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Short-run environmental effects of COVID-19: Evidence from forest fires

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ABSTRACT

The outbreak of the 2019 novel coronavirus disease (COVID-19) has raised questions about changes in economic production and subsequent effects on the environment. This article employs satellite data on real-time active fire locations in Nepal to evaluate the short-term environmental effects of COVID-19. Using plausibly exogenous variation in the number of reported COVID-19 cases across the country, this study finds that the incidence of COVID-19 led to a strong negative effect on the incidence of human-induced forest fires. Results indicate that an additional reported case of COVID-19 resulted in a 4.54% decrease in the number of forest fire incidents and a 11.36% reduction in fire radiative power associated with these events. Findings also show that districts with smaller areas of community-managed forests per capita experienced a 8.11% decrease in the number of forest fire incidents. Restrictions on movement of people across districts in response to the pandemic likely reduced the incidence of forest fire events in Nepal. These short-run estimates of environmental benefits, which do not account for negative consequences of the virus outbreak on health and labor market outcomes, partially offset the social cost of pandemics in the developing world.

1. Introduction

The outbreak of the 2019 novel coronavirus disease (COVID-19) is an unprecedented health crisis that has affected economic and social development across the globe (Zhou et al., 2020). According to the World Health Organization (WHO), the virus has caused over 15 million confirmed cases and 619,150 confirmed deaths in about 213 countries by July 23, 2020. Although the WHO declared a pandemic on March 11, 2020, relatively little evidence exists on how governments and individuals have altered their behavior in response to the threat (Chater, 2020). Such behavioral changes may influence the environment (Wang, Chen, Zhu, Wang, & Zhang, 2020), yet much remains unknown about the short-term environmental effects of the pandemic in the developing world. Among developing countries, Nepal faces the recurring threat of forest fires that damage around 200,000 hectares of land every year (Kantipur, 2019). Majority of these fires are a result of deliberate burning by grazers and non-timber forest product collectors, human negligence, and accidents (Kunwar & Khaling, 2006). Forest fires in Nepal result in natural regeneration and cause forest degradation, in addition to affecting livelihoods of people and damaging physical infrastructure (Matin et al., 2017). The ongoing COVID-19 outbreak has raised concerns about changes in economic produc-

tion, restrictions on movement of humans and subsequent effects on the incidence of forest fires in Nepal.

This article employs satellite data on real-time active fire locations in Nepal to evaluate the short-term environmental effect of COVID-19. Using plausibly exogenous variation in the number of reported COVID-19 cases across the country, the study employs a site-by-day national longitudinal dataset to determine the causal impact of the virus outbreak on three different measures of forest fire outcomes. These three measures include the brightness of the forest fire (a proxy for the severity), the fire radiative power of the forest fire (a proxy for the intensity) and the number of forest fire events (a proxy for the incidence). The empirical specification consists of a suite of fixed effects at different levels to isolate the effect of the pandemic from potentially confounding factors that also influence forest fire outcomes such as daily variation in temperature, land use and population. The model accounts for district fixed effects, day fixed effects, month-by-province fixed effects and month-by-zone fixed effects to control for both time-invariant and time-varying unobservable determinants of forest fire outcomes. This study also conducts additional robustness checks, including a placebo test, to strengthen the validity of the estimates on changes in three different measures of forest fire outcomes.

Results indicate that an additional reported case of COVID-19 resulted in a decrease of 1.94 Kelvins (K) in the brightness of forest fires, a 11.36% decrease in the fire radiative power associated with forest fires and a 4.54% decrease in the number of forest fire inci-

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dents. The overall effect of the pandemic on the number of forest fire incidents is statistically significant at the 10% level. The findings are robust across multiple empirical specifications that control for day fixed effects, district fixed effects, month-by-province fixed effects and month-by-zone fixed effects. The positive effects on the number of forest fire incidents are more pronounced among (i) districts with the lower area of community-managed forest per capita and (ii) districts located in the Bagmati Province. Estimates further imply that the nationwide lockdown may have a significant effect on the reduction in the brightness of forest fires and the fire radiative power associated with these events. A back-of-the-envelope calculation suggests that COVID19-induced reduction in the number of forest fire incidents resulted in an economic gain of 360 Rupees (Rs.) per household, equivalent to 3 US Dollars per household in Nepal. These estimates do not account for several other short-term or long-term negative consequences of the virus outbreak on health outcomes. Overall, findings from this study suggest that environmental benefits from reduced incidence of forest fires may partially offset the social cost of pandemics in the developing world.

This article makes a number of contributions to the literature on the short-term impact of COVID-19 on different measures of environmental quality. First, it contributes to a growing literature on the impact of the coronavirus pandemic on emissions, the natural environment and environmental policy (Helm, 2020). Majority of recent studies have focused on repercussions of COVID-19 on air pollution (Zangari, Hill, Charette, & Mirowsky, 2020; Muhammad, Long, & Salman, 2020; Marlier, Xing, Zhu, & Wang, 2020; Bao & Zhang, 2020; Rodríguez-Urrego & Rodríguez-Urrego, 2020), energy consumption (Aruga, Islam, & Jannat, 2020) and surface water quality (Yunus, Masago, & Hijioka, 2020) during the lockdown across the globe. For example, Zangari et al. (2020) report a 36% decrease in $PM_{2.5}$ concentrations and a 51% reduction in NO_2 concentrations in New York City in the aftermath of the COVID-19 shutdown. At the global scale, Rodríguez-Urrego and Rodríguez-Urrego (2020) document a 12% decrease in particulate matter emissions across 50 capital cities in the world during the lockdown induced by COVID-19. According to Marlier et al. (2020), a significant reduction in NO_2 emissions from transportation and industrial pollution sources has resulted in air quality improvements during the COVID-19 pandemic. To the author's knowledge, this is the first study in the developing world that explores the implications of the virus outbreak on changes in the incidence of forest fires. This is important because forest fires can exacerbate environmental justice, causing significant changes on deforestation, air quality and human health (Rosales-Rueda & Triyana, 2019; Bali, Mishra, & Singh, 2017; Quah, 2002).

Second, it sheds light on a combination of factors that may determine the incidence and the severity of forest fires in the aftermath of the COVID-19 pandemic. Prior literature has focused on estimating the economic costs of firest fires in different settings (Hansen & Naughton, 2013; Donovan, Champ, & Butry, 2007; Loomis, 2004). For example, Edwards, Naylor, Higgins, and Falcon (2020) combine detailed geospatial data on fire with rich administrative data to find that Indonesian villages, which tend to be more remote, less developed and share a history of using fire for agricultural purposes, are more likely to burn. In the context of Nepal, Sapkota (2017) reports that an average forest fire leads to an estimated economic loss of approximately 1.093 million US dollars, while not accounting for the cost of environmental damage and the destruction of flora and fauna. This study shows that economic benefits from reduced number of forest fire incidents during the virus outbreak differ across districts with high and low areas of community-managed forests per capita. Relatedly, prior literature has shown that community-managed forestry can enhance participation among forest users, improve food consumption and reduce

deforestation (Oldekop, Sims, Karna, Whittingham, & Agrawal, 2019; Paudel, 2018). This article provides evidence that institutional characteristics that govern different areas of community-managed forests at the district level may play an important role in reducing the incidence of forest fires in the aftermath of the virus outbreak.

Finally, the study contributes to an influx of quasi-experimental research design-based studies assessing both short-run and long-run effects of plausibly exogenous shocks in a developing country setting. Although the Himalayan Region is considered to be vulnerable to both natural and man-made hazards, previous studies exploring the short-term and long-term impact of an exogenous shock in the region have focused on health, education and agriculture (Nandi, Mazumdar, & Behrman, 2018; Paudel & Ryu, 2018; Paudel & Crago, 2017). To the author's knowledge, only two empirical studies have explored forest fires across all the districts of Nepal: Matin et al. (2017) estimate the spatial and temporal patterns of forest fires in Nepal using the historical fire incidence data and Paudel (2020) evaluates the linkage between the incidence of forest fires and property prices in Nepal. The findings from this study are crucial in the context of Nepal, given that potential economic gain from reduced fires is associated with a decrease in damage of physical infrastructure, an increase in air quality and an availability of forest resources among local people for their livelihoods. Policy makers, interested in evaluating the social cost of pandemics in the developing world, can benefit from the short-run estimates of economic gains associated with the decreased number of forest fires that partially offset the adverse effects of COVID-19.

The remainder of the paper is structured as follows. Section 2 presents a brief background on Nepal's recent developments on COVID-19 followed by the literature review on forest fires. Section 3 outlines the empirical strategy employed in the study. Section 4 presents the empirical findings and discusses potential economic and policy implications and Section 5 concludes.

2. Background

2.1. Study Area

Nepal is a land-locked country with a total area of 147,181 square kilometers surrounded by India on three sides and China to the north. Topographically, Nepal is divided into three distinct ecological zones: mountain, hill, and *terai* (or plains). According to 2011 Population Census, the population of Nepal stands at 26.6 million. For administrative purposes, Nepal is divided into seven provinces (Province 1, Province 2, Bagmati Province, Gandaki Province, Province 5, Karnali Province and Far-Western Province) and 77 administrative districts. Before 2015, the country consisted of 14 zones and 5 development regions (Eastern, Central, Western, Mid-western, and Far-western). According to Paudel (2018), forests cover almost forty percent of the country, one-fourth of which is comprised of community-managed forests[1].

The first coronavirus case in Nepal was reported on January 24th, 2020. Nepal's Ministry of Health and Population took different steps to battle the spread of the virus. The government established monitoring teams and health desks at major border checkpoints and cities such as Kathmandu, Lumbini, Chitwan, Pokhara, Bhairahawa and Ilam (Shrestha, Shrestha, Khanal, & Bhuvan, 2020). To facilitate timely detection of potential cases, the government also started a 24-h operating health desk in the only interna-

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[1] Community-managed forests in Nepal are areas of nationally owned forestland handed over to local community-based groups for meeting bare subsistence community needs and conserving forests.

tional airport of the country in Kathmandu, which consisted of screening facility with infrared thermometers along with an ambulance service (Shrestha et al., 2020). According to the National Public Health Laboratory, the testing facility had access to only 1,000 testing kits provided by the World Health Organization with an ability to test 500 coronavirus cases per week (De Silva, 2020).

In response to the criticism of the state's inadequate precautionary measures over coronavirus, Nepal's government enforced a week-long lockdown on March 24, 2020, further extending it until April 22. This entailed a complete ban on international flights, closure of the country's 1,800-km border with India and shutting down of all non-essential government services. During the lockdown, one could go out of home only for purchasing essential food items or receiving medical treatment. According to Nepali Times, the lockdown did not affect the transportation of food, fuel and essential supplies from India into Nepal through four border crossings, with two of its checkpoints with China open for imports (Times, 2020). Recent reports also claim that the government took actions against 740 residents of Kathmandu, 79 two-wheelers and five four-wheelers for violating the lockdown order. Although the government created the Coronavirus Control and Treatment Fund to limit the spread of the virus, newspaper articles report that Nepal currently lacks resources to fight the disease (Ghimire, 2020). Table 1 gives a summary of province-level statistics related to the virus outbreak. According to Nepal's National Disaster Risk Reduction and Management Authority, there have been a total of 18,374 confirmed cases and 44 deaths in Nepal as of July 24, 2020. Nepal's government officially ended the COVID-19 lockdown on July 21, 2020.

2.2. Literature review

A fire entails the process of the ignition and the propagation (Scott, Bowman, Bond, Pyne, & Alexander, 2013). Potential fire ignitions, which are set by humans either deliberately or accidentally, are measured by the number of fire incidents. Propagation or the spread of the fire, as measured by the fire intensity, is determined by the moisture content of the combustible material at the location of the ignition, the wind, air temperature, humidity and landscape slope (Costa & Fonseca, 2017; Laurent, Mouillot, Moreno, Chao, & Ciais, 2019). There exists well-documented evidence on why fires burn differently in different regions (Matin et al., 2017; Biswas, Vadrevu, Lwin, Lasko, & Justice, 2015). Topographic factors (including elevation and land slope), wind, precipitation and temperature affect the ignition and the spread of fire. Specifically, slope influences how fast fire can rise. Among different factors that impact fire radiative power, vegetation cover represents the availability of fuel (Roy, 2003). Fire radiative power depicts the pixel-integrated radiant heat output of detected fires. The amount of radiant heat energy liberated per unit time is related with the rate at which fuel is being consumed. The brightness temperature of hotspot or active fire pixel is measured in Kelvin using the MODIS channels 21/22 and channel 31. The incidence of forest fire is strongly correlated with fire radiative power and the brightness temperature of detected fires.

Nepal provides a unique setting to study changes in the incidence and the severity of forest fires because the majority of forest fire events in the country are human-induced. According to Kunwar and Khaling (2006), deliberate burning among non-timber forest product collectors (58%), negligence (22%) and accidental causes (20%) are three primary factors behind the overall rise of human-induced forest fire incidents in Nepal. Historical data suggest that Nepal experiences forest fires during the dry season from November to June every year, with high concentrations during April and May (Matin et al., 2017). The number of forest fires has increased in Nepal in recent years, mostly affecting natural vegetation and human settlements (Parajuli et al., 2015). Recent Moderate Resolution Imaging Spectroradiometer (MODIS) data report that Nepal faced 47,000 forest fire incidents averaging fire radiative power (FRP) of 29.88 Megawatts between 2000 and 2019. According to Matin et al. (2017), unplanned burning of the undergrowth in the forest affects natural regeneration, causing forest degradation in the long-run. Forest fires also damage physical infrastructure and reduce the availability of forest resources among local people (Matin et al., 2017; Paudel, 2020). Kunwar and Khaling (2006) report that the degree of recovery and the need for rehabilitation interventions depend on the intensity and the frequency of burning across regions of Nepal.

3. Empirical Strategy

To assess the impact of COVID-19 on different measures of forest fires, this study estimates the following:

$$Fire_{ij} = \beta_0 + \beta_1.Case_j + \eta_j + \theta_d + \gamma_{mp} + \delta_{mz} + \epsilon_{ij} \qquad (1)$$

where $Fire_{ij}$ is a measure of forest fire incidence or severity in site i from province p during day j of a given month and a year. The measure includes: (i) brightness of the forest fire (measured in Kelvins), (ii) fire radiative power (FRP) associated with the forest fire (measured in MegaWatts), which gives the rate of radiant heat output from a fire and (iii) number of forest fire incidents based on the number of individual fires detected by MODIS satellites. These indicators account for the severity, the intensity and the incidence of forest fires. For example, the higher the FRP, the higher the intensity of the forest fire reported in site i. $Case_j$ gives the number of reported cases of COVID-19 during day j of a given month and a year.

β_1 is the coefficient of interest in the estimating equation above. β_1 gives the change in a measure of forest fire incidence or severity for every unit additional increase in the number of reported cases of COVID-19. The hypothesis is that as the number of virus-related cases increased, restrictions on movement of people across locations intensified during the lockdown. The limited movement induced a behavioral change among individuals, causing a decrease in the frequency of outdoor activity as well as human-induced ignitions of fire. As explained in Section 2.2, the change in incidence of forest fires has direct consequences on the magnitude of fire radiative power and brightness, conditional on factors such as elevation, slope, vegetation cover and time of the day.

Five methodological issues are worth highlighting. First, η_j is a vector of day-level dummy variables that indirectly control for unobservable determinants of forest fire characteristics such as daily variation in temperature, precipitation, wind speed and direction that may vary across days in a given site. This is also important because economic circumstances within districts, provinces and zones in the aftermath of the COVID-19 pandemic are fluid and are likely to change on a day-by-day basis. Incorporating day fixed effects in the empirical specification accounts for time-varying unobservable determinants of forest fire outcomes at the day level.

Second, θ_d is a vector of district-level dummies that account for geographical heterogeneity and unobserved time-invariant differences in characteristics across districts such as differential population densities, political stability and institutional strength.[2] If a certain district with a strong institutional support exhibits a lower risk of the virus outbreak as well as a higher likelihood of preventing forest fires, it is necessary to control for unobserved factors such as the institutional strength when evaluating the impact of the virus outbreak on fire-related outcomes.

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[2] For example, Paudel and de Araujo (2017) report that district-level variation in unobserved factors can influence a wide variety of socioeconomic outcomes, including economic empowerment.

Table 1
Summary statistics on the status of COVID-19 in Nepal.

Province	Quarantined		Isolated		Tests
	Beds (1)	Sick Individuals (2)	Beds (3)	Sick Individuals (4)	Swab (5)
Province 1	8,639	2,008	480	40	1,919
Province 2	25, 535	9,490	1,470	1,216	9,747
Bagmati	6,833	1,591	1,048	108	8,338
Gandaki	6,342	2,253	270	52	234
Province 5	38,679	15,299	1,692	396	10,941
Karnali	13,148	3,292	1,380	249	3,374
Far Western	54,201	15,829	3,354	1,922	1,153

Note: Statistics available from Nepal's Ministry of Health and Population as of 07/20/2020.
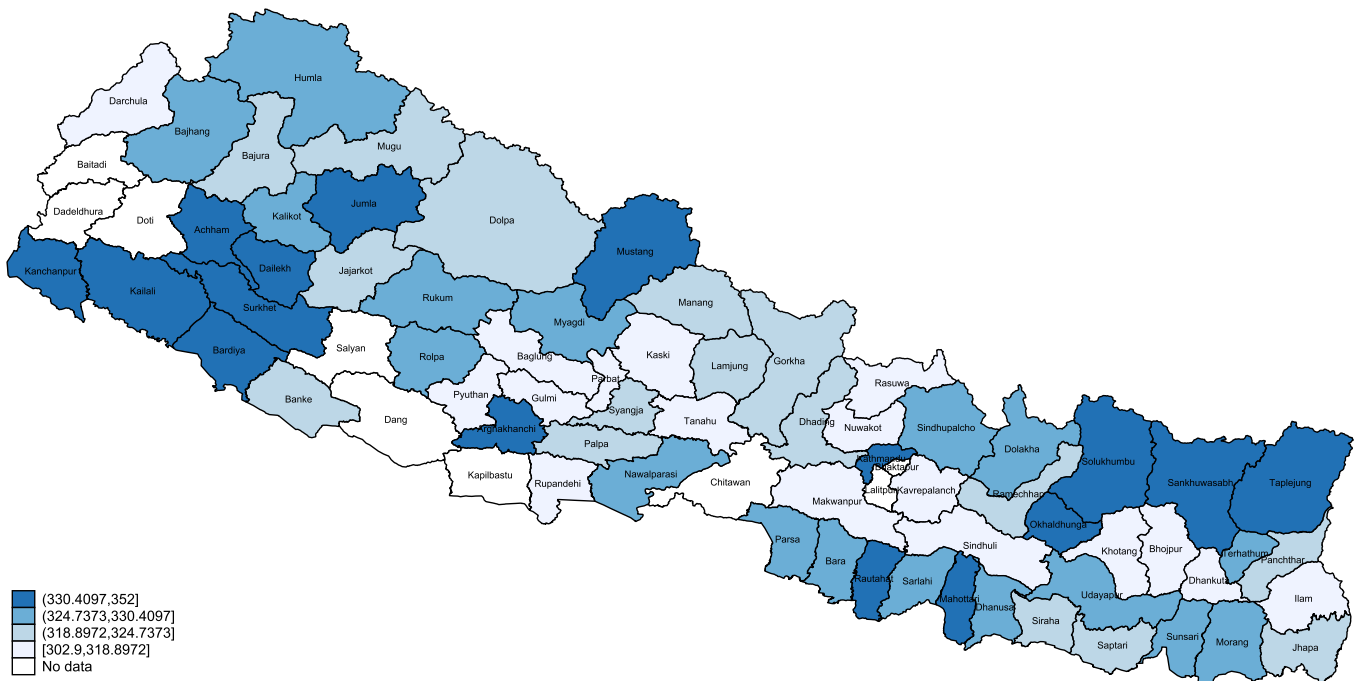

Fig. 1. Geographical heterogeneity in the brightness of forest fires in Nepal.

Third, δ_{mz} includes month-by-zone fixed effects, which account for any month-specific shocks such as earthquakes, macroeconomic conditions, governmental change that are common across sites in a given zone during the month of a given year. δ_{mp} accounts for month-by-province fixed effects, which control for time-varying differences in forest fire outcomes that are common across sites in a given province.

Fourth, a limited number of testing facilities in Nepal may have resulted in fewer reported cases of the virus. It is also likely that actual rates of COVID-19 infection may exceed the number of confirmed cases reported (Li et al., 2020), suggesting that coefficient estimates generated from the study may represent an underestimate of the link between virus infection and forest fire outcomes. Relatedly, while fewer reported cases may imply lower intensity of the virus outbreak, there exists well-documented evidence on how individuals and governments responded swiftly to mitigate the adverse effects of the pandemic (Shrestha et al., 2020). To further account for potential heterogeneous underreporting across space and time, the empirical specification includes a suite of fixed effects that vary across both spatial locations and time periods.

Finally, the strict exogeneity assumption associated with the virus outbreak may be disputable if the number of reported virus cases are potentially correlated with a number of unobservable characteristics of a region. To address this issue, the panel nature of data employed in the study allows for placebo tests to quantify the degree to which the intensity of virus outbreak affects forest fire events (see Section 4.4). Lack of statistical significance in coefficient estimates in the placebo test during a pre-COVID19 time period reinforces the exogeneity assumption, suggesting that significant differences in the incidence of forest fire events estimated from Eq. (1) can be directly attributed to the virus outbreak.

4. Data and results

The core analysis of the study is based on three primary data types: (i) active fire locations, (ii) COVID-19 confirmed cases and (iii) geographical boundaries within Nepal. The satellite data on real-time active fire locations from December 4th, 2019 to April 9th, 2020 are available from the Fire Information for Resource Management System (FIRMS). [3]

The location of active fires represents the center of a 1 km pixel that is flagged as containing one or more fire incidences within the

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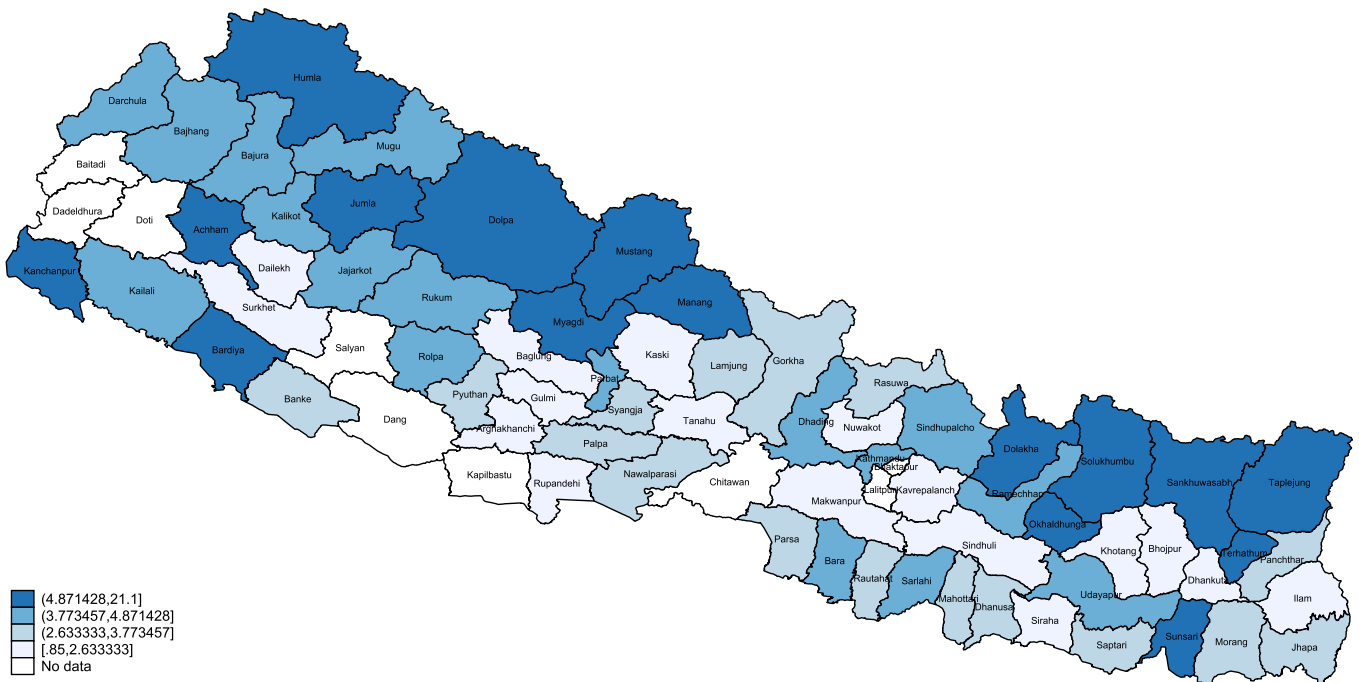[3] The data set can be downloaded at: https://firms.modaps.eosdis.nasa.gov/.

Fig. 2. Geographical heterogeneity in the fire radiative power associated with forest fires in Nepal.
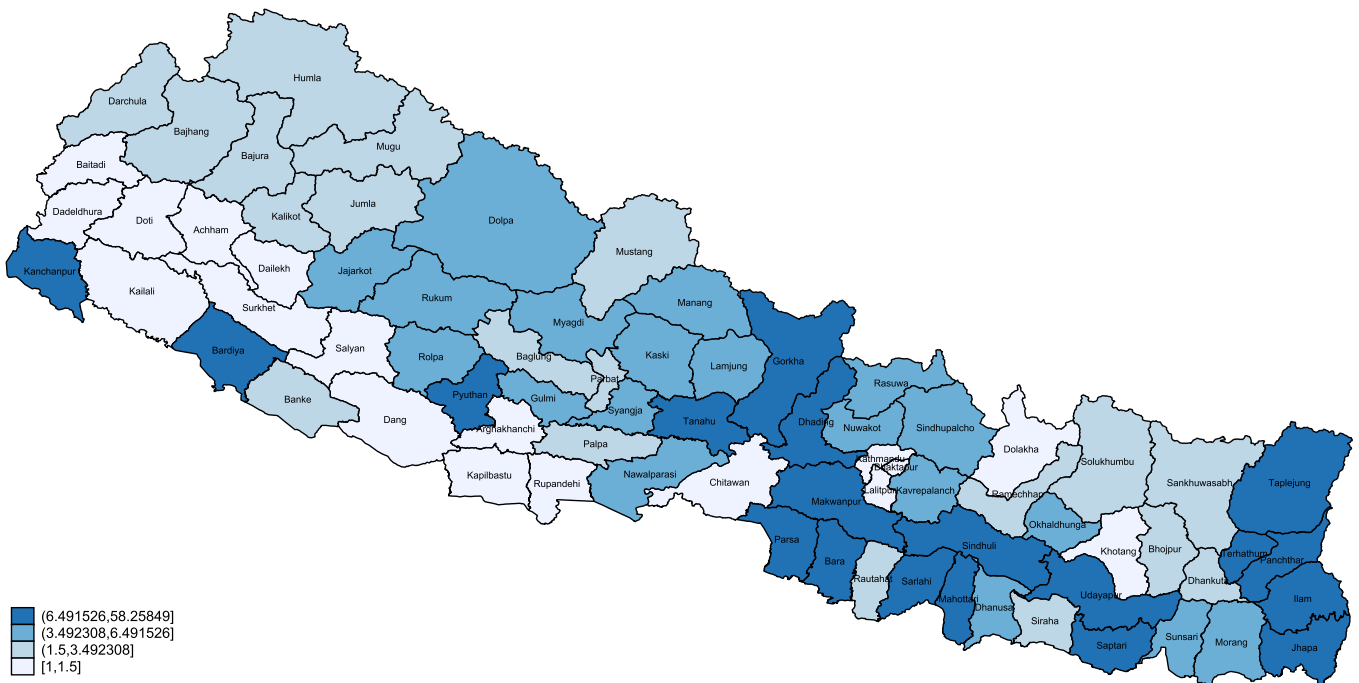

**Fig. 3.** Geographical heterogeneity in the number of forest fire incidents in Nepal.

pixel. The analysis uses the number of daily new COVID-19 cases in Nepal assembled by the Johns Hopkins University Center for Systems Science and Engineering (Dong, Du, & Gardner, 2020), in conjunction with statistics from Nepal's Ministry of Health and Population, for the period between January 24th, 2020 to April 9th, 2020. Finally, the analysis also uses geographical shapefiles of Nepal's provinces available from the Database of Global Administrative Areas (GADM). [4]

There are some caveats regarding satellite data on real-time active fire locations used in this study. First, multiple fire incidences within one pixel area are reported as a single incidence. This is because active fires "are detected by calculating the thermal anomalies on a pixel 1X1 km in size and the location of the fire is reported as the center of the pixel" (Matin et al., 2017). Second, minimum detectable fire size is a function of many different variables such as land surface temperature, cloud cover, amount of smoke and wind direction (Giglio, Descloitres, Justice, & Kaufman, 2003; Giglio et al., 2008; Matin et al., 2017). It is also pos-
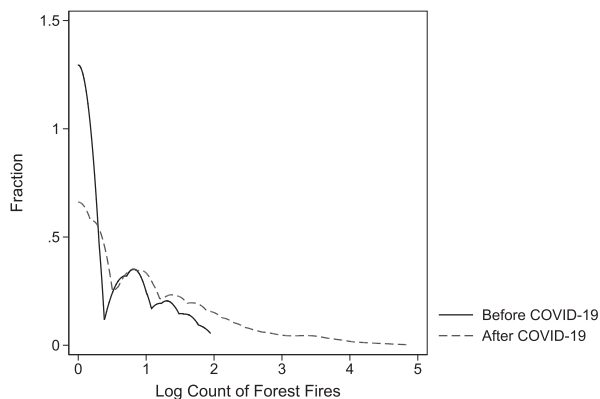
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[4] The data set can be downloaded at: https://gadm.org/data.html
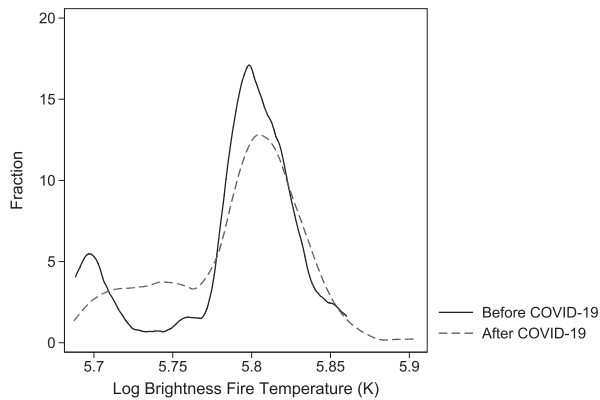
(a) Brightness
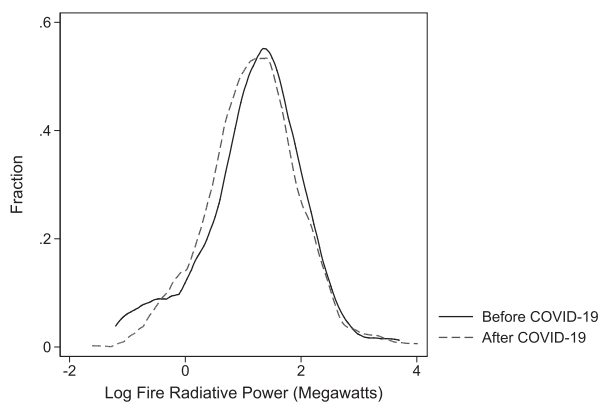
(b) Fire radiative power

(c) Number of forest fires

Fig. 4. Density plots of different indicators of forest fires in Nepal.

Table 2
Impact of COVID-19 on indicators of forest fires in Nepal.

	Panel A, Dependent Variable: Brightness		
	(1)	(2)	(3)
COVID-19 Case	−2.5071***	−2.6119***	−1.9497***
	(0.8994)	(0.7314)	(0.3901)
N	4349	4349	4349
R-Squared	0.2326	0.2499	0.2324
Day fixed effects	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes
Year-by-zone fixed effects	Yes	No	No
Month-by-zone fixed effects	No	Yes	No
Month-by-province fixed effects	No	No	Yes
	Panel B, Dependent Variable: Log Fire radiative power		
	(1)	(2)	(3)
COVID-19 Case	−0.1338***	−0.1508***	−0.1136***
	(0.0392)	(0.0436)	(0.0223)
N	4349	4349	4349
R-Squared	0.2584	0.2740	0.2574
Day fixed effects	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes
Year-by-zone fixed effects	Yes	No	No
Month-by-zone fixed effects	No	Yes	No
Month-by-province fixed effects	No	No	Yes
	Panel C, Dependent Variable: Log Forest Fire Events		
	(1)	(2)	(3)
COVID-19 Case	−0.0454*	−0.0468*	−0.0454*
	(0.0266)	(0.0266)	(0.0270)
N	4349	4349	4349
R-Squared	0.7813	0.8087	0.8431
Day fixed effects	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes
Year-by-zone fixed effects	Yes	No	No
Month-by-zone fixed effects	No	Yes	No
Month-by-province fixed effects	No	No	Yes

Notes: Each regression specification in Column (1) includes day fixed effects, district fixed effects and year-by-zone fixed effects. The specification in Column (2) includes day fixed effects, district fixed effects and month-by-zone fixed effects. The specification in Column (3) includes day fixed effects, district fixed effects and month-by-province fixed effects. Standard errors, in parentheses, are clustered at the district level. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

sible that the fire may have started and ended between satellite observations. Finally, confidence values associated with the quality of individual fire pixels included in the fire product are set to low, nominal and high.

4.1. Summary statistics

Figs. 1–3 show the geographical heterogeneity of three indicators of forest fires: brightness of forest fires, fire radiative power

(FRP) of forest fires and counts of forest fire incidents. Fig. 1 shows that the average brightness of a forest fire in a district is 286 Kelvin (K) with a standard deviation of 106 K and a maximum record of 352 K. Fig. 2 indicates that the brightness of a forest fire is positively correlated with the average fire radiative power associated with a forest fire among districts such as Taplejung, Sankhuwasabha and Solukhumbu in Province 1. On an average, districts in Nepal experienced forest fires with a mean FRP of 4.04 Megawatts, a standard deviation of 3.37 and a maximum record of 21.1. These two indicators reflect the intensity and the severity of forest fire incidents in Nepal. Fig. 3 shows that districts in Bagmati and Gandaki Provinces experienced forest fires more often, with maximum values ranging between 6 and 58. The average count of forest fire incidents in a sample district is 7.4, with a standard deviation of 11.2.

Fig. 4 presents density plots of forest fire outcomes before and after the first reported case of coronavirus. Fig. 4(a) shows that the sample consists of a higher proportion of forest fires with lower magnitudes of brightness during the post-coronavirus period. The distribution of the brightness of forest fires appears to be skewed to the left in both periods. Fig. 4(b) indicates that the distribution of the fire radiative power shifted to the left after the first reported coronavirus case, with a slight decrease in the mean value and almost no change in the standard deviation. Fig. 4(c) demonstrates

Table 3
Heterogenous impact of COVID-19 on indicators of forest fires in Nepal

| | Panel A, Dependent Variable: Brightness | | | |
| | Community Forestry Area Per Capita | | Provinces | |
	High (1)	Low (2)	Bagmati (3)	Non-Bagmati (4)
COVID-19 Case	−2.7986***	−1.0926**	−1.8450***	−0.0110
	(0.9641)	(0.4878)	(0.3057)	(0.4393)
N	2027	2169	1643	2706
R-Squared	0.2760	0.2597	0.2747	0.2587
Day fixed effects	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes
Month-by-zone fixed effects	Yes	Yes	Yes	Yes
	Panel B, Dependent Variable: Log Fire radiative power			
	Community Forestry Area Per Capita		Provinces	
	High (1)	Low (2)	Bagmati (3)	Non-Bagmati (4)
COVID-19 Case	0.0045	−0.0099	0.0140	−0.0174
	(0.0209)	(0.0264)	(0.0175)	(0.0270)
N	2027	2169	1643	2706
R-Squared	0.2731	0.3064	0.2422	0.3187
Day fixed effects	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes
Month-by-zone fixed effects	Yes	Yes	Yes	Yes
	Panel C, Dependent Variable: Log Forest Fire Events			
	Community Forestry Area Per Capita		Provinces	
	High (1)	Low (2)	Bagmati (3)	Non-Bagmati (4)
COVID-19 Case	0.0032	−0.0811***	−0.0651*	−0.0330
	(0.0425)	(0.0269)	(0.0330)	(0.0341)
N	2027	2169	1643	2706
R-Squared	0.7181	0.8609	0.8234	0.8137
Day fixed effects	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes
Month-by-zone fixed effects	Yes	Yes	Yes	Yes

Notes: Each regression specification in Columns (1), (2) and (3) includes day fixed effects, district fixed effects and month-by-zone fixed effects. Standard errors, in parentheses, are clustered at the district level. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

Table 4
Impact of the false treatment of COVID-19 on fire radiative power and number of forest fire incidents in Nepal.

| | Dependent Variable: | | | | | |
| | Log Fire Radiative Power | | | Log Forest Fire Events | | |
	(1)	(2)	(3)	(4)	(5)	(6)
False Treatment	0.8078	0.2116	0.4315	0.7397	−0.0178	−0.2328
	(0.5072)	(0.2730)	(0.4964)	(0.6500)	(0.2863)	(0.2992)
N	286	269	286	286	269	286
R-Squared	0.4874	0.5859	0.6827	0.6205	0.7793	0.9181
Day fixed effects	Yes	No	No	Yes	No	No
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Day-by-region fixed effects	No	Yes	No	No	Yes	No
Day-by-zone fixed effects	No	No	Yes	No	No	Yes

Notes: False treatment is a binary indicator that takes a value of 0 for the month of December 2019 and a value of 1 for the first three weeks of January 2020 when no coronavirus case was reported in Nepal. Each regression specification in Columns (1) and (4) includes day fixed effects and district fixed effects. Columns (2) and (5) include district fixed effects and day-by-region fixed effects. Columns (3) and (6) include district fixed effects and day-by-zone fixed effects. Standard errors, in parentheses, are clustered at the district level. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

a much wider spread of forest fire incidents after the first reported coronavirus case. This can be attributed to an influx of seasonal forest fire events reported in the month of April.

4.2. Impact of COVID-19 on human-induced forest fires

Table 2 presents the main regression results that evaluate the impact of the coronavirus outbreak on three indicators of forest fire events. Panel A shows that the brightness of a unique forest fire incident decreased by 1.9 K for every unit additional increase in

the reported case of coronavirus. The most preferred specification in Column (3) accounts for day fixed effects, district fixed effects and month-by-province fixed effects. Empirical estimates across three different empirical specifications from Column (1) to Column (3) are robust, suggesting that coronavirus outbreak led to a strong effect on the brightness of a forest fire in the short run.

Panel B of Table 2 finds that there is a strong association between the coronavirus outbreak and fire radiative power, a proxy for the intensity of a forest fire. The first three columns show a significant reduction in the average fire radiative power. In the

Table 5
Impact of normalized COVID-19 cases on forest fire events in Nepal.

	Dependent Variable: Log Forest Fire Events				
	(1)	(2)	(3)	(4)	(5)
Normalized COVID-19 Case	−0.1707*	−0.1774*	−0.1757*	−0.1711*	−0.1711*
	(0.0999)	(0.0994)	(0.0998)	(0.1018)	(0.1021)
N	4349	4271	4349	4349	4271
R-Squared	0.7813	0.7971	0.8087	0.8439	0.8444
Day fixed effects	Yes	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	No	No
Year-by-zone fixed effects	Yes	No	No	No	No
Month-by-region fixed effects	No	Yes	No	No	Yes
Month-by-zone fixed effects	No	No	Yes	Yes	Yes
Month-by-district fixed effects	No	No	No	Yes	Yes

Notes: A continuous normalized measure of COVID-19 cases is constructed by normalizing the number of cases with respect to the average and the standard deviation. Column (1) includes day fixed effects, district fixed effects and year-by-zone fixed effects. Column (2) includes day fixed effects, district fixed effects and month-by-region fixed effects. Column (3) includes day fixed effects, district fixed effects and month-by-zone fixed effects. Column (4) includes day fixed effects, month-by-zone fixed effects and month-by-district fixed effects. Column (5) includes day fixed effects, month-by-region fixed effects, month-by-zone fixed effects and month-by-district fixed effects. Standard errors, in parentheses, are clustered at the district level. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

most preferred specification in column (3), results indicate that average fire radiative power decreased by 11.36% for every unit additional increase in the reported case of coronavirus. Across all three specifications, the effect of the virus on the fire radiative power is negative, strong and statistically significant.

Panel C of Table 2 indicates that the number of forest fire incidents decreased significantly in response to the coronavirus outbreak. The naive specification in column (1), which does not account for month-varying fixed effects at the province level or at the zone level, shows that an additional unit increase in the reported case of coronavirus resulted in a 4.54% decrease in the number of forest fire incidents. Moving from left to right, the most preferred specification in column (3) shows that an additional increase in the coronavirus case reduced the number of forest fires by 4.54%. The three specifications show that forest fire incidents decreased significantly in response to the virus, ranging between 4.54% and 4.68%. It is worth pointing out that this decrease in the number of forest fire incidents is statistically significant only at the 10% level.

4.3. Heterogeneity in the impact of COVID-19 on human-induced forest fires

This section investigates the heterogeneity in the overall impact of coronavirus outbreak on human-induced forest fires across geographical locations with different characteristics. To explore differential effects of COVID-19, the study focuses on two different proxies that capture socioeconomic inequality in rural Nepal. First, there exists compelling evidence that community-managed forestry can enhance participation among forest users, improve food consumption and reduce deforestation (Oldekop et al., 2019; Paudel, 2018). To capture the role of community forestry, this study creates an indicator for high community forestry area per capita in a district. The indicator takes a value of 1 for districts that have higher than the median value of community-managed forest area per capita and zero for those that have smaller than the median value of community-managed forest area per capita. Second, the government's actions to reduce the spread of coronavirus have been more centered in the capital city of Kathmandu and neighboring districts in Bagmati Province. To explore region-level heterogeneity, this study divides the entire sample into two groups: Bagmati Province and non-Bagmati Province.

Table 3 breaks down the main regression results evaluating the impact of the coronavirus outbreak on indicators of forest fire events across four sub-samples: districts with high and low areas

of community-managed forests per capita, and districts belonging to Bagmati and non-Bagmati Province. Three results are worth highlighting: First, Panel A indicates that the coronavirus outbreak reduced the brightness of forest fires across districts with high and low community forestry area per capita and districts in Bagmati Province. Second, Panel B implies that there exists no heterogeneity in the impact of the virus on fire radiative power across all four sub-samples. Third, Panel C shows that the number of forest fire incidents decreased in response to COVID-19 only in districts with low community forestry area per capita and districts belonging to Bagmati Province. These results indicate that Bagmati Province experienced positive environmental benefits from the reduction in the severity and the incidence of forest fire events in response to the coronavirus outbreak.

The takeaway from the analysis on differences in the number of forest fire events between districts with high and low areas of community-managed forests per capita is threefold. First, no significant effect on the number of forest fire incidents among districts with high areas of community-managed forests per capita in the aftermath of the pandemic suggests that these districts may not have the problem of fires even prior to the pandemic. It is also likely that some of these districts are well-equipped to control fire incidence and its spread (Niraula, Gilani, Pokharel, & Qamer, 2013). Second, a significant effect on the number of forest fire incidents among districts with low areas of community-managed forests per capita indicates that the positive effect of the pandemic on fires does not exist across the entire country. This finding has implications for cost-benefit analysis regarding short-term and long-term environmental repercussions of the pandemic. Finally, this analysis calls for an in-depth long-term study on whether there is a differential effect of the pandemic on the incidence of fires between community-managed forests and government-managed forests.

4.4. Robustness checks

This sub-section performs two additional robustness checks to further investigate the linkage between the coronavirus outbreak and the incidence and the severity of forest fire events.

First, this study runs a placebo test to test the validity of the main estimates documented in Table 2. This analysis takes advantage of a binary variable reflecting the false incidence of the coronavirus in a pre COVID-19 time period. The study assigns the false treatment of COVID-19 to the month of December 2019 and the first three weeks of January 2020 when no coronavirus case was
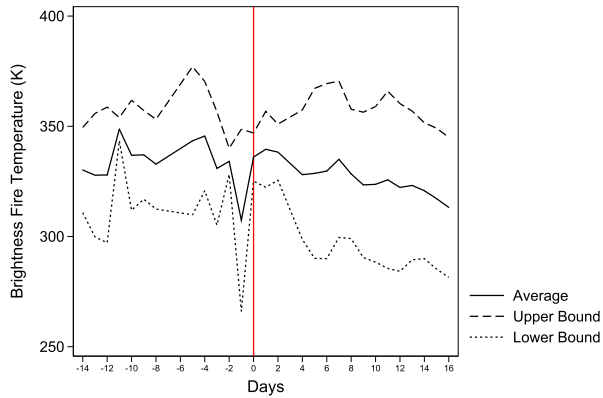
(a) Brightness
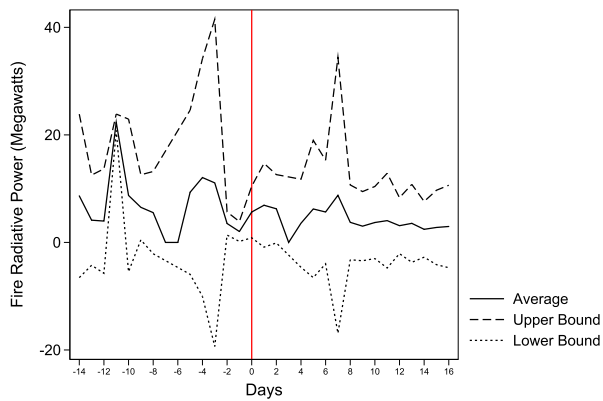
(b) Fire radiative power
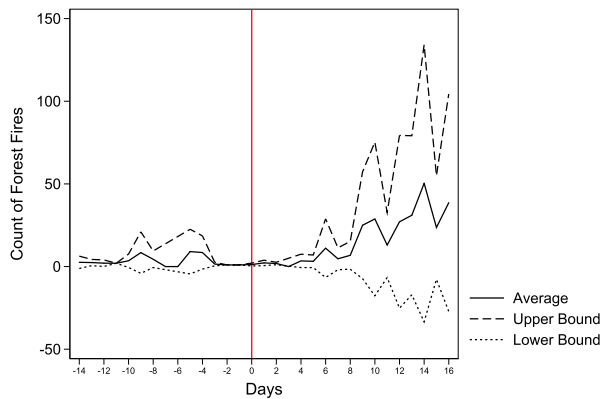
(c) Number of forest fires

Fig. 5. Daily trends in different indicators of forest fire in Nepal before and after the nationwide lockdown in response to COVID-19.

reported. If the coronavirus pandemic caused indicators of forest fire to change, one would expect this placebo test to give statistically insignificant estimates. As expected, Table 4 shows that the false treatment did not have any significant effect on fire radiative power and the number of forest fire events. This further strengthens the validity of the identifying assumption employed in the study.

Second, the study shows that the primary results reported in Table 2 are robust to a different measure of the coronavirus

pandemic. Table 5 runs the main empirical specification using a continuous normalized measure of coronavirus cases. This normalized measure is constructed by normalizing the number of coronavirus cases with respect to the average and the standard deviation. Across all the columns, the coefficient of the normalized coronavirus case number is strong, negative and statistically significant. In the most conservative specification in Column (5), Table 5 reports that a unit additional increase in normalized coronavirus case resulted in a 17.11% decrease in the number of forest fire incidents, while controlling for day fixed effects, month-by-region fixed effects, month-by-zone fixed effects and month-by-district fixed effects. The estimates are robust across multiple specifications, ranging from 17.07% to 17.74%.

4.5. Economic and policy implications

Recent media coverage has highlighted the role of the nationwide lockdown in minimizing the spread of the coronavirus across different countries. In the context of Nepal, the nationwide lockdown led to limited movements of people across spatial locations. In addition to the nationwide lockdown, more aggressive policy mechanisms were implemented across some districts in response to the pandemic. For example, stricter movement controls were implemented in some districts (including Arghakhanchi, Rupandehi, Sarlahi, Rautahat, Kapilvastu, Bara, Parsa and Dailekh) compared to the rest of the country. It is reasonable to assume that reduced movements of individuals across spatial locations in response to the pandemic likely contributed to a decrease in the number of forest fire incidents. Due to inadequate data on variation of district-level policy mechanisms over time, it is beyond the scope of the study to empirically tease out the causal effect of such measures on the incidence of forest fires.

This study offers suggestive evidence on implications of the nationwide lockdown on forest fire outcomes. Fig. 5 presents daily trends in three indicators of forest fire events two weeks before and after Nepal government's lockdown. Fig. 5 and Fig. 5(b) show that daily changes in the brightness and fire radiative power associated with forest fire events exhibited a downward trend after the lockdown. Strikingly, Fig. 5(c) indicates that the short-run reduction in the number of forest fire events lasted only for the first five days after the lockdown, with an increasing trend from the sixth day onward. Fig. A1, A2 and A3 break down the daily trends in brightness, fire radiative power and number of forest fires two weeks before and after the lockdown across seven Provinces. It is striking that daily trends in the number of forest fires in the majority of Provinces suggest that short-run effects on reduction of the number of forest fire events lasted only for few days after the implementation of the lockdown. Future research may benefit from identifying primary mechanisms that explain the causal role of the nationwide lockdown in improving proxies for the incidence and the severity of forest fire outcomes.

Table 2 shows that the intensity of the coronavirus spread, measured by additional reported cases, led to a substantial deterioration in the number of unique forest fire incidents in Nepal. To provide a concrete illustration of the magnitude of the estimated impact, this study combines the results in Table 2 with findings from a prior study and estimates the value of short-term environmental benefits associated with the reduction in the number of forest fire incidents. Specifically, Paudel (2020) uses property price information from Central Bureau of Statistics and applies regression estimates to report that a 1% reduction in the count of forest fire incidents in Nepal annually translates to 0.08% gain in property prices. This implies that a 4.68% reduction in the incidence of forest fires results in a 0.3744% gain in property prices, which corresponds to a short-term weekly benefit of 360 Rupees (Rs.) per household (3 US Dollars per household). The short-run economic

benefits calculated here do not account for several other short-term or long-term negative consequences of the virus outbreak on health outcomes; these harms vastly exceed any economic benefits from reduced incidence of forest fires.

5. Conclusion

This article has examined the short-term environmental impact of the ongoing COVID-19 outbreak on different measures of forest fire outcomes in a developing country setting. To assess the changes in forest fire outcomes in the aftermath of the virus outbreak, the study combines satellite data on real-time active fire locations in Nepal with the number of reported virus cases across the entire country. Controlling for district fixed effects, day fixed and month-by-province fixed effects, regression estimates indicate that a unit additional increase in reported case of COVID-19 resulted in a 4.54% decrease in the number of unique forest fire incidents and a 11.36% reduction in the fire radiative power associated with these events. Estimates also show that the brightness of human-led forest fires decreased by 1.94 K for every unit additional increase in the number of virus cases.

The study further explores the spatial heterogeneity in the overall impact of the virus outbreak on the incidence, the intensity and the severity of the forest fires. Findings demonstrate that districts with the lower area of community-managed forests per capita and those located in Bagmati Province experienced a 8.11% and a 6.51% decrease in the number of forest fire incidents, respectively. This significant reduction is much larger in magnitude compared to other parts of the country. The study also provides policy makers with estimates of economic benefits associated with the reduction of forest fires, which in turn can inform forest management policies in the developing world. These short-run estimates of economic gains from the reduction in the incidence of forest fires during the virus outbreak do not imply that pandemics are beneficial. While such estimates do not account for potential negative repercussions of the disease on health, they offset large social costs associated with pandemics in the developing world.
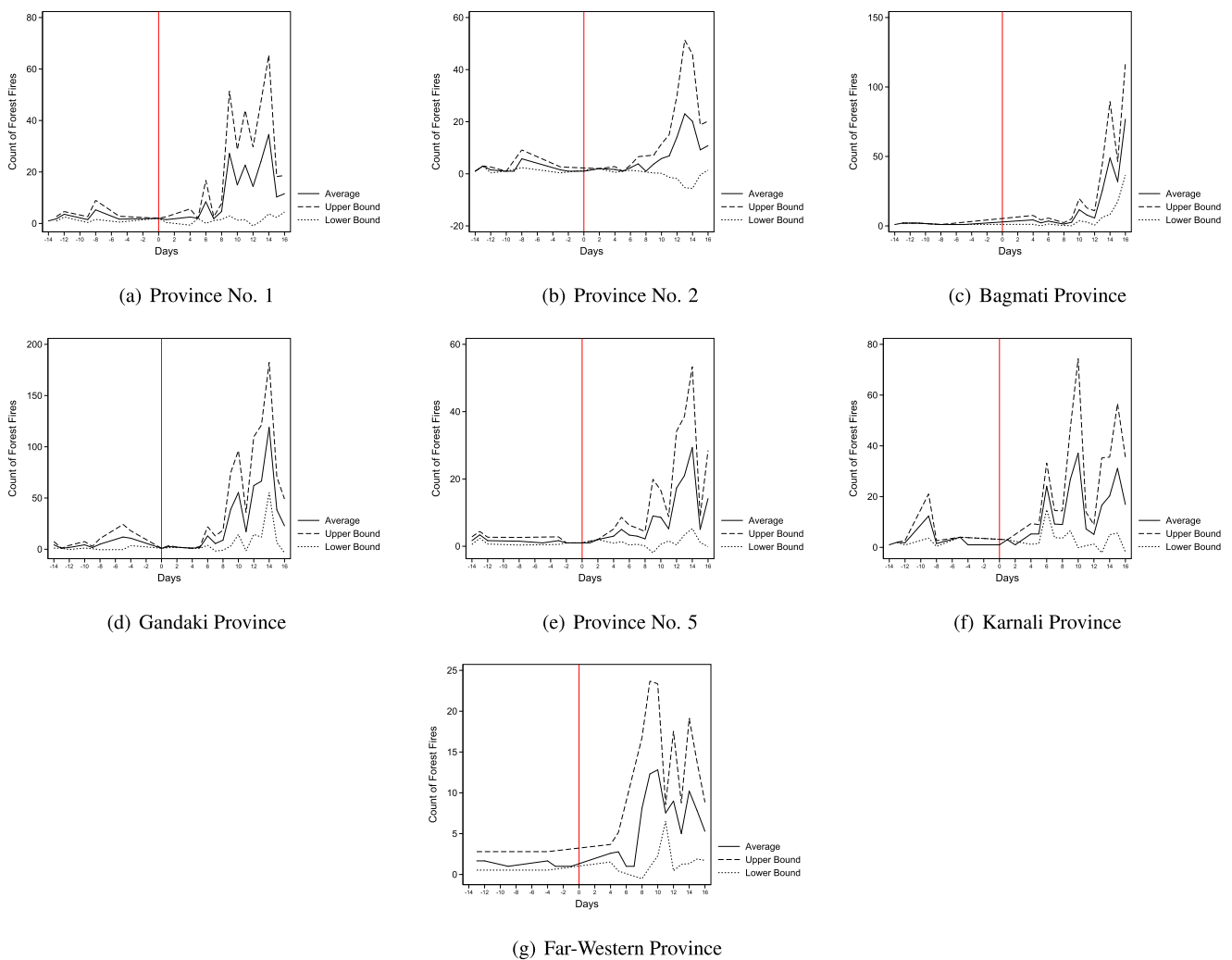
Appendix A

Fig. A1. Daily trends in counts of forest fire before and after the nationwide lockdown in response to COVID-19 across seven Provinces of Nepal.
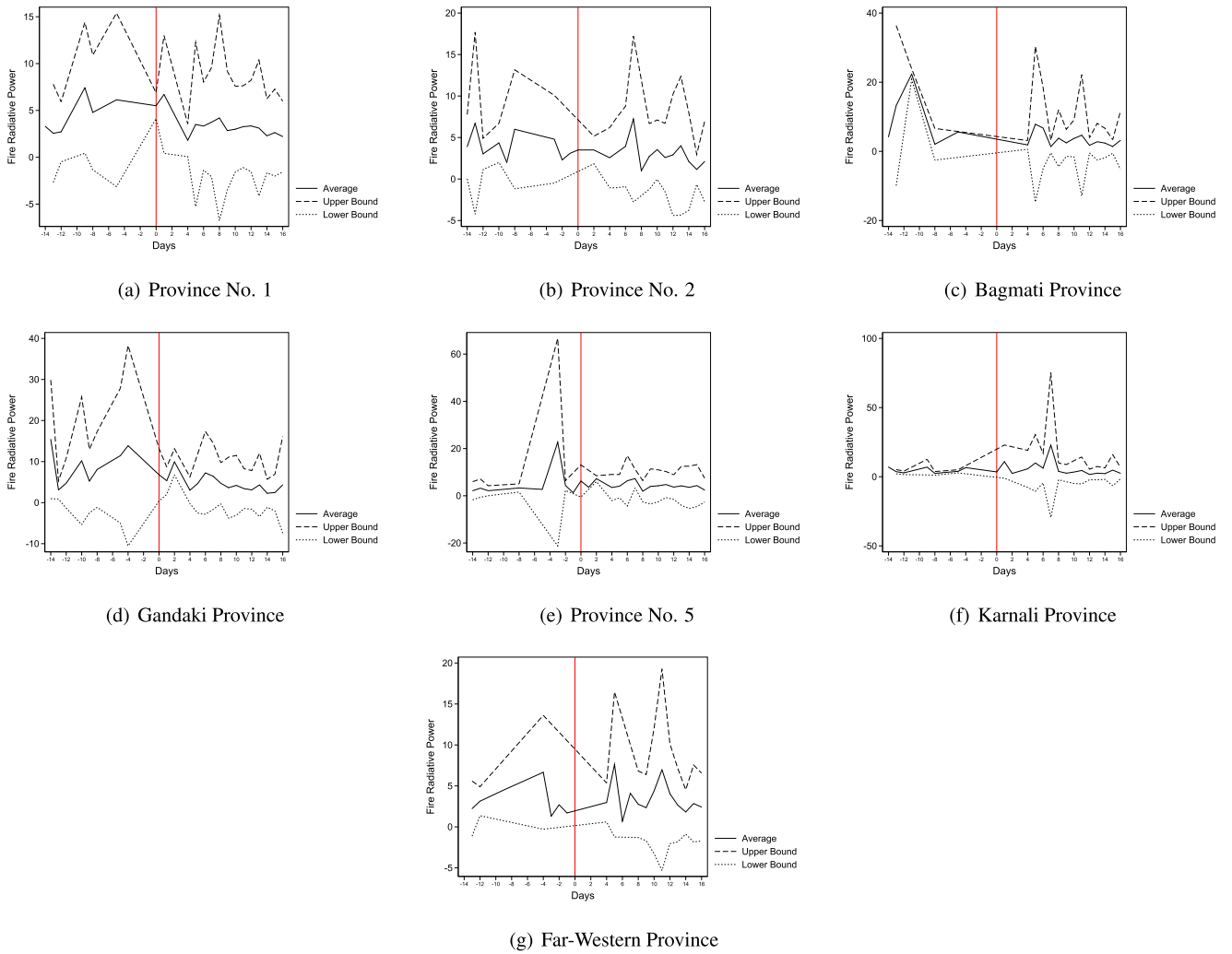
(a) Province No. 1

(b) Province No. 2

(c) Bagmati Province

(d) Gandaki Province

(e) Province No. 5

(f) Karnali Province

(g) Far-Western Province

Fig. A2. Daily trends in fire radiative power before and after the nationwide lockdown in response to COVID-19 across seven Provinces of Nepal.

(a) Province No. 1

(b) Province No. 2

(c) Bagmati Province

(d) Gandaki Province

(e) Province No. 5

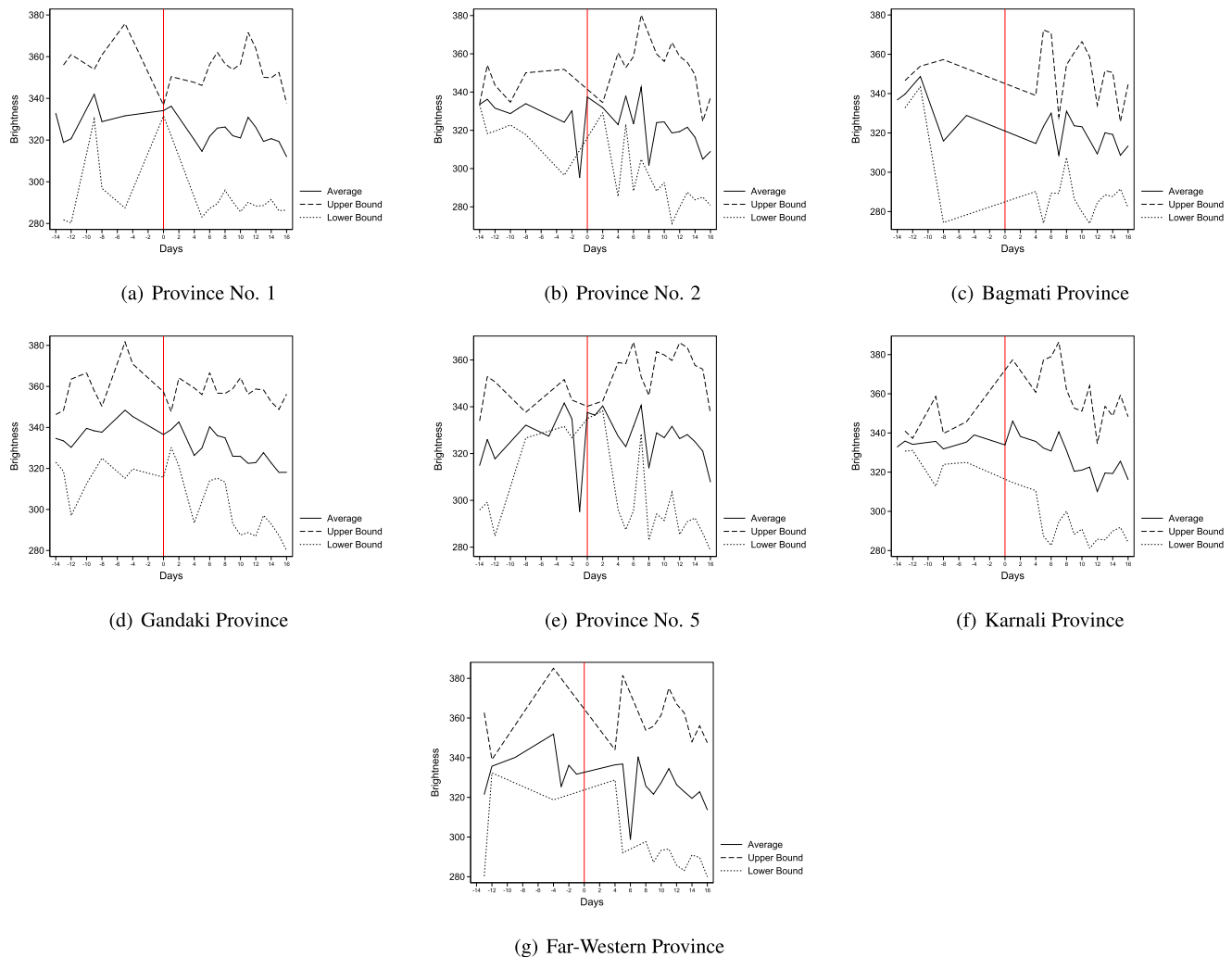(f) Karnali Province

(g) Far-Western Province

Fig. A3. Daily trends in brightness of forest fires before and after the nationwide lockdown in response to COVID-19 across seven Provinces of Nepal.

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