presents descriptive statistics for each country, and Tables A2–A4 present model results for Nepal, India, and Bangladesh, respectively. Consistent with our main results, we find that hotter-than-normal temperatures are positively linked to women's agricultural work in India and Bangladesh. However, we do not find a significant relationship between temperature and agricultural work in Nepal. Nepal is substantially cooler than the other two countries, with average maximum daily temperatures of 23.5°C (74°F) compared to 30.0°C (86°F) in Bangladesh and 31.5°C (89°F) in India. While warmer-than-usual temperatures are likely associated with heat-related declines in crop yields and agricultural income in India and Bangladesh, this may not be the case in Nepal given its relatively cooler climate.

Discussion and Conclusions

In this paper, we explored the relationship between climate change and the feminization of agriculture in South Asia by examining linkages between recent temperature and precipitation conditions in India, Nepal, and Bangladesh and a woman's likelihood of working in agriculture. We then tested whether these relationships varied by marital status and educational attainment. We predicted that adverse climatic conditions in the year prior to the survey (higher temperatures and drier- or wetter-than-normal precipitation) would be associated with a greater probability of a woman working in agriculture. In addition, based on the hypothesis that men's livelihood diversification drives the feminization of agriculture, we predicted these associations would be stronger for married women, as wives take over agricultural responsibilities when their husbands pursue other income sources. Further, we expected stronger associations among women with less education due to a lack of alternate livelihood opportunities.

We found support for the hypothesis that hotter-than-normal temperatures are positively associated with the likelihood that a woman works in agriculture, particularly in India and Bangladesh. The predicted probability of working in agriculture is nine percentage points higher following a warmer-than-average year (*z*-score of 2) than a cooler-than-average year (*z*-score of −1). There is a large body of research linking heat to crop failure and challenges to agricultural livelihoods and profits (e.g., Bohra-Mishra, Oppenheimer, and Hsiang 2014; Call et al. 2017; Jessoe, Manning, and Taylor 2018). Increases in temperature and heatwaves have been associated with increased migration, particularly for men and in agricultural settings (Carrico and Donato 2019; Falco, Galeotti, and Olper 2019; Feng, Krueger, and Oppenheimer 2010; Mueller, Gray, and Kosec 2014; Nawrotzki et al. 2015). Recent hot weather may thus negatively impact crop production and income in rural South Asia, leading men to diversify income sources, thereby pushing women into agricultural roles.

However, we did not find support for the hypothesis that precipitation variability is positively associated with women's work in agriculture. Indeed, Precipitation variability generally has weaker associations with migration than temperature (Bohra-Mishra et al. 2014; Call et al. 2017; Gray and Wise 2016; Mueller et al. 2014; Nawrotzki et al. 2015). There are two potential explanations for why precipitation does not have as strong of a relationship with the feminization of agriculture. The first is, as hypothesized to be the case in Pakistan, extreme precipitation events such as floods receive more relief aid than extreme temperature events (Mueller et al. 2014). Aid serves to buffer flood-related income losses, potentially enabling households—particularly adult male household members—to maintain agricultural livelihoods (Mueller et al. 2014). A second potential explanation, provided by Chen and Mueller (2018) with regards to flooding in Bangladesh, is that farmers have already developed adaptation strategies to rainfall extremes due to the long-standing seasonal precipitation variation inherent in a monsoonal climate. This adaptability potential may be key in explaining why we find that temperature variability is significant while precipitation variability is not. Research has demonstrated heat stress has less potential for adaptation as extreme heat causes "grave damage to crops" (205), leading to plant death at certain temperatures (Taraz 2018).

We find additional support for our third hypothesis, as the effects of temperature are more pronounced among married women and less educated women. The stronger relationship between heat and working in agriculture for less-educated women aligns with Pattnaik et al.'s (2018) theory of the feminization of agrarian distress. Their findings show that poverty is positively associated with an increase in women's participation in agriculture. This connects to education in that the gendered education gap in South Asia is a major barrier to better employment opportunities for poor women (Garikipati 2008; Srivastava and Srivastava 2010). Thus, our findings conform with the idea that the women most likely to enter into agricultural work are those with few other economic opportunities. This is particularly concerning, as Kelkar (2009) argues women experiencing feminization of agriculture "sacrifice their opportunity for education and skill development to manage land and agriculture" (1). This sacrifice, often regardless of personal preference (Pattnaik and Lahiri-dutt 2021), indicates a self-replicating cycle wherein some women become further entrenched in agriculture even as it becomes more precarious.

The finding that high temperatures are more strongly linked with agricultural work among married women suggests there is likely a relationship between climate change, men's livelihood diversification, and women's subsequent increased participation in agriculture. The feminization of agriculture has long been understood as a consequence of men's out-migration due to rural poverty and agricultural precarity (Deere 2005; Jiggins 1998). As Zuo (2004) notes in her study of the feminization of agriculture in China, "among male-outmigrant couples the gendered division of labor—'men work and women plough'—serves as a collective strategy to cope with poverty." (1). In other words, the gendered division of agricultural labor under agrarian distress becomes a division of labor on and off the farm for women and men respectively as livelihood diversification becomes necessary for farm survival. As climate change exacerbates challenges for smallholders, it is likely that more married women will find themselves at the 'plow' while their husbands find other work. Thus, while the literature has already demonstrated linkages between climate change and men's migration in South Asia (Bhatta et al. 2015; Call et al. 2017; Carrico and Donato 2019; Mueller et al. 2014), our findings suggest an additional, yet understudied, effect of this migration—the feminization of agrarian distress.

Our study is subject to several limitations. The primary limitation is the cross-sectional nature of our data, which measures a woman's reported employment in agriculture at one time point. Given that the feminization of agriculture is a process occurring over time, longitudinal data would be better suited to examine the extent to which climatic conditions are linked to a woman's movement into and out of agriculture. Regardless, this study offers valuable insight into potential linkages between climate change and the feminization of agriculture. Second, the data likely underestimate women's employment in agriculture due to underreporting. Data on women's participation in agriculture are notorious for underreporting due to both data collectors' biases that obscure women's work in agriculture, and to women's own internalizations of patriarchal notions of work, leading them to discount their own agricultural labor as formal work (Doss 2014; FAO 2011; Pattnaik and Lahiri-dutt 2021). Thus, the 29 percent of women in the sample who reported working in agriculture is likely an underestimate, as many women engaged in agriculture may be classified as not in the labor force. Lastly, our quantitative analysis does not enable us to identify the complicated and nuanced mechanisms underlying the links between climatic conditions and the feminization of agriculture, which are better suited to qualitative methods. Regardless, our findings indicate that a woman is more likely to report working in agriculture following a hotter-than-normal year, and these estimates are likely conservative given the known underreporting of women's employment in agriculture.

The findings from this study provide a variety of policy-relevant insights. The linkages between climate change and the feminization of agriculture point to a need for climate change adaptation strategies to be gender-sensitive. This is particularly relevant as research has demonstrated that under the conditions of the feminization of agriculture, women receive less extension services than their husbands had due to gender discrimination in perceptions of who a farmer is (Paris et al. 2009). Similarly, in Nepal, a lack of gender-appropriate technology was found to cause farms experiencing male out-migration to be less productive than they would be if farmed by both spouses (Tamang et al. 2014). Thus, trainings and technologies explicitly serving women are needed.

Further, the findings suggest women have different needs based on intersecting elements of their identity. Less-educated women face more constraints in engaging in livelihood opportunities outside of agriculture, and in accessing education that increases their employability. Married women should also be specifically targeted for such policies and programs. Additional policies that would best aid women should address the root causes of agrarian distress and climate change by mitigating CO_2 emissions and strengthening smallholder food systems.

There is ample opportunity for future research that builds on this study to further explore linkages between climate change and the feminization of agriculture. Focusing on extreme weather events including heatwaves, droughts, and floods may reveal additional relationships. Further, while the feminization of agrarian distress hypothesis has thus far only been applied to South Asia, there is strong evidence it may be a relevant subject of interest for other areas, for instance in Mexico where climate change and agrarian distress have already been associated with increased male migration (Feng et al. 2010; Lyon, Bezaury, et al. 2010; Nawrotzki et al. 2015). Future research is also needed to explore mechanisms underlying the linkages between climate change and the feminization of agriculture, including gendered migration as a mediating factor. A better understanding of the complex relationship between climatic conditions, agrarian distress, and the feminization of agriculture is critical for reducing poverty and fostering gender equality amidst climate change.

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APPENDIX A

Table A1. Descriptive Statistics by Country

	Nepal				India				Bangladesh			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Outcome variable												
Woman works in agriculture	0.50		0	1	0.32		0	1	0.03		0	1
Climate variables												
Temperature variation (*z*-score)	0.86	1.27	−0.97	2.11	0.30	0.90	−1.52	3.21	0.17	1.39	−1.44	2.16
Precipitation variation (*z*-score)	0.44	0.95	−2.01	1.38	0.16	0.78	−1.78	2.08	0.19	0.57	−1.02	1.40
Woman's characteristics												
Age	31.41	13.01	14	60	32.39	12.85	14	60	31.23	12.38	14	60
Has young child (under the age of 5)	0.27		0	1	0.29		0	1	0.33		0	1
Religion												
Hindu	0.81		0	1	0.84		0	1	0.10		0	1
Muslim	0.04		0	1	0.10		0	1	0.89		0	1
Other	0.15		0	1	0.05		0	1	0.01		0	1
Marital status			0	1			0	1			0	1
Not married	0.24		0	1	0.24		0	1	0.22		0	1
Married	0.76		0	1	0.76		0	1	0.78		0	1
Educational attainment												
Less than primary	0.68		0	1	0.71		0	1	0.64		0	1
Primary or more	0.32		0	1	0.29		0	1	0.36		0	1
Household type												
Single parent	0.07		0	1	0.05		0	1	0.07		0	1
One generation	0.34		0	1	0.43		0	1	0.46		0	1
Multi-generation	0.47		0	1	0.49		0	1	0.17		0	1
Other	0.12		0	1	0.03		0	1	0.31		0	1

Table A1. *Continued*

	Nepal				India				Bangladesh			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Other controls												
Historic mean annual precipitation (mm)	1,660.94	378.7	704.51	2,390.61	1,143.92	477.27	175.17	4,005.12	2,402.42	444.63	1,504	3,838.09
Historic mean annual temperature (°C)	23.52	6.26	4.54	29.92	31.52	2.7	3.72	34.53	30.02	0.88	27.24	32.38
Decade												
1980s	0		0	1	0.27		0	1	0		0	1
1990s	0		0	1	0.35		0	1	0.26		0	1
2000s	0.5		0	1	0.38		0	1	0.33		0	1
2010s	0.5		0	1	0		0	1	0.41		0	1
N	1,282,500				362,341				6,697,009			
Weighted *N*	12,505,470				579,167,614				84,274,690			

Table A2. Binary Logistic Regression Models Predicting the Odds of Women Working in Agriculture Based on Recent Temperature and Precipitation Conditions in Nepal

	Model 4	
	Odds Ratio	Std. Err.
Climate variables		
Temperature	0.94	0.27
Temperature Squared	0.54	0.19
Precipitation	0.92	0.12
Precipitation Squared	1.08	0.07
Woman's characteristics		
Age	1.01***	.001
Has young child	1.16***	0.02
Household type (reference: nuclear household)		
One-generation household	0.61***	0.01
Multi-generation household	0.69***	0.03
Other	0.62***	0.02
Married	2.75***	0.13
Religion (reference: Hindu)		
Other	1.52***	0.09
Muslim	0.54***	0.06
Educational attainment		
Primary or more	0.40***	0.02
Other controls		
Historic mean temperature	0.88***	0.01
Historic mean precipitation	1.002***	0.0003
Decade (reference: 2000s)		
2010s	8.71	15.27
Pseudo R^2	.15	
N	1,282,500	
Weighted *N*	12,505,470	

Note: Models also include fixed effects for first-level administrative units. Standard errors are clustered at the district level.

***$p < .001$.

Table A3. Binary Logistic Regression Models Predicting the Odds of Women Working in Agriculture Based on Recent Temperature and Precipitation Conditions in India

	Model 4	
	Odds Ratio	Std. Err.
Climate variables		
Temperature	1.33***	0.08
Temperature Squared	0.90***	0.02
Precipitation	1.002	0.04
Precipitation Squared	0.96	0.03
Woman's characteristics		
Age	1.008***	0.001
Has young child	0.95**	0.02
Household type (reference: nuclear household)		
One-generation household	0.56***	0.02
Multi-generation household	0.50***	0.02
Other	0.74***	0.04
Married	1.55***	0.04
Religion (reference: Hindu)		
Other	1.13	0.09
Muslim	0.40***	0.02
Educational attainment		
Primary or more	0.35***	0.01
Other controls		
Historic mean temperature	0.93***	0.02
Historic mean precipitation	0.99975*	0.0001
Decade (reference: 1980s)		
1990s	1.16*	0.09
2000s	1.23**	0.09
Pseudo R^2	.13	
N	362,341	
Weighted N	579,167,614	

Note: Models also include fixed effects for first-level administrative units. Standard errors are clustered at the district level.

*$p < .05$; **$p < .01$; ***$p < .001$.

Table A4. Binary Logistic Regression Models Predicting the Odds of Women Working in Agriculture Based on Recent Temperature and Precipitation Conditions in Bangladesh

	Model 4	
	Odds Ratio	Std. Err.
Climate variables		
Temperature	1.75*	0.40
Temperature Squared	1.03	0.12
Precipitation	0.96	0.11
Precipitation Squared	1.05	0.12
Woman's characteristics		
Age	1.01***	0.0007
Has young child	0.94***	0.01
Household type (reference: nuclear household)		
One-generation household	0.53***	0.03
Multi-generation household	0.55***	0.03
Other	0.81***	0.05
Married	0.91***	0.02
Religion (reference: Hindu)		
Other	4.48***	0.74
Muslim	0.79**	0.06
Educational attainment		
Primary or more	0.75***	0.02
Other controls		
Historic mean temperature	1.17**	0.05
Historic mean precipitation	1.0004**	0.0001
Decade (reference: 1990s)		
2000s	4.6***	0.43
2010s	0.26	0.23
Pseudo R^2	.07	
N	6,697,009	
Weighted N	84,274,690	

Note: Models also include fixed effects for first-level administrative units. Standard errors are clustered at the district level.

*$p < .05$; **$p < .01$; ***$p < .001$.