The Impact of Indonesian Forest Fires on Singaporean Pollution and Health

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Between 1990 and 2015, Indonesia lost nearly 25% of its forests, largely due to intentional burning to clear land for cultivation of palm oil and timber plantations.[1] The neighboring "victim countries" experienced severe deteriorations in air quality as a result of these fires. For example, Singapore experienced record air pollution levels in June of 2013 and again in September of 2015 as a result of the Indonesian forest fires.[2] This air pollution is associated with increased incidences of upper respiratory tract infections, acute conjunctivitis, lung disease, asthma, bronchitis, emphysema, and pneumonia, among other ailments.[2]

Quantifying the impact of air pollution on health outcomes is challenging because pollution levels are often non-random for a variety of reasons, including policy endogeneity and sorting (Dominici, Greenstone, and Sunstein, 2014).

In this paper we offer the first causal analysis of the transboundary health effects of the Indonesian forest burning. The Indonesian fires induce exogenous variation in Singaporean air quality. We take advantage of this by using satellite fire data to instrument for changes in Singaporean air quality. Since Singapore is only 277.6 square miles in area (two-thirds the size of New York City), air pollution resulting from the fires is homogeneously spread so that sorting is unlikely to be an issue.

We find that from 2010 through mid-2016 the Indonesian fires increased the Singaporean Pollution Standards Index by 16% on average. This caused more than a 1.5% increase in both acute respiratory tract infections and acute conjunctivitis over this period, with effects increasing over time.

[1] Indonesian forested area fell from 1,185,450 sq. km to 910,100 sq. km from 1990 to 2015 (see www.databank.worldbank.org/.)

[2] See www.nea.gov.sg and www.moh.gov.sg.

I. Methodology and Data

Existing literature on the health impacts of the Indonesian fires is limited to analyzing health data in Indonesia or neighboring countries during specific haze episodes (e.g., Frankenberg, McKee, and Thomas, 2005; Jayachandran, 2009) or regressing health outcomes on a measure of air pollution (e.g., Sastry, 2002). This method is problematic because air pollution may be endogenous, co-varying with health outcomes as a result of policy changes and macroeconomic trends. In related literature, sorting is also an issue if households choose to relocate to avoid pollution exposure. We provide an improved quantification of air quality impacts on health using satellite fire data to instrument for Singaporean air pollution. Since Singapore is small, it is homogeneously impacted by fire smoke, with a correlation of at least 0.97 between each pair of the five air pollution monitoring stations in the country. Thus, moving within-country does not reduce air pollution exposure, so sorting is not a concern for this analysis.

The National Aeronautics and Space Administration's (NASA) Fire Information for Resource Management System provides global fire data collected by satellite. In this paper, we use the fire radiative power (FRP) measured in megawatts (MW) from all Indonesian latitudes and longitudes from January of 2010 to June of 2016.[3] Since our health data are at the weekly level, we use cumulative FRP over each week as the fire variable. The average daily FRP during this time period is 7,190MW, with a minimum of 0MW and a maximum of 230,815MW observed in October 2015. There tends to be more fires during the inter-monsoon seasons from February to March and July to November when the fires are less likely to be extinguished by rainfall.

Data on air quality is obtained from Singapore's National Environmental Agency.[4] These data include daily readings of the Pollution Standards Index (PSI) from January 2010 through June 2016 taken at 4pm from the north, south, east, west, and central air quality monitoring stations. The PSI is an overall measure of air quality, which gives equal weight to sulfur dioxide, particulate matter (PM10), fine particulate matter (PM2.5), nitrogen dioxide, carbon monoxide, and ozone. Prior to April of 2014, PM2.5 was reported separately and not included in the PSI. The PSI data show that air quality differs

[3] Wind direction in Singapore varies hourly and daily in a non-consistent manner (see www.weather.gov.sg). Therefore, lacking data on wind direction, we include all Indonesian coordinates. Restricting FRP data to Indonesian coordinates east or west of Singapore results in smaller (but still highly statistically significant) results than utilizing all Indonesian coordinates, suggesting that air pollution comes from both sides of Indonesia.

[4] See http://www.nea.gov.sg.

little across monitoring stations, suggesting that pollution blown over from Indonesia is well mixed over Singapore.[5] Since the average PSI of the five monitoring stations is strongly correlated with the PSI at each individual station, our study utilizes the average PSI measured at 4pm across the five stations over the week as a measure of air quality. Singapore classifies a PSI under 50 as good air quality, 51-100 as moderate, 101-200 as unhealthy, 201-300 as very unhealthy, and above 300 as hazardous. On average, Singapore experienced good air quality between January 2010 and June 2016 with an average PSI at 4pm of 39.3. However, the variation in daily air quality is large, with a minimum PSI of 10.6 and a maximum of 258.0.

From Singapore's Ministry of Health[6] we obtain weekly data from January of 2010 through June of 2016 on polyclinic attendances for acute upper respiratory tract infections (ARTIs), acute conjunctivitis (AC), acute diarrhea, and chickenpox. Primary healthcare in Singapore is comprised of private general practitioner clinics and government polyclinics; these clinics are normally the first point of contact with patients (Hwee, Yee, and Vrijhoef, 2014). The public polyclinics are subsidized at a rate of 80% by the government and allow for full access to government healthcare.[7] Over our sample, the maximum (minimum) average daily polyclinic visits for ARTIs was 4,241 (1,839) and for AC was 168 (62).

We obtain weather variables from Meteorological Service Singapore[5] to use as controls in our estimation. These data include daily rainfall, mean, maximum, and minimum temperature, and mean and maximum wind speed recorded at the Newton weather station, which is located near the center of Singapore. The weather affects the spread of the smoke from the Indonesian fires to Singapore. Weather may also impact health outcomes and polyclinic attendances. As the polyclinic data are reported weekly, we use average weekly values of weather variables in our analyses.

Instrumenting for air pollution with fires, we estimate the following two-stage least squares equations:

[5] The correlation between the PSI of each pair of Singapore's five air quality monitoring stations is at least 0.97. The correlation between each station's PSI and the average PSI of the five monitoring stations is 0.99. The correlation between each station's PSI and Indonesian FRP are similar, around 0.7 (ranging from 0.66 to 0.72). Thus, not only is air quality homogenous across Singapore, but air quality in all locations seems to be similarly affected by the Indonesian fires.

[6] See www.moh.gov.sg and www.weather.gov.sg.

[7] The Primary Care Survey Report (2010) conducted by Singapore's Ministry of Health (www.moh.gov.sg) shows that the market share split between public polyclinics and private clinics for sick visits was 20% to 80% with most demographics, such as sex and race, of those who visit polyclinics and private clinics being similar. This split between polyclinic and private clinic patients varies for the elderly and different income groups with 47% of the population aged 65 and above, 28% of patients in the lower income group, and 15% of patients in the higher income group visiting polyclinics while the rest visit private clinics.

$$(1)\ PSI_t = \theta_1 FRP_t + \theta_2 FRP_t \times wind_t + \gamma_1 PSIchange_t + weather_t' \beta_1 + \alpha_t + \varepsilon_t$$

$$(2)\ H_t = \theta_3 \widehat{PSI}_t + \beta_2 diarrhea_t + weather_t' \beta_3 + \alpha_t + \varepsilon_t$$

where PSI_t is the mean Pollution Standards Index in week t, FRP_t is fire radiative power in Indonesia, $FRP \times wind_t$ is an interaction term to capture the effect of mean wind speed on the concentration of wildfire smoke blown into Singapore, $PSI\ change_t$ is an indicator variable for the incorporation of PM2.5 into the PSI after April 2014, $weather_t'$ is a vector of weather controls, H_t is polyclinic attendances for ARTIs or AC, $\widehat{PSI}_t$ is the predicted value of the PSI from the estimation of Equation (1), $diarrhea_t$ is the number of polyclinic attendances for acute diarrhea (a health trend control), and α_t is month and year fixed effects. All data in this analysis are aggregated or averaged to the weekly level in order to conform to the availability of the polyclinic attendance data.

A Cumby-Huizinga test for autocorrelation suggests there might be first order serial correlation in the first stage and up to fourth order serial correlation in the second stage (and reduced form). Therefore, we estimate Newey-West standard errors robust to first and fourth order serial correlation for first and second stage, respectively.

Year fixed effects account for health and population trends and month fixed effects account for seasonality of pollution and health. Year by month fixed effects are not included because they would reduce or eliminate the effects from the Indonesian fires, which often last a month or longer. To capture health trends not fully accounted for in the year fixed effects, we use polyclinic attendances for acute diarrhea as a proxy for general health trends in Equation (2). Since diarrhea is an intestinal symptom presumably not affected by air pollution, it is sometimes used as a control variable in air pollution studies (e.g., Gordian et. al, 1996). The reason for this is that a patient with a respiratory illness or conjunctivitis as a result of a cold virus, rather than air pollution, could experience associated diarrhea.[8]

II. Results

A. Impacts on Air Pollution

Our estimation of Equation (1) shows that Indonesia's FRP is a statistically significant determinant of Singaporean PSI at the 1% level whereby a one standard deviation increase in Indonesian FRP increases

[8] See http://www.webmd.com.

Singaporean PSI by 1.43 standard deviations. A one kilometer per hour increase in the wind speed reduces this impact by 0.10 standard deviations (significant at the 1% level) as higher wind speeds cause the fire smoke to blow through Singapore faster. The first stage F-statistic of 26 suggests that FRP is a strong instrument for PSI.[9]

Figure 1 shows the PSI predicted using the results from the first stage estimation with the actual FRP data (blue) and assuming a counterfactual of no fires (red). These predictions indicate that without the Indonesian fires, Singapore would have experienced approximately 50% fewer weeks with average PSI over 50 (48 versus 90 weeks) and 75% fewer weeks with average PSI over 100 (6 versus 24 weeks). The increase in PSI due to the fires has been getting larger over time as shown in Table 1, increasing from under 5% in 2010 to 23% in 2015.

[Insert Figure 1 Here]

[Insert Table 1 Here]

[9] Estimates of the coefficients are smaller when the lagged FRP is used. When both the FRP and lagged FRP are used, the lagged term is not significant. When a quadratic specification is used, the quadratic term is not significant.

B. Impacts on Polyclinic Attendances

The results from estimating Equation (2) show that a one standard deviation increase in the predicted Singaporean PSI causes a 0.35 and 0.29 standard deviation increase in weekly polyclinic attendances for ARTIs and AC, respectively. All the estimated coefficients are statistically significant at the 1% level.

The reduced form estimates of Equation (1) and (2) indicate that a one standard deviation increase in Indonesian FRP causes a 0.67 and 0.73 standard deviation increase in polyclinic visits for ARTI and AC, respectively, with all estimated coefficients statistically significant at the 1% level.

As a falsification test, we estimate the two-stage regression using polyclinic attendances for chickenpox as the health variable, since there is no medical evidence that air pollution impacts chickenpox. We find no statistically significant impact of the Indonesian fires on chickenpox.

Predicting polyclinic attendances for ARTI and AC using estimation results with actual FRP data and assuming a counterfactual of no fires, we find the Indonesian fires caused a 1.8% increase in ARTI and a 1.5% increase in AC visits to Singapore polyclinics over our sample. These impacts have been increasing over time. As shown in Columns 3 and 4 in Table 1, we find that in 2010, 0.4% of ARTI and AC visits to polyclinics were attributable to the Singaporean fires. In 2015, these numbers increased to 4.1% and 3.7%, respectively.

III. Conclusion

This study presents the first casual analysis of the impact of the Indonesian forest fires on air quality and health outcomes in Singapore. The fires induce exogenous variation in Singaporean air quality. This, combined with Singapore's small size, provides a framework that is not plagued by the endogeneity and sorting issues that have challenged previous attempts to estimate air pollution impacts.

We quantify the increases in PSI, upper respiratory tract infections, and acute conjunctivitis resulting from the fires. In ongoing work we also find evidence of averting behavior and estimate associated welfare costs (Sheldon and Sankaran, 2016). International negotiations should account for these health and avoidance costs in Singapore as well as in other Southeast Asian countries impacted by the Indonesian fires.

While our study uses polyclinic attendances for acute upper respiratory tract illnesses and acute conjunctivitis, future research could use other estimates of health, such as hospital admittances and mortality rates from haze related diseases.

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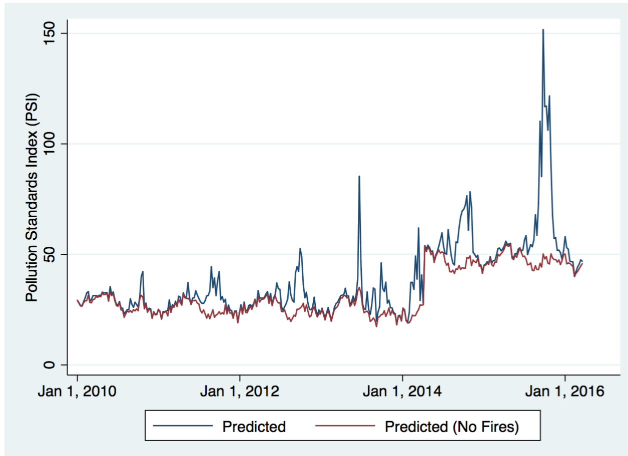

FIGURE 1. PREDICTED PSI, WITH AND WITHOUT FIRES

Note: In April 2014, PM2.5 was added to the PSI, causing an upward shift in PSI levels.

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TABLE 1— INCREASES IN SINGAPOREAN PSI AND POLYCLINIC VISITS ATTRIBUTABLE TO INDONESIAN FIRES

	PSI	ARTI	AC
2010	4.75%	0.39%	0.40%
2011	13.54%	1.04%	0.76%
2012	15.45%	1.30%	1.15%
2013	15.18%	1.38%	1.31%
2014	18.26%	2.86%	2.32%
2015	23.04%	4.13%	3.73%
Full Sample (1/2010-6/2016)	16.01%	1.75%	1.50%

Source: Author calculations using the predicted values from two-stage least squares estimates using actual FRP and assuming a counterfactual of no fires.