Women Leaders Improve Environmental Outcomes: Evidence from Crop Fires in India

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Abstract

This paper provides causal evidence that women leaders improve environmental outcomes. Using a close-election regression discontinuity design, we find that the election of a female politician over a male politician decreases crop fire incidence and biomass-related particulate emissions in India. These effects are concentrated during the harvest and post-harvest months in districts that follow fire-suited cropping patterns. To understand mechanisms, we survey 424 male and female village council leaders between December 22-March 23 in Punjab, the Indian state with the highest per capita incidence of crop fires. We find women leaders are more likely to consider crop fires a serious issue, weigh their impacts on child health, support regulation to decrease crop fire incidence, and implement specific crop residue management policies like private residue collection or encouraging crop residue use as fodder.

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1 Introduction

Given the enormous scale of environmental decline and political gridlock in legislatures around the world, committed action by local leaders may be one of the most effective tools to address environmental health problems like air pollution. However, despite prior evidence that the identity of a decision maker has an influence on policy decisions (Besley and Coate, 1997; Chattopadhyay and Duflo, 2004; Levitt, 1996; Osborne and Slivinski, 1996; Pande, 2003), survey evidence that women have a greater concern for the environment (McCright, 2010; McCright and Dunlap, 2011), and the existence of quotas for women in legislative assemblies in many countries (Pande and Ford, 2012), we know little about the causal impact of women leaders on environmental outcomes.[1]

In this paper, we use satellite-measured crop fire data from India and a close-election regression discontinuity design to provide the first causal evidence that women leaders improve environmental outcomes. We show that the election of a female legislator over a male legislator in a close election decreases the number of fires by 13% and monthly maximum biomass-related particulate emissions by 40%. These effects are concentrated during the harvest and post-harvest months in districts that follow fire-suited cropping patterns. To understand mechanisms, we surveyed 424 male and female village council leaders between December 22-March 23 in Punjab, the state with the highest per capita incidence of crop fires in India. We find female leaders are more likely to consider crop fires a serious issue, weigh their impacts on child health, support regulation to decrease crop fire incidence, and implement specific crop residue management policies like private residue collection or encouraging crop residue use as fodder.

Air pollution remains one of the leading causes of mortality, accounting for 9 million premature deaths annually or roughly 16% of all deaths worldwide and a staggering 268 million disability-adjusted life-years (Landrigan et al., 2018). Nowhere is the problem more pronounced than in India, which is home to 14 of the 20 most polluted cities in the world. In fact, if the city of New Delhi, the capital of India, were to meet World Health Organization

[1]There exists cross-country evidence that female representation in parliament leads to more stringent climate change policies (Mavisakalyan and Tarverdi, 2019) However, survey evidence on gender differences in environmental concerns amongst elected female officials within (developed) countries is inconclusive (see Sundstrom and McCright (2014), for a review); women leaders in a male-dominated environment may be similar to men (Adams and Funk, 2012).

air quality standards, average life expectancy would increase by 10 years (Greenstone and Fan, 2019), roughly equivalent to the gains in life expectancy made by the country on average in the 21st century (Max Roser and Ritchie, 2013). Of course, a number of factors – both moderate but perpetual and seasonal but acute – contribute to the poor air quality in India. Crop fires are a seasonal but acute factor that can raise local PM2.5 concentrations to more than 1,000% above the WHO 24-hour guideline of 25 ug/m^3 (Bikkina et al., 2019; Liu et al., 2018),[2] and contribute to as much as half of the particulate pollution during the winter months (Bikkina et al., 2019; Cusworth et al., 2018; Shyamsundar et al., 2019).[3]

The use of crop fires by farmers in India is widespread (Figure A.1). Farmers use crop fires for three reasons: (i) clearing harvest residue off fields in preparation for planting in the next season, (ii) making sugarcane harvesting less labor-intensive, and (iii) clearing the undergrowth in fields left fallow between cropping seasons. The use of fire is particularly prevalent in a coupled rice-wheat cropping arrangement, a widespread agriculture system across India. In this system, farmers grow rice during the monsoon season (Kharif) from June to November and wheat during the winter season (Rabi) from January to May. Farmers must undertake a large-scale removal of crop residue between rice harvest (in Oct-Nov) and wheat planting (in Dec-Jan), and between wheat harvest (in Apr-May) and rice planting (in Jun-Jul), and setting fire to crop residue is particularly helpful in this process. Fire also plays a role in the sugarcane production process, an important crop across the country. Farmers light sugarcane fields to remove the outer leaves around the cane stalk before harvesting the cane (in Dec-Mar) to make the process easier and require less manual labor. Finally, the use of fire is widespread alongside forest lands in central and north-east India that follow shifting cultivation, where fields are left fallow for more than a year, and farmers switch between alternate plots of land. Undergrowth often overtakes fallow fields, which needs to be cleared before the subsequent season's planting.

Of course, alternative mechanisms like labor and mechanized equipment are available to farmers. However, farmers prefer fire because it is cheaper and quicker than alternatives,

[2]Exposure to pollution from crop fires decreases birth weight, gestational length, and in-utero survival (Rangel and Vogl, 2019), increases infant mortality (Pullabhotla et al., 2022), decreases child height for age and weight for age scores (Singh et al., 2019), decreases cognitive performance (Graff Zivin et al., 2020), and increases risk of acute respiratory infections (Chakrabarti et al., 2019).

[3]In India, weather conditions in the winter months are more conducive to trapping pollutants from crop fires, exacerbating air quality issues compared to the rest of the year (Singh et al., 2023).

despite the associated human health costs (Behrer, 2023; Garg, Jagnani and Pullabhotla, 2023; Hernández-Cortés, 2023). Indeed, in our survey of 424 village council leaders in Punjab, India – a majority of whom earn their livelihood via agriculture – more than 50% of respondents said that the use of both labor and machines was more expensive, even though they recognized that crop fires negatively affect human health outcomes (Figure A.2).

To examine the causal effect of women leaders on crop fire incidence, we compare the number of fires – as captured via satellites – between state legislative constituencies where women narrowly won over men and where women narrowly lost to men in state assembly elections across India from 1998 to 2022.

India is a federal nation with its constitution granting significant self-governing authority to its 28 states and 7 union territories. The state legislative assemblies, which are vested with the exclusive power to decide on public health and agricultural policies, undergo elections every 5 years. The members of these assemblies, known as Members of Legislative Assembly (MLAs), are elected through the first-past-the-post system from single-member constituencies. These MLAs play a pivotal role in shaping policy, influencing the allocation of federal funds to local administration for effective policy implementation, and overseeing the progress and enforcement of these policies. However, a glaring disparity exists in women's representation in federal and state politics in India. Recent statistics show women's representation hovering around a meager 10 percent (Beaman, Pande and Cirone, 2012). This is significant also because female MLAs have distinct policy priorities compared to their male counterparts, with a marked preference towards increased investments in child health and education (Bhalotra and Clots-Figueras, 2014; Clots-Figueras, 2012).

We find the election of a female MLA over a male MLA in a close election decreases the number of fires by 13% and monthly maximum biomass-related particulate emissions by 40%. The assumption underlying our research design is that no other differences exist between constituencies where women narrowly won over men and where women narrowly lost to men. In fact, we find that the characteristics of elections with a narrow female winner are similar to those of elections with a narrow female loser (e.g., candidate's party affiliation, education, number of votes). Similarly, assemblies with a narrow female winner share similar characteristics to those with a narrow female loser (e.g., electricity access,

number of schools). In a falsification test, we show there are no differences in fire activity or particulate emissions prior to the close election victory of a woman over a man. We also show that these effects are only observed for newly elected women, with null effects for re-elected incumbent women leaders. Lastly, we show the decrease in fire incidence and particulate emissions is concentrated during the harvest and post-harvest months in districts that follow fire-suited cropping patterns, with comparatively modest effects during the rest of the year in districts that follow fire-suited cropping patterns or during the harvest and post-harvest months in districts that do not follow fire-suited cropping arrangements.

To investigate mechanisms, we conducted telephonic surveys with 230 female and 194 male village council leaders (VCLs) between December 22-March 23 in Punjab, India. Although VCLs are not equivalent to MLAs,[4] they share analogous roles and responsibilities at a more grassroots level. These local leaders are responsible for implementing state policies and discerning the needs of the villages they represent. While their primary financial backing comes from the state, they are granted, in theory, total autonomy in the disbursement of these funds. It should be noted that Punjab ensures a 50% reservation for women in VCL elections: Prior evidence has shown that reservation for women in VCL elections causes an increase in investments directed toward public goods that benefit women and children (Beaman et al., 2007; Chattopadhyay and Duflo, 2004).

We find women leaders are 20% more likely to consider crop fires a very serious problem, plausibly because they are more concerned about the health costs of crop fires for children: women leaders are 50% more likely to be worried about the child health impacts than male leaders. Furthermore, women leaders are more likely to strongly favor regulation to decrease crop fire incidence. They are aware of a larger number of policies implemented by the government to tackle this issue (e.g., penalties). Finally, women leaders are more likely to implement crop residue management policies, such as private residue collection, or encourage the use of crop residue as feed. This is significant as private residue collection has been shown to decrease the incidence of crop fires in other developing countries in Asia (Nian, 2023). These results are robust to controlling for differences in demographic characteristics between

[4]We chose to focus on village council leaders (VCLs) instead of MLAs for two main reasons. First, we wanted to see if male and female leaders at this tier of government have different perspectives on stubble burning. Second, from a logistical standpoint, we opted for telephone surveys and anticipated a significantly higher response rate from VCLs compared to their constituency-level counterparts.

male and female VCLs (e.g., education, age, occupation).

This paper contributes to the growing economics literature that examines the influence of women leaders on socioeconomic outcomes.[5] We provide the first causal evidence that women leaders improve environmental outcomes. Our study shows that female leaders decrease the incidence of crop fires, likely due to the health risks to children from particulate emissions. This complements previous research that women elected as leaders invest more in public goods more closely linked to women's concerns (Beaman et al., 2007; Chattopadhyay and Duflo, 2004), including greater investments in child health and education (Beaman et al., 2007; Bhalotra and Clots-Figueras, 2014; Clots-Figueras, 2012). It also aligns with a broader literature in economics that shows that women are more likely to support policies that encourage spending on child-related expenses (Edlund and Pande, 2002; Edlund, Haider and Pande, 2005; John R. Lott and Kenny, 1999), and that household income or assets in the hands of women raise spending on expenditures that benefit children (Duflo, 2003; Lundberg, Pollak and Wales, 1997; Thomas, 1990, 1997).

Our findings also contribute to a rich ethnographic literature on the historical role of women in designing policies that promote environmental justice. Women have been at the forefront of environmental awareness and advocacy worldwide for several decades (Merchant, 1981). Environmental activism in India traces its feminist roots to 1973 when Indian women coined the term "Chipko movement" (tree huggers). This women-led movement is unique among international feminist movements in its inextricable link to the environment. It gained traction in the 1980s, beginning with the anti-nuclear protests in Tamil Nadu, and more momentum after the 1984 Bhopal Gas Disaster, where over 40 tons of toxic gas leaked from a pesticide plant. The Bhopal Gas Disaster caused the deaths of tens of thousands of individuals and had severe negative health impacts, injuries, and disabilities for over half a million people in the following years (Gupta et al., 1988; Misra and Kalita, 1997). A particularly tragic consequence was the long-term effect on women's health, including their inability to have children or to give birth to children with birth defects (Eckerman, 2005). However, given the particular salience to women, disproportionately affecting children and

[5]Studies have focused on provision of public goods that are more closely linked to women's concerns (Beaman et al., 2007; Chattopadhyay and Duflo, 2004), child health and education (Beaman et al., 2007; Bhalotra and Clots-Figueras, 2014; Clots-Figueras, 2012), maternal mortality (Bhalotra et al., 2023), crime against women (Iyer et al., 2012), economic activity (Baskaran et al., 2023), and voter attitudes toward women politicians (Beaman et al., 2009; Bhalotra, Clots-Figueras and Iyer, 2017).

women as the tragedy did (Sarangi, 1996), it gave rise to a powerful enviro-feminist movement (Mukherjee, 2010). The institutions and movements started by these tragedies live on, and environmental issues remain important to women voters in the country.

Finally, our paper contributes to a new literature in economics on how political motives shape the design and enforcement of environmental policies (Balboni, Burgess and Olken, 2023; Balboni et al., 2021; Burgess et al., 2011; Duflo et al., 2013; Greenstone and Jack, 2015; Lipscomb and Mobarak, 2017). Unlike previous studies, we explore the impact of leader identity on this dynamic.[6] This is particularly relevant in developing countries like India, where strong environmental laws coexist with weak regulatory institutions and inconsistent enforcement (Duflo et al., 2013, 2018; Greenstone and Hanna, 2014; Jack et al., 2023; Piette, 2018). For instance, Gulzar and Dipoppa (2023) show that the influence of strong farmer lobbies and cross-border externalities from crop fires hinder local enforcement efforts in South Asia. In such a context, our findings indicate that female leaders are more inclined to view crop fires as a serious issue, strongly support regulation, and implement proven crop residue management strategies, such as private residue collection, to reduce crop fire occurrence.

2 Data

2.1 Elections

Our research utilizes the Trivedi Center for Political Data's Indian Elections Dataset for analyzing legislative assembly elections in India from 1998 to 2022 (Agarwal et al., 2021*a*,*b*).[7] Importantly, the data encompasses candidate details such as party affiliation, vote counts, incumbency status, gender, and educational backgrounds.

India, as of 2023, has 4,126 legislative assembly constituencies. In each, a Member of Legislative Assembly (MLA) is elected every five years to contribute to state lawmaking and

[6]The only related prior work is a recent paper in political science that studies a 1996 law in India that extended local government councils to 'Scheduled Areas,' a territorial designation linked to the customary rights of the Scheduled Tribes, with mandated representation for Scheduled Tribes (Gulzar, Lal and Pasquale, 2023). Using variation in the time of law implementation in a difference-in-differences framework, the article finds that the arrival of local government councils to Scheduled Areas and mandated representation for Scheduled Tribes led to a substantial increase in tree cover and a reduction in deforestation.

[7]This dataset, available at https://lokdhaba.ashoka.edu.in/browse-data?et=GE, aggregates comprehensive data sourced from the Election Commission of India.

budget decisions. The political party securing the majority in these constituencies forms the state government. The first-past-the-post electoral system used makes determining election winners of each constituency and their victory margins clear. Our analysis restricts the sample to assembly elections where the top two candidates were female and male. Figure A.3 illustrates India's assembly constituencies, with those witnessing victories or defeats of female MLAs against male counterparts from 1998 to 2022.

2.2 Crop fires

We merge data on assembly elections with satellite-detected fire activity data from two different sources: (i) NASA's Earth Observing System Data and Information System (EOSDIS) prior to 2017, and (ii) the Visible Infrared Imaging Radiometer Suite (VIIRS) from 2016 onwards. NASA's fire product relies on information from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument carried by two satellites – Terra and Aqua. The MODIS instrument on Terra became operational on November 2000, while the data from Aqua started in July 2002. These data are only available till 2016. The VIIRS fires data are collected by sensors aboard the Suomi National Polar-Orbiting Partnership (Suomi NPP) and NOAA-20 satellites launched in 2011.

Both data are based on infrared radiation detections that are a signature of biomass fires (Giglio, Csiszar and Justice, 2006). MODIS identifies a pixel (approximately 1000 square meter area) with fire activity if at least one thermal anomaly is detected within that pixel.[8] VIIRS provides even better spatial resolution, around 375 square meter area. Unlike other remotely sensed products (for example, forest cover), fires data are considerably more precise since temperatures of fires are orders of magnitude higher than those of other non-fire pixels. Both MODIS and VIIRS have a similar overpass frequency, providing at least two observations per day over each location globally, ensuring daily coverage of fires.[9] These data on thermal anomalies have been used extensively by atmospheric scientists to study the effects of agricultural fires on pollution in India and elsewhere (Liu et al., 2018).

[8]For comparison, at baseline, the average farm size in India was more than 10 times larger at 1.330 hectares (Ministry of Agriculture, 2012), suggesting that MODIS likely captures most agricultural fires.

[9]Some fires may be missed in cases there is heavy cloud cover obscuring the view. However, it is unlikely that the presence of such meteorological phenomena is correlated with narrow election wins or losses for women.

Together, MODIS and VIIRS provides us with a daily, geocoded record of fire pixels from 2002 - 2022. We calculate monthly counts of fires as well as monthly total, mean, maximum, and minimum fire brightness within each assembly-level polygon.[10]

2.3 Air pollution

To examine seasonal impacts on air pollution, we use monthly data on black carbon, organic carbon, and sulphur dioxide emissions (precursors to particulate pollution) at the assembly level from the Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) (Gelaro et al., 2017). MERRA-2 is the latest version of global atmospheric reanalysis for the satellite era produced by NASA Global Modeling and Assimilation Office (GMAO) using the Goddard Earth Observing System Model (GEOS) version 5.12.4. The dataset covers the period 1980-present with a latency of 3 weeks after the end of a month and is a time-averaged 2-dimensional monthly mean data collection effort. The MERRA-2 model apportions emissions into those specifically arising from biomass burning (which are driven by agricultural fires). The MERRA-2 data are gridded ($0.50^\circ \times 0.625^\circ$) monthly estimates of emissions based on satellite and climate reanalysis measurements. We interpolate both biomass emissions gridded values to each assembly polygon in our sample.

In contrast to the fires data, our measures of air pollution suffer from two different sources of measurement error. First, air pollution data are obtained from calibrated chemical transport models that translate satellite imagery into ground-level exposure of air pollution. Second, air pollution, unlike agricultural fires, can travel long distances and spill over into nearby assemblies. Despite these measurement errors in the air pollution data, we are able to estimate precise effects of women leaders on air pollution that correspond to estimates of the effects on crop fires.

[10]The brightness temperature is a measure of the intensity of infrared radiation captured by the MODIS and VIIRS instrument. The higher the temperature, the more intense is the thermal radiation from a fire.

3 Empirical Strategy: Close-Election Regression Discontinuity Design

In India, elections for the state legislative assembly occur every 5 years. Each state is broken down into specific areas known as constituencies. Eligible voters within these constituencies vote for a representative, who is then titled the Member of Legislative Assembly (MLA). To examine the causal effect of women leaders we compare crop fire incidence and particulate pollution between state legislative constituencies where women narrowly won over men and where women narrowly lost to men in state assembly elections across India from 1998 to 2022 (Figure A.4).[11] We estimate the following regression discontinuity specification:

$$Y_{cset} = \beta_0 + \beta_1 WomanWinner_{cse} + \beta_2 WinningMargin_{cse} + \beta_3 WomanWinner_{cse} \times WinningMargin_{cse} + \eta_{s,e} + \eta_t + \varepsilon_{cset} \quad (1)$$

$WomanWinner_{cse}$ takes the value 1 if the winner of a legislative constituency c in state s in election term e is a woman politician, 0 otherwise. $WinningMargin_{cse}$ is the victory margin for a woman against a man in legislative constituency c in state s in election term e. Figure A.5 shows the density of the winning margin is continuous across the treatment threshold (0); the McCrary test statistic is -0.004 (s.e. 0.1) (McCrary, 2008). Y_{cset} is the outcome of interest (monthly crop fires, black carbon, organic carbon, and sulphur dioxide) for legislative constituency c in state s in election term e in year t. η_t are year fixed effects. $\eta_{s,e}$ are state-by-election fixed effects. Thus, the RD estimates compare outcomes in year t for legislative constituencies c within the same state s during the same five-year election term e but on opposite sides of the treatment threshold. We estimate equation (1) using a bandwidth of 3%; that is, we consider the election victories or defeats of women against men as narrow if the margin was less than or equal to 3%. However, as a robustness test, we show that our estimates are robust to bandwidths between 1% and 5%. Standard errors are clustered at the legislative constituency level.

[11] A straightforward comparison of crop fire incidences in constituencies electing female versus male leaders could be misleading due to inherent differences in those constituencies. Additionally, using a difference-in-difference approach might be compromised, as the election of female leaders over males could be influenced by time-varying unobservables that are also correlated with crop fire occurrences.

Balance and falsification tests. In the context of India, the method of close-election regression discontinuity design is particularly relevant and has been discussed in various studies (Bardhan and Mookherjee, 2010). This is because elections at the constituency level in India are extremely competitive and influenced by a multitude of factors, making them unpredictable. The validity of using a close-election regression discontinuity approach increases when the outcome, especially near the RD cutoff, is nearly random (Eggers et al., 2015). This is particularly the case when assessing the likelihood of a female candidate winning in a constituency close to that cutoff. Indeed, we find characteristics of elections with a narrow female winner are similar to those of elections with a narrow female loser (e.g., candidate's party affiliation, education, number of votes) (Table A.1). Similarly, we use the 2001 and 2011 village and town census directories to show that assemblies with a narrow female winner share similar characteristics to those with a narrow female loser (e.g., electricity access, number of schools) (Table A.2 and Table A.3).[12] Furthermore, in a falsification test, we show that there are no differences in fire activity or particulate emissions prior to the close election victory of a woman over a man (Table A.4 and Table A.5).

4 Impact of Women Leaders on Crop Fires and Particulate Emissions

Figure A.6 shows the graphical representation of the reduced-form effect: the percentage change in the count of fires at the treatment threshold. We observe a large and statistically significant decrease in fires in legislative constituencies where women narrowly won against men. Table 1, Panel A, shows the corresponding point estimates: constituencies where women narrowly won against men observe 13% fewer fires monthly than constituencies where women narrowly lost against men.[13] We also examine the effects of narrow election win for

[12]The 2001 and 2011 village and town Census Directories are part of the Indian census. They provide detailed information about each village and town in India, including demographic, social, and economic data. The 2001 directory was part of the Census of India conducted in that year, and the 2011 directory was a similar effort from the subsequent census. These directories are key resources for understanding the changing dynamics of rural and urban areas in India over time.

[13]Our regression discontinuity estimates are robust to bandwidth choice (Figure A.7 and A.8). In our baseline specification, we consider all election wins or defeats for women against men as narrow if the margin was less than or equal to 3%. However, as a robustness test, we show that our estimates are robust to bandwidths between 1% and 5%, with some decrease in precision for bandwidths above 3%.

women against men on fire intensity as captured by the brightness temperature detected by the MODIS and VIIRS instrument. Consistent with the decrease in fire counts, we find that a narrow election win for women decreases the monthly total fire intensity by 1380.37 Kelvin (Table 1, Panel A). We also observe a decrease in mean, maximum, and minimum brightness of roughly 15 Kelvin, however, these estimates are not always precisely estimated.

Next, we examine the effect of women leaders on particulate emissions. Our outcomes are satellite-based estimates of ambient black carbon, organic carbon, and sulphur dioxide concentrations – precursors to PM2.5 – at the state legislative constituency level. We observe a statistically significant decrease in monthly *maximum* black carbon, organic carbon, and sulphur dioxide concentrations for constituencies where women narrow won against men. Constituencies where women narrowly won against men observe a roughly 40% decrease in monthly maximum particulate emissions compared to constituencies where women narrow lost against men (Table 2, Panel A).

We also estimate a roughly 11% decrease in monthly mean particulate emissions, although these estimates are not precisely estimated (Table A.6).[14] Nonetheless, this statistically imprecise decrease in monthly mean black carbon, organic carbon, and sulphur dioxide concentrations translates to a roughly 15 $\mu g/m^3$ decrease in monthly average PM2.5 levels, which is non-trivial; the World Health Organization guidelines say that annual average PM2.5 concentrations should not exceed 5 $\mu g/m^3$ (World Health Organization, 2021). Furthermore, Greenstone and Hanna (2014) show that the most stringent air pollution regulations in India decreased urban PM2.5 concentrations by 12 $\mu g/m^3$. Therefore, the improvement in local PM2.5 concentrations due to the election of women leaders is comparable to the improvement in PM2.5 concentrations due to regulations in India.

Lastly, as one would expect, we show the effects of narrow election win for women against men on fire activity and particulate emissions are driven by newly elected women leaders, with small and statistically insignificant effects for re-elected incumbent women leaders (Table A.7 and Table A.8).

[14] It is important to note, however, that we observe a statistically precise decrease in monthly mean particulate emissions during the harvest and post-harvest months in districts that follow fire-suited cropping patterns (Figure A.9).

Heterogeneity by season and crop. Next, we examine whether these effects on crop fires and particulate emissions are concentrated during the harvest and post-harvest months in districts that follow fire-suited cropping patterns. The use of fire to clear harvest residue in the coupled rice-wheat cropping arrangement occur between October and December (rice-wheat transition) and April and May (wheat-rice transition). The use of fire to make sugarcane harvesting less labor-intensive occur between December and March. Therefore, if the election of women leaders decreases *crop* fires, one would expect the decrease in fires and particulate emissions to be concentrated between October and May in districts with a higher (above median) baseline production rice or sugarcane.[15]

First, we show that the election of women leaders decreases both fires and particulate pollution in the harvest and post-harvest months of October to May, with comparatively smaller and statistically insignificant effects during the rest of the year. Figure A.10 shows the graphical representation of the reduced-form effect on fires for October to May and June to September, respectively, while Figure A.11 shows the month-by-month estimates for both fires and particulate emissions. Second, the effects of women leaders on fires and particulate emissions are driven by districts with a higher share of rice or sugarcane acreage at baseline, with comparatively modest effects in districts with lower (below median) share of rice and sugarcane acreage at baseline (Figure A.12; Table 1, Panels B-C and Table 2, Panels B-C).

Together, we find that the decrease in both fires and particulate pollution is predictably concentrated during the harvest and post-harvest months (October-May), in districts with higher share of rice or sugarcane acreage at baseline, with small and statistically insignificant effects during the rest of the year in districts with higher share of rice or sugarcane acreage at baseline, or throughout the year in districts with lower share of rice and sugarcane acreage at baseline; Figure 1 shows the graphical representation of these reduced form effects for fire incidence, while Figures A.13 and A.14 show the month-by-month estimates for fire activity and particulate emissions, respectively.

[15]We match districts in the analysis sample to agricultural data obtained from the ICRISAT District Level Database. The ICRISAT District-Level Data are available online from the following website: http://data.icrisat.org/dld/src/crops.html. We use data for the year 2001 as a baseline to classify higher/lower rice or sugarcane districts based on the sample median of acreage share for the respective crops.

5 Why and How Do Women Leaders Decrease Crop Fires?

To understand mechanisms, we survey 424 male and female gram panchayat (village council) leaders between December 22-March 23 in Punjab, the Indian state with the highest per capita incidence of crop fires.[16] The purpose of these surveys was to gather information on the leaders' views, knowledge, and policy preferences concerning crop fires (known as stubble burning in Punjab).

We chose to focus on village council leaders (VCLs) instead of MLAs for two main reasons. First, we wanted to see if male and female leaders at this tier of government have different perspectives on stubble burning. Second, from a logistical standpoint, we opted for telephone surveys and anticipated a significantly higher response rate from VCLs compared to their constituency-level counterparts.

Both levels of government – village council and legislative constituency – are vested with significant administrative and executive powers. For example, MLAs have the authority to allocate funds to village councils in their constituency, prioritize policies, and set objectives. Similarly, VCLs, known as sarpanchs or mukhiyas, have a comparable role but on a smaller scale. They manage village funds and implement higher-level policies. In the context of controlling stubble burning, both MLAs and VCLs have the ability to enforce regulations and respond to the concerns of their constituents.

The survey data enhances our prior empirical analysis by examining whether one of the reasons for the estimated decrease in crop fires is a difference in attitudes towards stubble burning between male and female leaders.[17]

Several key findings emerge from the data. First, a significantly higher percentage of female VCLs view stubble burning as a very serious problem compared to their male counterparts; 64% female VCLs view stubble burning as a very serious issue, compared to 54%

[16] We employed a stratified random sampling method at the district level to ensure representation across different geographical and demographic segments within Punjab.

[17] Unlike in our close-election regression discontinuity design, where we compare outcomes in constituencies where women narrowly won or lost against men, there exists differences between the average male and female VCL in Punjab; while both male and female VCLs are roughly the same age, married, and have two children; women VCLs are less experienced, have fewer years of education, less likely to be engaged in farm work, and more likely to be engaged in home production (Table A.9). However, reassuringly, our survey results are quantitatively robust to controlling for these demographic differences between male and female VCLs (Table A.10).

male VCLs (Figure 2, Panel (a)). They are also substantially more likely to strongly support regulations against crop burning: 69% female VCLs strongly favor regulation against subble burning, compared to 59% male VCLs (Figure 2, Panel (b)). These responses indicate differing beliefs between male and female leaders about the severity and consequences of stubble burning. Specifically, a larger proportion of female VCLs believe that stubble burning has a detrimental effect on child health; 27% female VCLs are concerned about the child health costs of stubble burning, compared to 19% male VCLs (Figure 2, Panel (c)). Together, these results complements prior research that women elected as leaders invest more in the public goods more closely linked to women's concerns, including greater investments in child health, as well as a broader literature in economics that shows that women are more likely to support policies that encourage spending on child-related expenses, and that household income or assets in the hands of women raise spending on expenditures benefiting children.

Investigating how female leaders might have contributed to the reduction in crop burning reveals further nuances. In terms of policy awareness, female VCLs are generally more informed about government policies to curb stubble burning compared to male leaders, although the number of policies implemented by both groups may be similar (Figure 3, Panels (a)-(b)). Female VCLs show higher awareness of penalties associated with crop burning (56% vs. 48%), aligning with their view that it is a significant problem. However, a similar proportion of male and female VCLs report imposing these penalties (30%). Additionally, female VCLs report implementing alternative methods of managing crop residues in Punjab (Figure 3, Panels (c)-(d)). They particularly favor using stubble as animal fodder and support private stubble collection initiatives: 36% female VCLs implement policies that encourage farmers to use stubble as fodder, compared to 27% male VCLs; 18% female VCLs facilitate private collection of stubble, compared to 12% male VCLs. This is significant, as private residue collection has been shown to decrease the incidence of crop fires in other developing countries in Asia. On the other hand, female VCLs are less likely to encourage farmers to diversify their crops to reduce stubble burning, although this difference is not statistically significant. This comprehensive set of findings helps illuminate some underlying reasons for the observed reduction in crop fires in legislative constituencies narrowly won by female representatives.

6 Conclusion

In legislative assemblies where women narrowly defeated men, there is a significant environmental impact: a 13% reduction in monthly fire activity and a 40% decrease in biomass-related monthly maximum particulate emissions. Importantly, these changes are neither observed before the women's election, nor are they observed after re-election of incumbent women leaders. They are concentrated in harvest and post-harvest months and in regions with cropping patterns conducive to fires. Women leaders tend to regard crop fires as a serious issue, often attributing their concern to the impact of fires on child health. They are also better informed about existing governmental policies to combat crop fires and are more proactive in implementing alternative residue management strategies, such as private collection or use as fodder.

Turning to broader implications, as economies expand, the initial effect is an increase in pollution and environmental degradation. While policies can be drafted to mitigate these issues, their efficacy is compromised in settings with weak institutions and uneven enforcement. Therefore, individuals in leadership positions play a vital role in implementing and supporting policies that benefit the environment. Our study indicates that increasing the political representation of women can be a robust strategy to address both current and emerging environmental and health challenges in developing economies. In fact, subsequent work has already documented the applicability of our findings to other contexts and outcomes: Bandyopadhyay et al. (2023) and Baragwanath and Zheng (2023) employ a similar close-election regression discontinuity design to demonstrate that the election of female leaders reduces deforestation in India and Brazil, respectively. This underscores the importance of diversifying leadership not just for social equity but also for effective policy implementation in the realms of economic development and environmental sustainability.

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Tables and Figures

Table 1: Election of women leaders decreases fire activity

	(1) Log Monthly Number of Crop Fires β / SE	(2) Total Fire Brightness (in Kelvins) β / SE	(3) Mean Fire Brightness (in Kelvins) β / SE	(4) Max Fire Brightness (in Kelvins) β / SE	(5) Min Fire Brightness (in Kelvins) β / SE
Panel A: All					
Female Winner	-0.13**	-1380.37**	-14.87	-15.65*	-14.27
	(0.07)	(614.70)	(9.14)	(9.46)	(8.88)
State-by-Election Year FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Control Mean	0.39	1554.64	66.87	68.85	65.13
Observations	25452	25452	25452	25452	25452
R^2	0.170	0.061	0.149	0.152	0.146
Panel B: High Rice or High Sugar					
Female Winner	-0.21***	-2101.54***	-24.86**	-26.15**	-23.70**
	(0.07)	(770.40)	(10.21)	(10.53)	(9.96)
State-by-Election Year FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Control Mean	0.48	2058.58	80.69	83.05	78.66
Observations	15816	15816	15816	15816	15816
R^2	0.168	0.064	0.144	0.148	0.141
Panel C: Low Rice and Low Sugar					
Female Winner	0.07	1017.74	10.60	11.40	10.19
	(0.15)	(921.35)	(21.36)	(22.19)	(20.81)
State-by-Election Year FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Control Mean	0.22	838.99	44.77	45.97	43.58
Observations	7176	7176	7176	7176	7176
R^2	0.227	0.081	0.181	0.185	0.177

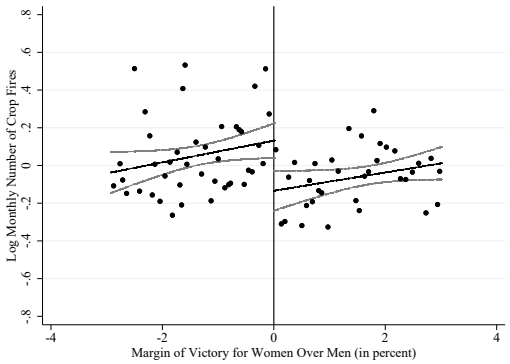
Notes: This table presents the effects of women leaders narrowly winning against male candidates on log monthly fire counts, and monthly total, mean, maximum, and minimum fire brightness. Panels A, B, C present the effects of a narrow election win for women against men on monthly fire activity for (i) all districts, (ii) districts with high rice or high sugarcane production where cop fires would be expected to be more prevalent, and (iii) districts with low rice and low sugarcane production, respectively. "High rice or high sugar" sample consists of districts which had high (above sample median) share of cropped area under rice or sugarcane at baseline (2001). "Low rice and low sugar" consists of districts which had low (above sample median) share of cropped area under rice and sugarcane at baseline (2001). All regressions include state-by-election-year and year fixed effects, and present RD estimates for a bandwidth of 3% in vote margin. Standard errors in parentheses are clustered at assembly level. Significance at 1%, 5% and 10% are indicated by ***, ** and *, respectively.

Table 2: Election of women leaders decreases monthly maximum particulate emissions

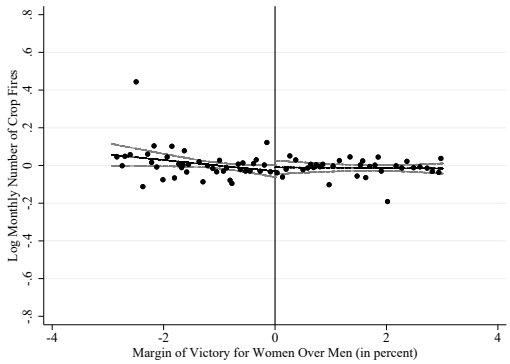
	(1) Max Black Carbon (nano-gram/sq-meter/sec) β / SE	(2) Max Organic Carbon (nano-gram/sq-meter/sec) β / SE	(3) Max SO2 (nano-gram/sq-meter/sec) β / SE
Panel A: All			
Female Winner	-3.39**	-55.66*	-4.31*
	(1.72)	(29.95)	(2.29)
State-by-Election Year FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Control Mean	9.27	131.78	9.98
Observations	25452	25452	25452
R^2	0.098	0.094	0.093
Panel B: High Rice or High Sugar			
Female Winner	-4.31*	-74.16*	-5.68*
	(2.28)	(41.20)	(3.16)
State-by-Election Year FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Control Mean	8.79	114.54	8.48
Observations	15816	15816	15816
R^2	0.111	0.086	0.084
Panel C: Low Rice and Low Sugar			
Female Winner	0.32	2.32	0.09
	(0.78)	(7.80)	(0.56)
State-by-Election Year FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Control Mean	2.56	27.91	2.07
Observations	7176	7176	7176
R^2	0.085	0.101	0.103

Notes: This table presents the effects of women leaders narrowly winning against male candidates on monthly maximum black carbon, organic carbon, and sulphur dioxide. Panels A, B, C present the effects of narrow election win for women against men on monthly maximum particulate emissions for (i) all districts, (ii) districts with high rice or high sugarcane production where crop fires would be expected to be more prevalent, and (iii) districts with low rice and low sugarcane production, respectively. "High rice or high sugar" sample consists of districts which had high (above sample median) share of cropped area under rice or sugarcane at baseline (2001). "Low rice and low sugar" consists of districts which had low (above sample median) share of cropped area under rice and sugarcane at baseline (2001). All regressions include state-by-election-year and year fixed effects, and present RD estimates for a bandwidth of 3% in vote margin. Standard errors in parentheses are clustered at assembly level. Significance at 1%, 5% and 10% are indicated by ***, ** and *, respectively.

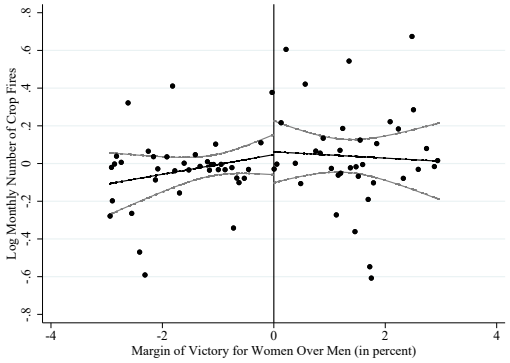
Figure 1: Effects of election of women leaders concentrated in districts that grow rice or sugarcane in the harvest and post-harvest months (Oct-May)



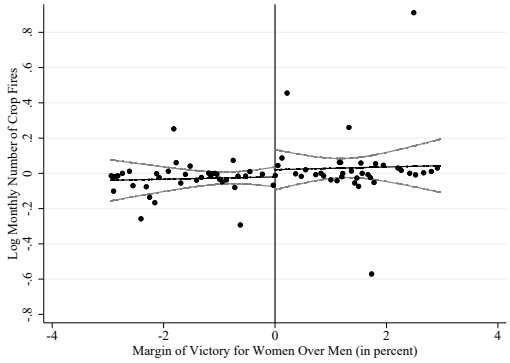
(a) Fires: High Rice or High Sugar (Oct-May)



(b) Fires: High Rice or High Sugar (Jun-Sep)



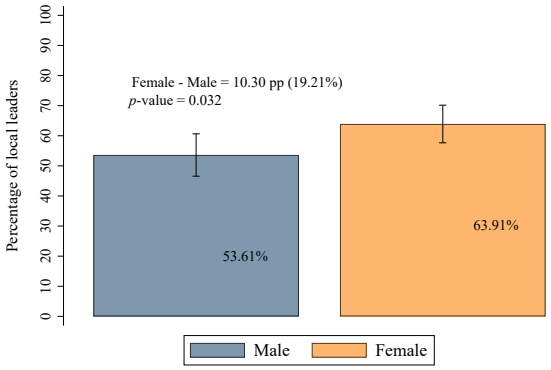
(c) Fires: Low Rice and Low Sugar (Oct-May)



(d) Fires: Low Rice and Low Sugar (Jun-Sep)

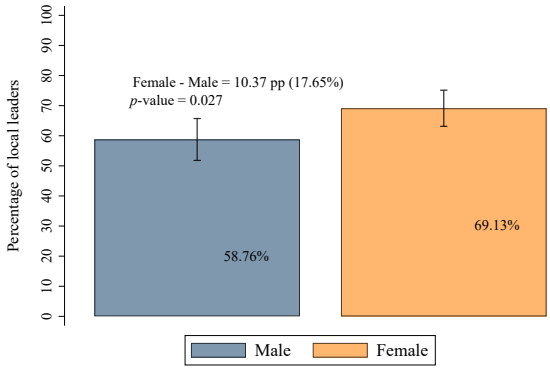
Notes: This table presents the effects of women leaders narrowly winning against male candidates on log monthly fire counts for (i) districts with high rice or high sugarcane production during the harvest and post-harvest months (Oct-May), (ii) districts with high rice or high sugarcane production during the rest of the year (June-Sep) where crop fires would be expected to be more prevalent, (iii) districts with low rice and low sugarcane production during the harvest and post harvest months (Oct-May), and (iv) districts with low rice and low sugarcane production during the rest of the year (June-Sep), respectively. "High rice or high sugar" sample consists of districts which had high (above sample median) share of cropped area under rice or sugarcane at baseline (2001). "Low rice and low sugar" consists of districts which had low (above sample median) share of cropped area under rice and sugarcane at baseline (2001). All regressions include state-by-election-year and year fixed effects, and present RD estimates for a bandwidth of 3% in vote margin. Standard errors are clustered at assembly level. 95% confidence intervals are presented.

Figure 2: Women leaders more likely to believe that stubble burning is a very serious problem and strongly favor regulation against stubble burning, perhaps due to their concerns about the associated child health costs



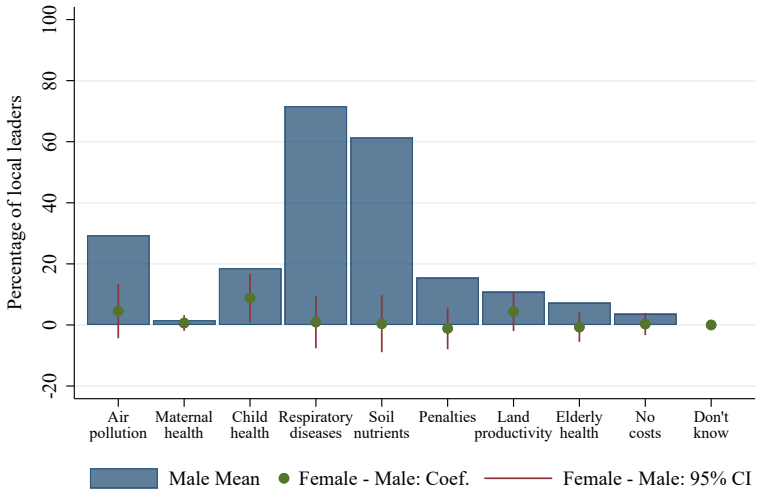
Notes: Survey data from 230 female and 194 male panchayat mukhiyas (community leaders) across Punjab, India, December 22 - March 23. Heteroskedasticity robust standard errors presented.

(a) Women leaders aware of > # policies implemented by govt. for crop fires



Notes: Survey data from 230 female and 194 male panchayat mukhiyas (community leaders) across Punjab, India, December 22 - March 23. Heteroskedasticity robust standard errors presented.

(b) ...for example, women leaders more aware of penalties against crop fires

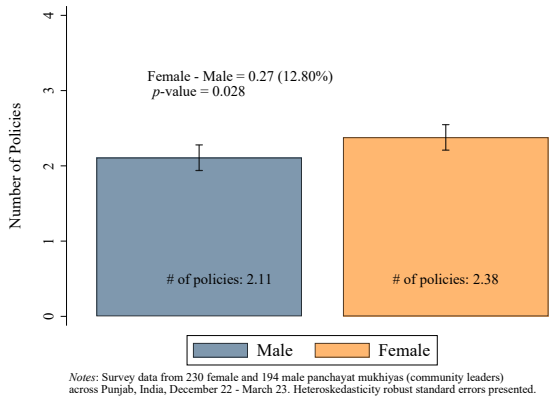


Notes: Survey data from 230 female and 194 male panchayat mukhiyas (community leaders) across Punjab, India, December 22 - March 23. Heteroskedasticity robust standard errors presented.

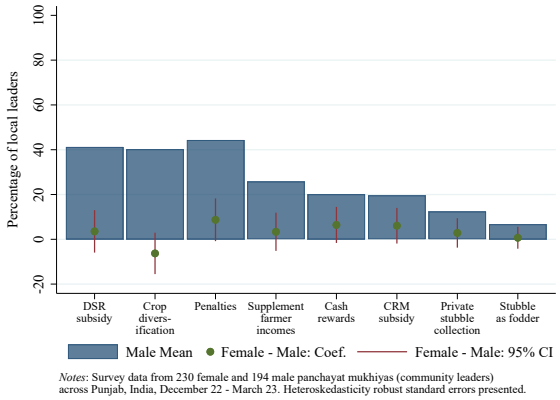
(c) Women and male leaders implement similar # policies for crop fires

Notes: We surveyed 424 male and female village council leaders (VCLs) between December 22-March 23 in Punjab, the Indian state with the highest per capita incidence of crop fires. Panel (a) shows that female VCLs are much more likely to consider stubble burning as a very serious problem. Panel (b) shows that female VCLs are much more likely to be in favor of regulation to tackle stubble burning. Panel (c) shows that female VCLs are much more likely to consider child health as a cost of stubble burning. 95% confidence intervals are presented.

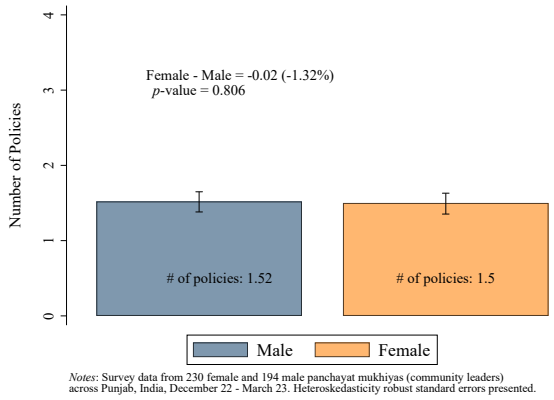
Figure 3: Women leaders aware of larger number of policies implemented by government to tackle stubble burning, including penalties; women leaders implement similar number but different types of policies to tackle stubble burning



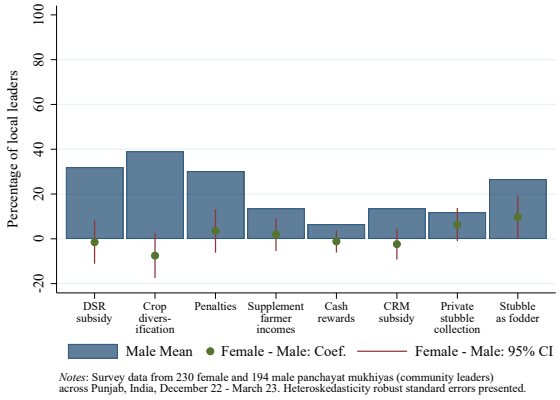
(a) Women leaders aware of greater number of policies implemented by government to tackle stubble burning



(b) ...for example, women leaders more aware of penalties against stubble burning



(c) Women and male leaders implement similar number of policies to tackle stubble burning



(d) Women leaders more likely to implement crop residue management policies

Notes: We surveyed 424 male and female village council leaders (VCLs) between December 22-March 23 in Punjab, the Indian state with the highest per capita incidence of crop fires. Panels (a) and (b) show that female VCLs are aware of greater number of policies implemented by the government to tackle stubble burning, including penalties. Panels (c) and (d) show that although women and male leaders implement similar number of policies to tackle stubble burning, the types of policies implemented by female leaders are different: women leaders more likely to implement crop residue management policies. 95% confidence intervals are presented.

Women Leaders Improve Environmental Outcomes: Evidence from Crop Fires in India

Maulik Jagnani and Meera Mahadevan

Online Appendix

A Tables and Figures

Tables

Table A.1: Summary statistics and balance for assembly election characteristics: Elections with female winner similar to elections with male winner

	Full sample	Below threshold	Over threshold	Difference of means	p-value on difference	RD estimate	p-value on RD estimate
INC Winner (0/1)	0.24	0.23	0.24	0.02	0.31	0.03	0.70
BJP Winner (0/1)	0.28	0.28	0.28	-0.00	0.90	0.13	0.14
# of Winner Votes	61615.54	61516.11	61726.14	210.03	0.84	3207.40	0.19
# of Valid Votes	132635.25	132350.59	132940.67	590.08	0.77	2083.16	0.64
# of Eligible Voters	199852.27	198309.47	201455.72	3146.25	0.31	2958.13	0.63
Turncoat Winner (0/1)	0.07	0.08	0.05	-0.03	0.00	-0.05	0.35
Incumbent Winner (0/1)	0.32	0.37	0.27	-0.09	0.00	-0.03	0.78
# of Terms (Winner)	1.81	2.00	1.61	-0.39	0.00	-0.34	0.20
SC/ST Constituency (0/1)	0.33	0.33	0.33	-0.01	0.74	0.02	0.82
Years of Education (Winner)	13.25	13.49	13.00	-0.49	0.01	-0.23	0.81

Notes: This table shows the mean values for election characteristics using data on Indian legislative elections from 1998-2022. Columns 1-3 show the unconditional means for all assembly elections, assembly elections below the treatment threshold, and assembly elections above the treatment threshold, respectively. Column 4 shows the difference of means across Columns 2 and 3, and Column 5 shows the p-value for the difference of means. Column 6 test for balance in these outcomes. It shows the regression discontinuity estimate, following the main estimating equation (with a bandwidth of 3% in vote margin), of the effect of being above the treatment threshold. Column 7 is the p-value for this estimate, using cluster robust standard errors at the assembly level.

Table A.2: Summary statistics and balance for baseline (2001) constituency characteristics: Assemblies with female winner similar to those with male winner

	Full sample	Below threshold	Over threshold	Difference of means	p-value on difference	RD estimate	p-value on RD estimate
Town characteristics:							
Area of town (sq. km)	23.79	21.73	26.17	4.44	0.14	-12.94	0.49
# of senior secondary schools	4.52	4.32	4.63	0.31	0.37	0.06	0.95
# of college	2.13	1.74	1.83	0.09	0.68	0.73	0.17
# of secondary schools	7.99	7.03	7.84	0.81	0.24	2.04	0.22
# of middle schools	12.60	10.56	12.91	2.35	0.02	3.22	0.21
# of primary schools	24.55	22.04	24.39	2.36	0.18	9.15	0.10
Village characteristics:							
Share with power	0.70	0.62	0.65	0.03	0.31	0.03	0.52
Share with agriculture power	0.09	0.06	0.12	0.06	0.01	0.27	0.07
Share with domestic power	0.79	0.75	0.73	-0.03	0.49	0.07	0.67
Area of village (hectares)	79986.81	79458.44	76164.90	-3293.54	0.63	18110.50	0.45
Share access to dirt road	0.71	0.74	0.70	-0.05	0.04	-0.07	0.23
Share access to paved road	0.72	0.71	0.71	-0.01	0.64	0.03	0.39
# of college	1.35	1.34	1.16	-0.18	0.19	0.20	0.63
# of senior secondary schools	5.88	6.38	5.51	-0.87	0.01	0.02	0.98
# of secondary schools	22.78	21.90	20.13	-1.78	0.08	-2.96	0.26
# of middle schools	60.58	58.30	57.48	-0.82	0.75	-5.34	0.48
# of primary schools	208.01	209.99	211.07	1.08	0.88	-40.54	0.26
All:							
Literate total population	135575.78	137605.11	137951.47	346.36	0.91	1857.86	0.82
ST total population	28184.81	31010.55	29795.70	-1214.85	0.72	-2218.64	0.87
# of households	49809.23	50095.15	51541.00	1445.85	0.13	-3805.00	0.15
SC total population	44203.11	46971.17	48249.00	1277.82	0.54	-2844.06	0.64
Urban population	40082.51	38007.73	39215.70	1207.98	0.72	5377.40	0.59
Rural population	224986.13	229669.00	241129.09	11460.09	0.05	-14222.10	0.31
Total population	265098.44	267854.75	280265.25	12410.50	0.02	-10147.58	0.37

Notes: This table shows the mean values for town and village characteristics measured in 2001 in constituencies where assembly elections that took place after 2001. Columns 1-3 show the unconditional means for all towns/villages, towns/villages in constituencies below the treatment threshold, and towns/villages in constituencies above the treatment threshold, respectively. Column 4 shows the difference of means across Columns 2 and 3, and Column 5 shows the p-value for the difference of means. Column 6 shows the regression discontinuity estimate, following the main estimating equation, of the effect of being above the treatment threshold, and Column 7 is the p-value for this estimate, using cluster robust standard errors at the assembly level. Source: 2001 Population Census.

Table A.3: Summary statistics and balance for baseline (2011) constituency characteristics: Assemblies with female winner similar to those with male winner

	Full sample	Below threshold	Over threshold	Difference of means	p-value on difference	RD estimate	p-value on RD estimate
Town characteristics:							
Area of town (sq. km)	35.47	25.47	29.93	4.46	0.11	-27.98	0.29
# of senior secondary schools	7.94	7.56	7.95	0.39	0.47	-0.85	0.69
# of college	4.78	4.25	4.42	0.17	0.68	-1.69	0.31
# of secondary schools	13.39	11.98	12.83	0.85	0.39	-2.54	0.42
# of middle schools	21.96	19.06	21.64	2.58	0.13	-0.95	0.90
# of primary schools	36.74	34.62	38.10	3.48	0.13	-2.76	0.82
Village characteristics:							
Share with power	0.66	0.64	0.62	-0.03	0.25	0.14	0.09
Share with agriculture power	0.72	0.72	0.71	-0.01	0.60	0.13	0.13
Share with domestic power	0.94	0.94	0.92	-0.02	0.11	0.12	0.18
Area of village (hectares)	80586.36	80640.72	76844.55	-3796.17	0.59	13937.43	0.37
Share access to paved road	0.79	0.76	0.75	-0.01	0.48	0.06	0.47
# of college	2.99	2.68	3.24	0.56	0.06	1.79	0.14
# of senior secondary schools	16.88	17.73	17.48	-0.25	0.78	0.10	0.98
# of secondary schools	44.99	44.65	44.56	-0.09	0.97	6.68	0.22
# of middle schools	117.07	116.94	118.89	1.94	0.67	15.83	0.39
# of primary schools	263.93	266.21	271.90	5.70	0.54	43.00	0.34
All:							
Share of HHs-income from agr.	0.32	0.31	0.32	0.01	0.37	-0.00	0.97
Per capita consumption (Rs)	17605.68	17440.53	17336.72	-103.80	0.71	66.65	0.94
Literate total population	186196.23	188188.48	193004.98	4816.50	0.23	3263.43	0.80
ST total population	34871.71	38743.97	37558.59	-1185.38	0.78	12247.58	0.58
# of households	63825.82	64645.27	66754.67	2109.41	0.09	-203.26	0.96
SC total population	53156.66	56189.30	57459.63	1270.33	0.60	-4972.94	0.62
Urban population	54768.22	53673.74	53849.82	176.09	0.97	-4118.64	0.80
Rural population	255409.80	260101.89	276302.16	16200.27	0.03	11543.37	0.63
Total population	310178.03	313775.63	330152.00	16376.38	0.02	7424.72	0.69

Notes: This table shows the mean values for town and village characteristics measured in 2011 in constituencies where assembly elections that took place after 2011. Columns 1-3 show the unconditional means for all towns/villages, towns/villages in constituencies below the treatment threshold, and towns/villages in constituencies above the treatment threshold, respectively. Column 4 shows the difference of means across Columns 2 and 3, and Column 5 shows the p-value for the difference of means. Column 6 shows the regression discontinuity estimate, following the main estimating equation, of the effect of being above the treatment threshold, and Column 7 is the p-value for this estimate, using cluster robust standard errors at the assembly level. Source: 2011 Population Census.

Table A.4: Falsification test: No decrease in fire activity before election of women leader

	(1) Log Monthly Number of Crop Fires β / SE	(2) Total Fire Brightness (in Kelvins) β / SE	(3) Mean Fire Brightness (in Kelvins) β / SE	(4) Max Fire Brightness (in Kelvins) β / SE	(5) Min Fire Brightness (in Kelvins) β / SE
Female Winner	0.01	-228.69	-0.91	-1.20	-0.95
	(0.08)	(495.20)	(11.76)	(12.13)	(11.48)
State-by-Election Year FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Control Mean	3.38	1110.50	66.59	68.34	65.16
Observations	11592	11592	11592	11592	11592
R^2	0.199	0.102	0.170	0.172	0.167

Notes: This table presents the effects of a narrow election win for women against men on monthly fire activity before the elections as a falsification test. We find that no differences exist in fire incidence or fire brightness prior to the close election victory of a woman over a man. All regressions include state-by-election-year and year fixed effects. Standard errors in parentheses are clustered at assembly level. Significance at 1%, 5% and 10% are indicated by ***, ** and *, respectively.

Table A.5: Falsification test: No decrease in particulate emissions before election of women leader

	(1) Max Black Carbon (nano-gram/sq-meter/sec) β / SE	(2) Max Organic Carbon (nano-gram/sq-meter/sec) β / SE	(3) Max SO2 (nano-gram/sq-meter/sec) β / SE
Female Winner	2.43	25.41	1.72
	(1.47)	(19.92)	(1.47)
State-by-Election Year FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Control Mean	10.57	155.09	11.90
Observations	11592	11592	11592
R^2	0.105	0.107	0.106

Notes: This table presents the effects of a narrow election win for women against men on monthly particulate emissions before the elections as a falsification test. We find no differences exist in particulate emissions prior to the close election victory of a woman over a man. All regressions include state-by-election-year and year fixed effects, and present RD estimates for a bandwidth of 3% in vote margin. Standard errors in parentheses are clustered at assembly level. Significance at 1%, 5% and 10% are indicated by ***, ** and *, respectively.

Table A.6: Election of women leaders decreases monthly mean particulate emissions by a statistically insignificant 11%

	(1) Mean Black Carbon (nano-gram/sq-meter/sec) β / SE	(2) Mean Organic Carbon (nano-gram/sq-meter/sec) β / SE	(3) Mean SO2 (nano-gram/sq-meter/sec) β / SE
Panel A: All			
Female Winner	-0.89	-9.99	-0.78
	(1.23)	(14.44)	(1.01)
State-by-Election Year FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Control Mean	6.44	88.25	6.65
Observations	25452	25452	25452
R^2	0.100	0.097	0.097
Panel B: High Rice or High Sugar			
Female Winner	-1.29	-19.09	-1.46
	(1.69)	(19.60)	(1.36)
State-by-Election Year FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Control Mean	5.47	63.16	4.57
Observations	15816	15816	15816
R^2	0.145	0.121	0.115
Panel C: Low Rice and Low Sugar			
Female Winner	-0.21	-1.96	-0.18
	(0.47)	(4.67)	(0.34)
State-by-Election Year FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Control Mean	1.58	16.96	1.25
Observations	7176	7176	7176
R^2	0.077	0.092	0.093

Notes: This table presents the effects of a narrow election win for women against men on monthly mean black carbon, organic carbon, and sulphur dioxide. Panels A, B, C present the effects of narrow election win for women against men on monthly mean particulate emissions for (i) all districts, (ii) districts with high rice or high sugarcane production where crop fires would be expected to be more prevalent, and (iii) districts with low rice and low sugarcane production, respectively. "High rice or high sugar" sample consists of districts which had high (above sample median) share of cropped area under rice or sugarcane at baseline (2001). "Low rice and low sugar" consists of districts which had low (above sample median) share of cropped area under rice and sugarcane at baseline (2001). All regressions include state-by-election-year and year fixed effects, and present RD estimates for a bandwidth of 3% in vote margin. Standard errors in parentheses are clustered at assembly level. Significance at 1%, 5% and 10% are indicated by ***, ** and *, respectively.

Table A.7: No decrease in fire activity for incumbent women winners

	(1) Log Monthly Number of Crop Fires Incumbent = 0 β / SE	(2) Log Monthly Number of Crop Fires Incumbent = 1 β / SE	(3) Total Fire Brightness (in Kelvins) Incumbent = 0 β / SE	(4) Total Fire Brightness (in Kelvins) Incumbent = 1 β / SE
Female Winner	-0.14*	-0.02	-1599.02**	345.66
	(0.08)	(0.10)	(749.69)	(868.35)
State-by-Election Year FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Control Mean	5.08	3.84	5.08	3.84
Observations	18840	6612	18840	6612
R^2	0.167	0.279	0.062	0.111

Notes: This table presents the effects of a narrow election win for women against men on monthly fire counts and monthly total fire brightness for incumbent and non-incumbent women leaders, respectively. We find the effects of close election victory of a woman over a man are concentrated amongst non-incumbent women leaders, with null effects for incumbent women leaders. All regressions include state-by-election-year and year fixed effects, and present RD estimates for a bandwidth of 3% in vote margin. Standard errors in parentheses are clustered at assembly level. Significance at 1%, 5% and 10% are indicated by ***, ** and *, respectively.

Table A.8: No decrease in particulate emissions for incumbent women winners

	(1) Max Black Carbon Incumbent = 0 β / SE	(2) Max Black Carbon Incumbent = 1 β / SE	(3) Max Organic Carbon Incumbent = 0 β / SE	(4) Max Organic Carbon Incumbent = 1 β / SE	(5) Max SO2 Incumbent = 0 β / SE	(6) Max SO2 Incumbent = 1 β / SE
Female Winner	-2.66*	0.59	-44.02**	12.16	-3.54**	0.80
	(1.54)	(2.41)	(21.65)	(21.74)	(1.61)	(1.57)
State-by-Election Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Control Mean	9.29	9.21	132.59	129.87	10.07	9.74
Observations	18840	6612	18840	6612	18840	6612
R^2	0.098	0.119	0.095	0.113	0.095	0.111

Notes: This table presents the effects of narrow election win for women against men on monthly maximum particulate emissions for incumbent and non-incumbent women leaders, respectively. We find the effects of close election victory of a woman over a man are concentrated amongst non-incumbent women leaders, with null effects for incumbent women leaders. All regressions include state-by-election-year and year fixed effects, and present RD estimates for a bandwidth of 3% in vote margin. Standard errors in parentheses are clustered at assembly level. Significance at 1%, 5% and 10% are indicated by ***, ** and *, respectively.

Table A.9: Similarities and differences in observables between women and men VCLs

	Full sample	Male	Female	Difference of means	p-value on difference
Age	47.59	48.15	47.12	-1.03	0.32
# of Children	2.15	2.08	2.22	0.14	0.18
Married (0/1)	0.95	0.94	0.96	0.01	0.54
Years of Education	9.59	10.61	8.72	-1.89	0.00
Years of Education (Spouse)	8.75	7.73	9.62	1.89	0.00
First Term (0/1)	0.86	0.82	0.90	0.08	0.03
Lead Discussion in Meetings (0/1)	0.56	0.56	0.56	-0.00	0.98
Homemaker (0/1)	0.51	0.11	0.85	0.74	0.00
Homemaker (Spouse) (0/1)	0.40	0.78	0.08	-0.70	0.00
Farm Work (0/1)	0.31	0.59	0.07	-0.53	0.00
Farm Work (Spouse) (0/1)	0.34	0.05	0.58	0.53	0.00

Notes: This table shows the demographic characteristics of the 424 VCLs from Punjab surveyed between December 2022 and March 2023. Columns 1-3 show the unconditional means for all VCLs, male VCLs, and female VCLs, respectively. Column 4 shows the difference of means across Columns 2 and 3, and Column 5 shows the p-value for the difference of means, using heteroskedasticity robust standard errors.

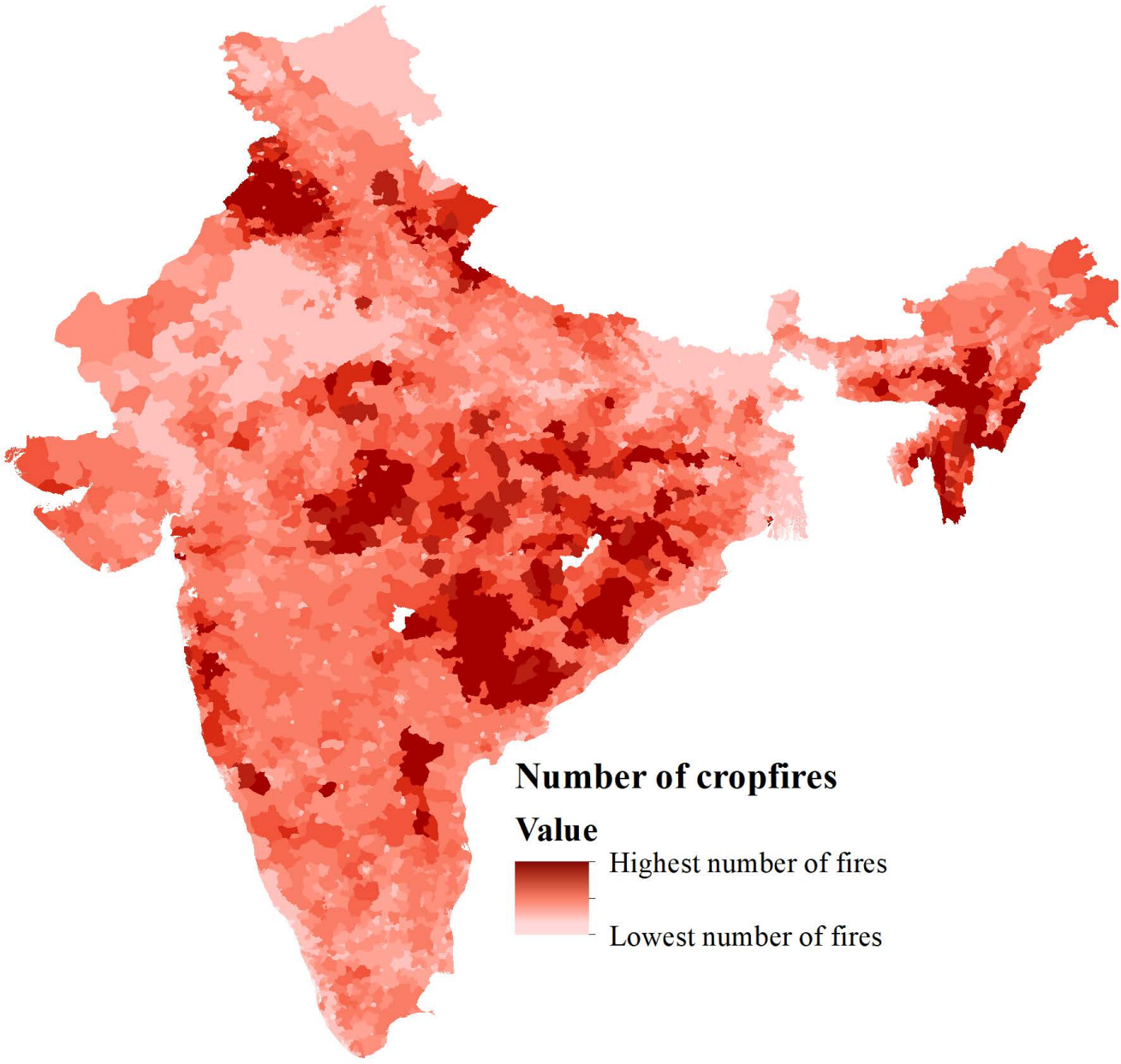
Table A.10: Survey-based gender differences in attitudes towards stubble burning robust to controlling for observables and district fixed effects

	Full sample	Male	Female	Difference of means	p-value on difference	OLS estimate estimate (controls)	p-value on OLS OLS estimate (controls)
Very Serious Problem (0/1)	59.20	53.61	63.91	10.30	0.03	12.64	0.14
Strongly Agree Regulation Needed (0/1)	64.39	58.76	69.13	10.37	0.03	13.95	0.09
Effects on Child Health (0/1)	0.23	0.19	0.27	0.09	0.03	0.12	0.06
Aware of # of Policies Implemented by Govt.	2.25	2.11	2.38	0.27	0.03	0.20	0.24
Aware of Penalties (0/1)	0.52	0.48	0.56	0.08	0.09	0.15	0.05
# of Policies Implemented	1.50	1.52	1.49	-0.02	0.81	-0.15	0.40
Private Stubble Collection (0/1)	0.15	0.12	0.18	0.06	0.09	0.05	0.41
Stubble as Fodder (0/1)	0.32	0.27	0.36	0.10	0.05	0.16	0.02

Notes: This table shows the differences in attitudes towards stubble burning between the 194 male and 234 female VCLs from Punjab surveyed between December 2022 and March 2023. Columns 1-3 show the unconditional means for all VCLs, male VCLs, and female VCLs, respectively. Column 4 shows the difference of means across Columns 2 and 3, and Column 5 shows the p-value for the difference of means, using heteroskedasticity robust standard errors. Column 6 further controls for demographic differences between male and female VCLs. Column 7 is the p-value for this estimate, using heteroskedasticity robust standard errors.

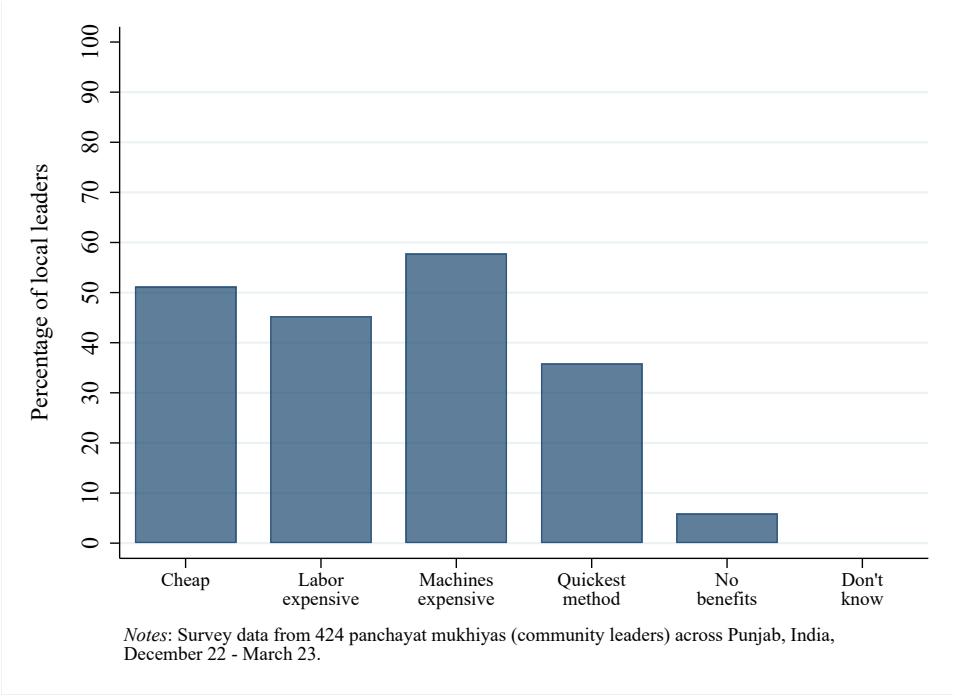
Figures

Figure A.1: Use of crop fires in India is widespread (2002-2022)

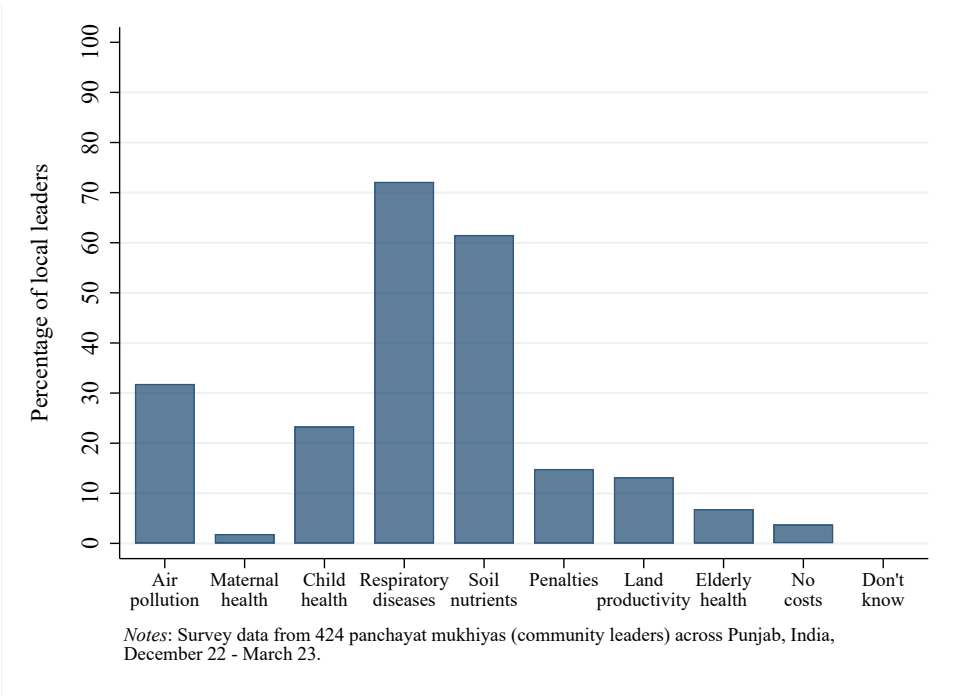


Notes: The map presents all state assemblies in India and uses color shades to illustrate the frequency of crop-fire incidents due to biomass burning. Darker colors indicate higher frequencies. This visualization is based on data from two satellite sources: MODIS for the years 2002-2016 and VIIRS for 2016-2022. The state assembly boundaries displayed in this map reflect the post-2008 delimitation.

Figure A.2: Farmers use fire because it is cheaper than alternatives, despite the associated human health costs



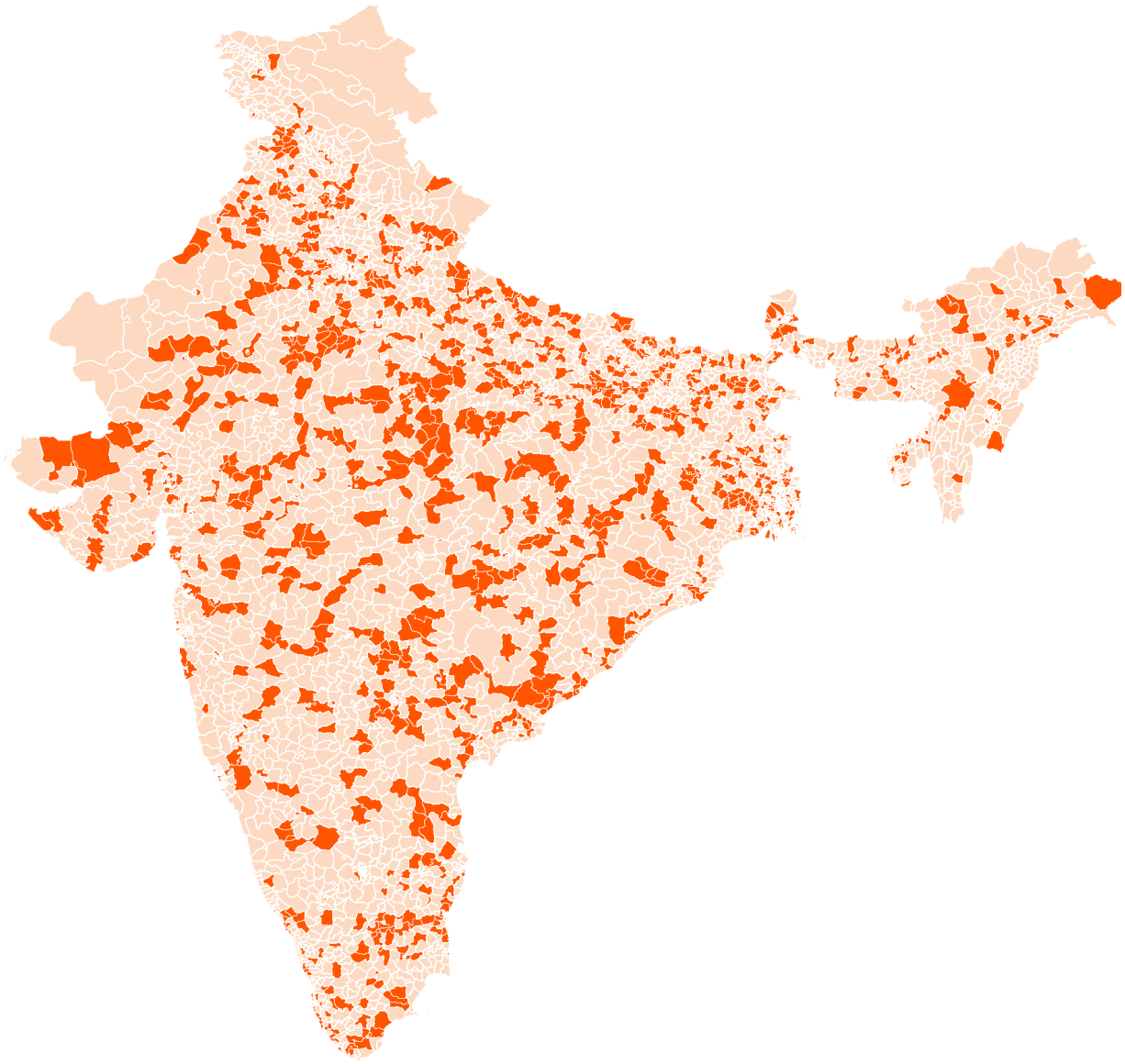
(a) Why do farmers use fire?



(b) Private and public costs of agricultural fires

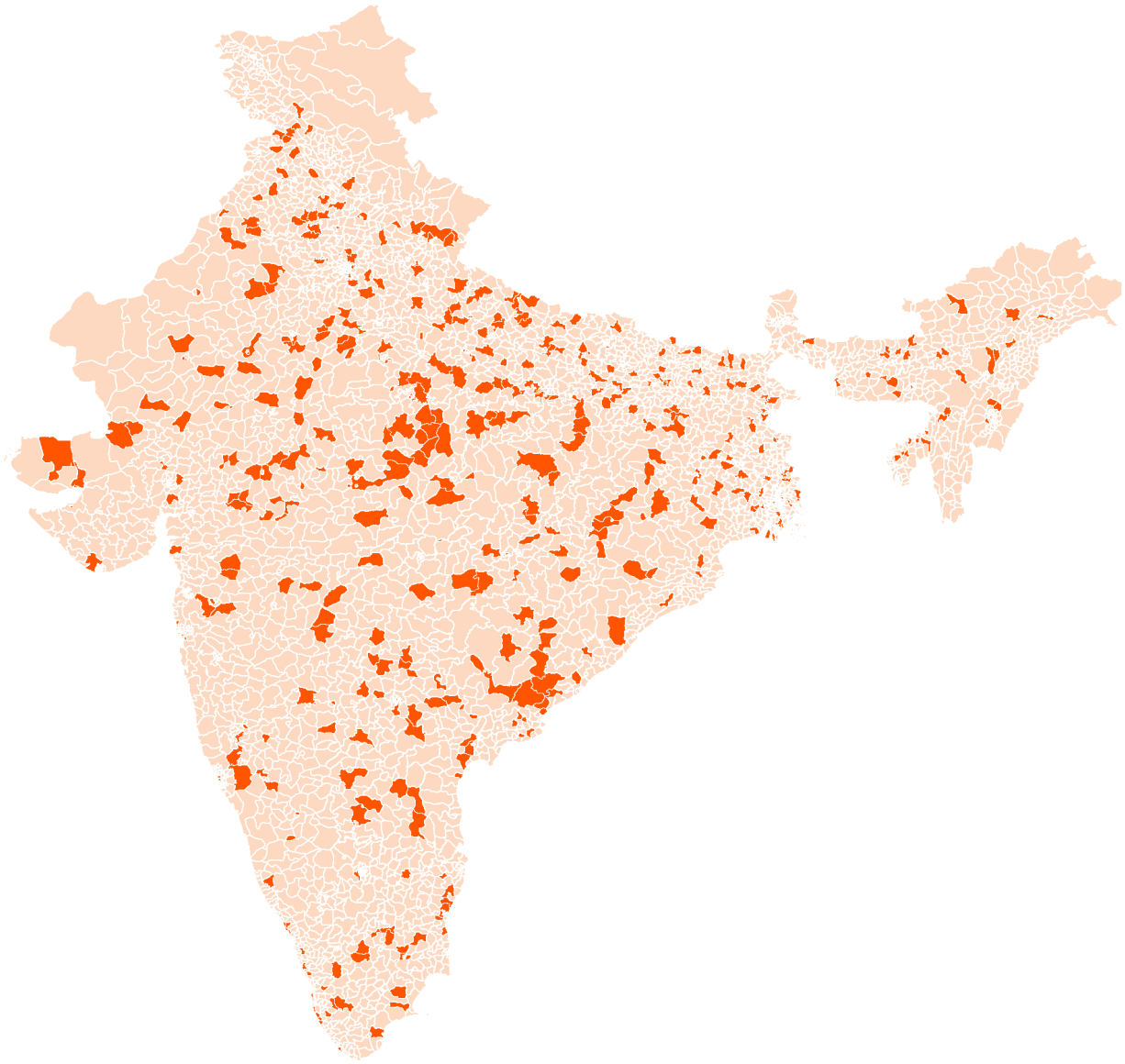
Notes: Panel (a) shows that VCLs (most of whom are farmers) consider the lower cost of fire compared to alternatives like labor and machines as the main reason why farmers use agricultural fires. Panel (b) presents evidence that VCLs are aware of the human health costs associated with crop fires.

Figure A.3: All woman vs. man legislative assembly elections (1998-2022)



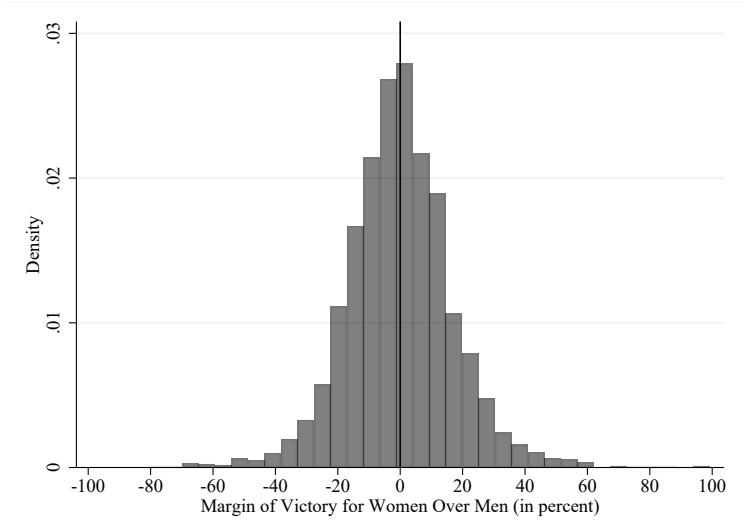
Notes: The map presents all state assemblies in India and uses color shades to illustrate the assemblies where women won or lost against men in all elections between 1998 and 2022. The state assembly boundaries displayed in this map reflect the post-2008 delimitation.

Figure A.4: Close ($\leq$3%) woman vs. man legislative assembly elections (1998-2022)

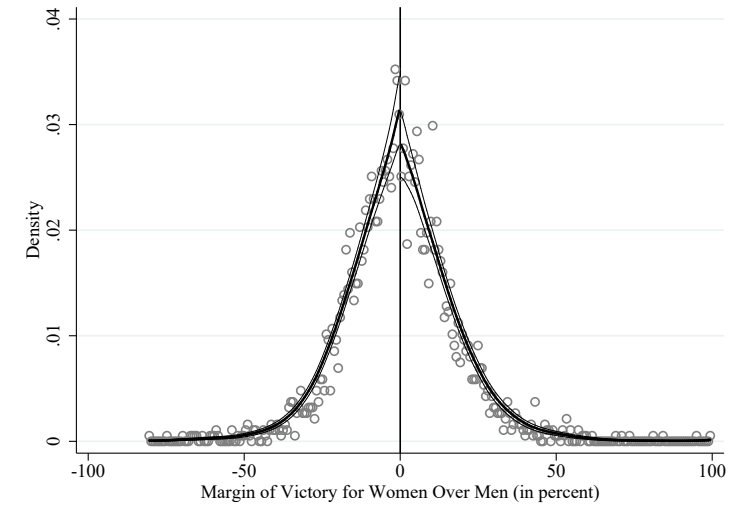


Notes: The map presents all state assemblies in India and uses color shades to illustrate the assemblies where women narrowly won or lost against men in all elections between 1998 and 2022. The state assembly boundaries displayed in this map reflect the post-2008 delimitation.

Figure A.5: Distribution of the margin of win for women over men at victory threshold and McCary test



(a) Distribution of the margin of win for women over men



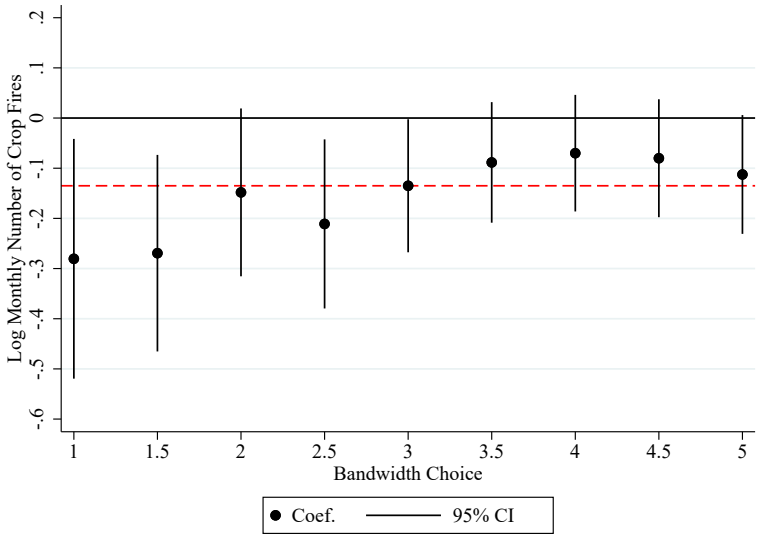
(b) McCary Test

Notes: This graph shows the distribution of margin of victory for women over men (in percent). The top panel is a histogram of margin of victory for women over men (in percent) for all legislative elections in India from 1998-2022. The bottom panel fits a non-parametric regression to each half of the distribution following McCrary (2008), testing for a discontinuity at zero. The point estimate for the discontinuity is -0.04, with a standard error of 0.1. The graphs do not show evidence of any significant discontinuities in the running variable at the RD cutoff.

Figure A.6: Election of women leaders decreases monthly fire incidence

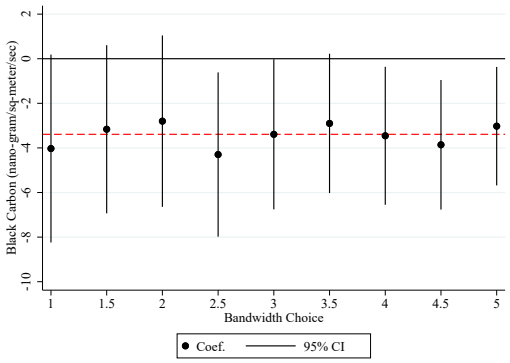
Notes: This figure presents the effects of a narrow election win for women against men on monthly fire counts. We find that a narrow election win for women against men decreases monthly fire counts by 13%. All regressions include state-by-election-year and year fixed effects. Standard errors are clustered at assembly level. 95% confidence interval is presented.

Figure A.7: Decrease in monthly fire incidence robust to bandwidth choice

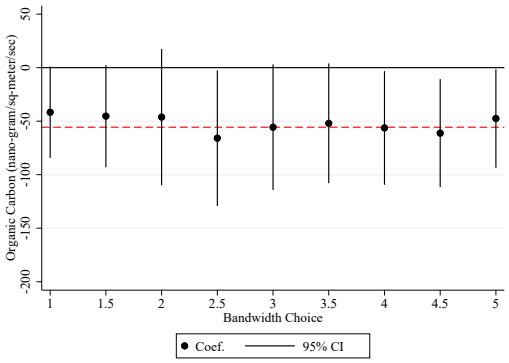


Notes: This figure presents the effects of narrow election win for women against men on monthly fire counts for badwidths between 1% and 5%. We find the result that narrow election win for women against men decreases monthly fire counts is robust to bandwidth choice. All regressions include state-by-election-year and year fixed effects, and present RD estimates for a bandwidth of 3% in vote margin. Standard errors are clustered at assembly level. 95% confidence intervals are presented.

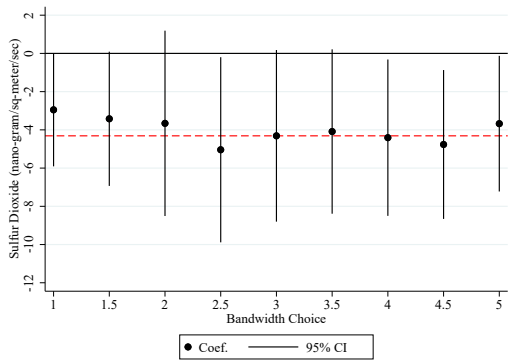
Figure A.8: Decrease in monthly maximum emissions robust to bandwidth choice



(a) Black Carbon



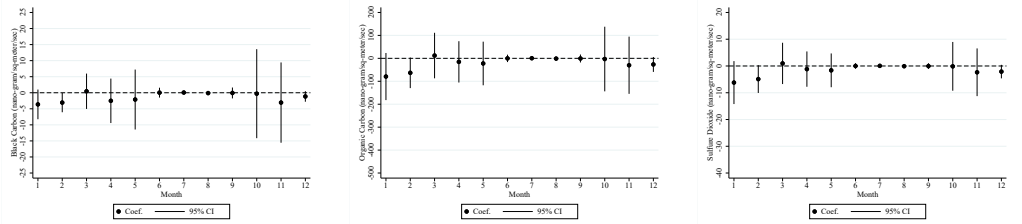
(b) Organic Carbon



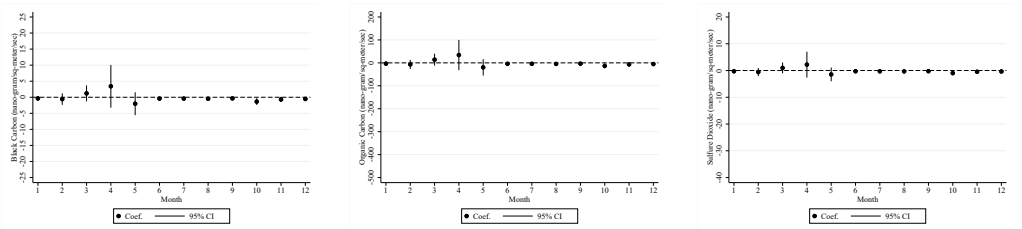
(c) Sulfur Dioxide

Notes: This figure presents the effects of narrow election win for women against men on monthly maximum black carbon, organic carbon, and sulphur dioxide for badwidths between 1% and 5%. We find the result that narrow election win for women against men decreases monthly maximum particulate emission is robust to bandwidth choice. All regressions include state-by-election-year and year fixed effects, and present RD estimates for a bandwidth of 3% in vote margin. Standard errors are clustered at assembly level. 95% confidence intervals are presented.

Figure A.9: Effects of election of women leaders on monthly mean particulate emissions concentrated in districts that grow rice or sugarcane during the harvest and post-harvest months (Oct-May)



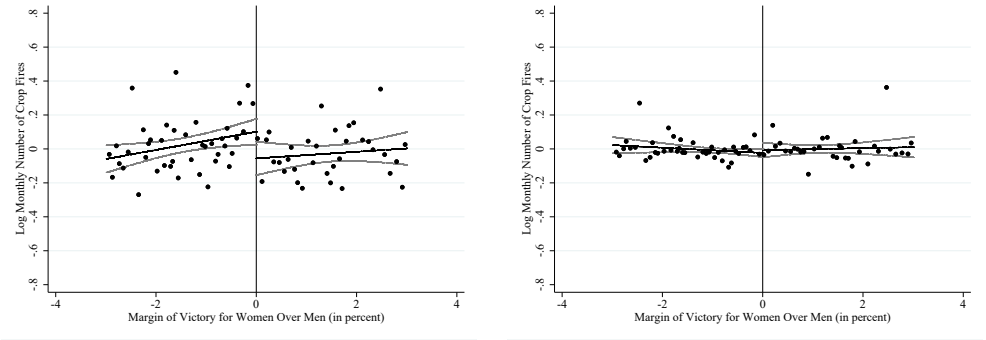
(a) Mean BC: High Rice or High Sugar (b) Mean OC: High Rice or High Sugar (c) Mean SO2: High Rice or High Sugar



(d) Mean BC: Low Rice and Low Sugar (e) Mean OC: Low Rice and Low Sugar (f) Mean SO2: Low Rice and Low Sugar

Notes: This figure presents the month-by-month estimates of the effect of narrow election win for women against men on monthly mean black carbon, organic carbon, and sulphur dioxide for (i) districts with high rice or high sugarcane production where crop fires would be expected to be more prevalent, and (ii) districts with low rice and low sugarcane production, respectively. "High rice or high sugar" sample consists of districts which had high (above sample median) share of cropped area under rice or sugarcane at baseline (2001). "Low rice and low sugar" consists of districts which had low (above sample median) share of cropped area under rice and sugarcane at baseline (2001). We find the effect of narrow election win for women against men on particulate emissions is concentrated in districts with high rice or high sugarcane production during the harvest and post harvest months (Oct-May). All regressions include state-by-election-year and year fixed effects, and present RD estimates for a bandwidth of 3% in vote margin. Standard errors are clustered at assembly level. 95% confidence intervals are presented.

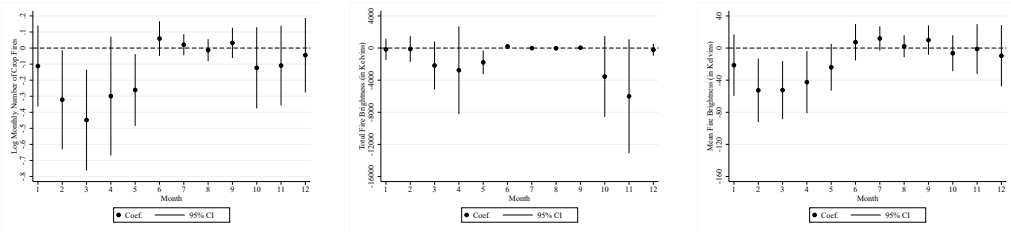
Figure A.10: Effects of election of women leaders on fire incidence concentrated in the harvest and post-harvest months



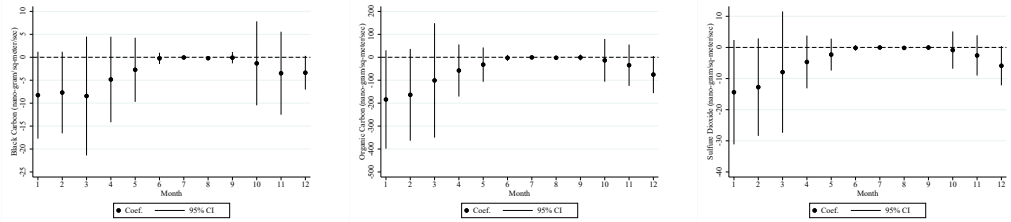
(a) Fires: Oct-May (b) Fires: June-Sep

Notes: This figure presents the effects of a narrow election win for women against men on monthly fire counts for (i) harvest and post-harvest months (Oct-May) and (ii) rest of the year (June-Sep), respectively. We find that a narrow election win for women against men decreases monthly fire counts during the harvest and post-harvest months, with null effects during the rest of the year. All regressions include state-by-election-year and year fixed effects, and present RD estimates for a bandwidth of 3% in vote margin. Standard errors are clustered at assembly level. 95% confidence intervals are presented.

Figure A.11: Effects of election of women leaders on fire activity and particulate emissions concentrated in the harvest and post-harvest months



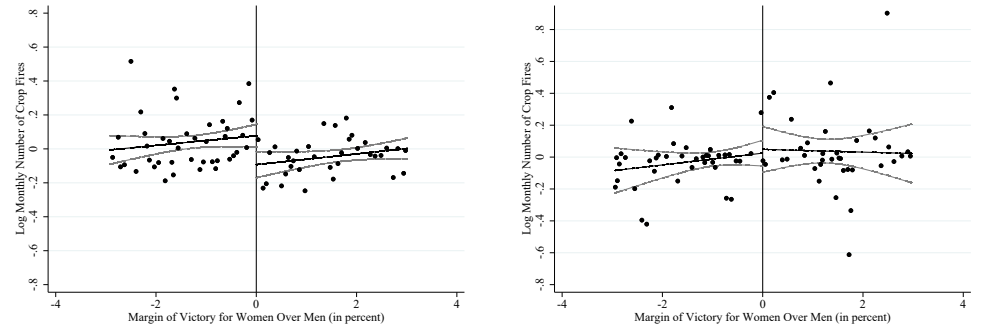
(a) Fires (b) Total Fire Brightness (c) Mean Fire Brightness



(d) Max Black Carbon (e) Max Organic Carbon (f) Max Sulfur Dioxide

Notes: This figure presents the month-by-month estimates of the effect of a narrow election win for women against men on fire counts, total and mean fire brightness, and maximum black carbon, organic carbon, and sulphur dioxide for (i) harvest and post-harvest months (Oct-May) and (ii) rest of the year (June-Sep), respectively. We find narrow election win for women against men decreases monthly fire counts during the harvest and post-harvest months, with null effects during the rest of the year. All regressions include state-by-election-year and year fixed effects, and present RD estimates for a bandwidth of 3% in vote margin. Standard errors are clustered at assembly level. 95% confidence intervals are presented.

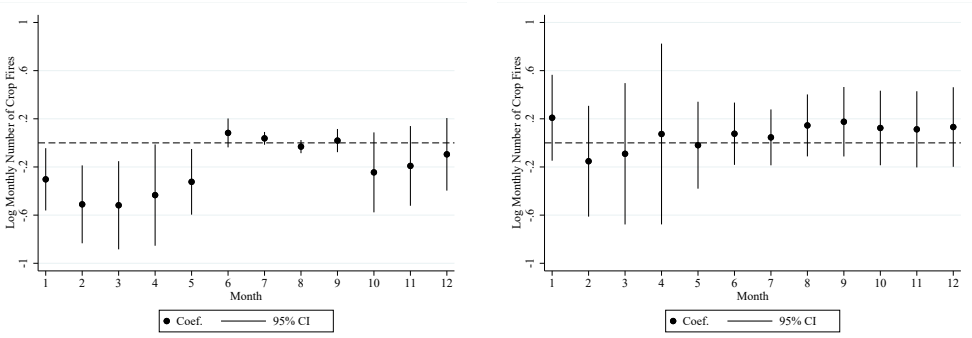
Figure A.12: Effects of election of women leaders on fire incidence concentrated in districts that grow rice or sugarcane



(a) Fires: High Rice or High Sugar (b) Fires: Low Rice and Low Sugar

Notes: This figure presents the effects of narrow election win for women against men on monthly fire counts for (i) districts with high rice or high sugarcane production where crop fires would be expected to be more prevalent and (ii) districts with low rice and low sugarcane production, respectively. "High rice or high sugar" sample consists of districts which had high (above sample median) share of cropped area under rice or sugarcane at baseline (2001). "Low rice and low sugar" consists of districts which had low (above sample median) share of cropped area under rice and sugarcane at baseline (2001). We find narrow election win for women against men decreases monthly fire counts by 21% in high rice or high sugarcane districts, with null effects in districts with low rice and low sugarcane. All regressions include state-by-election-year and year fixed effects, and present RD estimates for a bandwidth of 3% in vote margin. Standard errors are clustered at assembly level. 95% confidence intervals are presented.

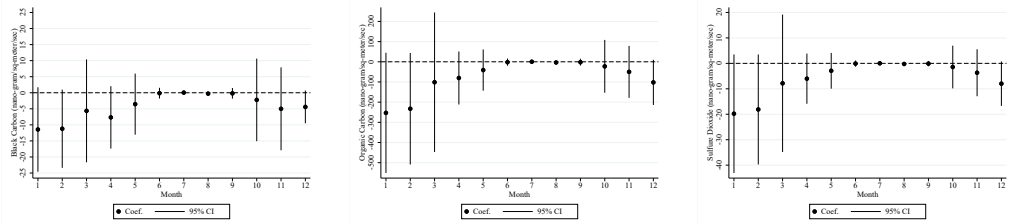
Figure A.13: Effects of election of women leaders on fire incidence concentrated in districts that grow rice or sugarcane during the harvest and post-harvest season (Oct-May)



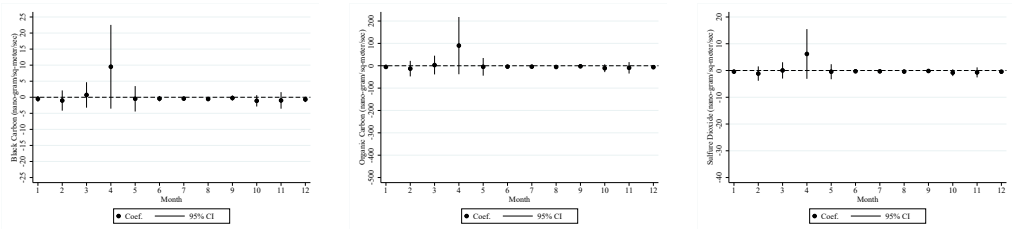
(a) Fires: High Rice or High Sugar (b) Fires: Low Rice and Low Sugar

Notes: This figure presents the month-by-month estimates of the effect of narrow election win for women against men on monthly fire counts for (i) districts with high rice or high sugarcane production where crop fires would be expected to be more prevalent, and (ii) districts with low rice and low sugarcane production, respectively. "High rice or high sugar" sample consists of districts which had high (above sample median) share of cropped area under rice or sugarcane at baseline (2001). "Low rice and low sugar" consists of districts which had low (above sample median) share of cropped area under rice and sugarcane at baseline (2001). We find the effect of narrow election win for women against men on crop fire incidence is concentrated in districts with high rice or high sugarcane production during the harvest and post harvest months (Oct-May). All regressions include state-by-election-year and year fixed effects, and present RD estimates for a bandwidth of 3% in vote margin. Standard errors are clustered at assembly level. 95% confidence intervals are presented.

Figure A.14: Effects of election of women leaders on monthly maximum particulate emissions concentrated in districts that grow rice or sugarcane during the harvest and post-harvest months (Oct-May)



(a) Max BC: High Rice or High Sugar (b) Max OC: High Rice or High Sugar (c) Max SO2: High Rice or High Sugar



(d) Max BC: Low Rice and Low Sugar (e) Max OC: Low Rice and Low Sugar (f) Max SO2: Low Rice and Low Sugar

Notes: This figure presents the month-by-month estimates of the effect of narrow election win for women against men on monthly maximum black carbon, organic carbon, and sulphur dioxide for (i) districts with high rice or high sugarcane production, where crop fires would be expected to be more prevalent, and (ii) districts with low rice and low sugarcane production, respectively. "High rice or high sugar" sample consists of districts which had high (above sample median) share of cropped area under rice or sugarcane at baseline (2001). "Low rice and low sugar" consists of districts which had low (above sample median) share of cropped area under rice and sugarcane at baseline (2001). We find the effect of narrow election win for women against men on particulate emissions is concentrated in districts with high rice or high sugarcane production during the harvest and post harvest months (Oct-May). All regressions include state-by-election-year and year fixed effects, and present RD estimates for a bandwidth of 3% in vote margin. Standard errors are clustered at assembly level. 95% confidence intervals are presented.