The Impact of Indonesian Forest Fires on Singaporean Pollution and Health

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ABSTRACT
Forest burning in Indonesia results in severe episodes of “seasonal haze” in neighboring Singapore. We offer the first causal analysis of the transboundary health effects of the Indonesian forest burning. Instrumenting for air pollution with satellite fire data, we estimate the impacts of the Indonesian fires on Singaporean polyclinic attendances for acute upper respiratory tract infections and acute conjunctivitis. We find that a one standard deviation increase in the Indonesian fire radiative power increases Singaporean pollution by 1.4 standard deviations, and causes a 0.7 standard deviation increase in polyclinic attendances for each of the illnesses examined in this paper.

INTRODUCTION
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).

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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/.)

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 less likely to be an issue.

Using a two-stage least squares approach, we find that from 2010 through mid-2016, the Indonesian fires caused a statistically significant increase in pollution levels in Singapore. Our study also provides evidence that polyclinic attendances for acute respiratory tract infections and acute conjunctivitis in Singapore increased as a result of the deterioration in air quality. The reduced form estimates show that a one standard deviation increase in our measure of fires causes a 0.7 standard deviation increase in polyclinic attendances for each of these illnesses. These findings provide causal evidence of the transboundary pollution and health impacts of the Indonesian forest burning on neighboring Singapore.

I. Methodology and Data

Existing literature on the health impacts of the Indonesian fires is limited. Jayachandran (2009) estimates the impact of the 1997 fires in Indonesia, finding 15,600 child, fetal, and infant deaths attributable to the pollution in Indonesia during the 1997 fires. This results in early life mortality costs of over $15 billion for Indonesia. Studies attempting to provide evidence on the impact of the Indonesian fires on neighboring countries have analyzed the correlation between the pollution levels within a neighboring country and health outcomes within the same country during a specific fire episode (e.g., Glover and Jessup, 1999; Quah, 1999; Emmanuel, 2000; Quah, 2002; Sastry, 2002; Frankenberg, McKee, and Thomas, 2005). Correlating health outcomes with the pollution levels within the same country does not accurately capture the transboundary impact of the Indonesian fires since air pollution may be endogenous, co-varying with health outcomes as a result of policy changes and macroeconomic trends.

We provide an improved quantification of air quality impacts on health using satellite fire data to instrument for Singaporean air pollution. Since Singapore is a geographically small country, it is homogeneously impacted by the fire smoke blown in from Indonesia. Our data show a high correlation of at least 0.97
between each pair of the five air pollution monitoring stations in the country. Since moving within-country does not reduce air pollution exposure, sorting is less likely a concern for this analysis. Using time-series data from 2010 through mid-2016, we also perform a more extensive analysis of the impacts of the Indonesian fires than has been provided in previous literature. Furthermore, our study offers the first statistical analysis of the more recent and more severe fire episodes.

The National Aeronautics and Space Administration’s (NASA) Fire Information for Resource Management System (FIRMS) 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. 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. The radiative power of the fires tends to be stronger during the inter-monsoon seasons from February to March and July to October, when the fires are less likely to be extinguished by rainfall.

Data on air quality is obtained from Singapore’s National Environmental Agency. 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 includes 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 little across monitoring stations, suggesting that pollution blown over from Indonesia is well mixed over Singapore. 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

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.
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.
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 (in December 2013) and a maximum of 258.0 (in September 2015).

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 is 4,241 (1,839) and for AC is 168 (62).

We obtain weather variables from Meteorological Service Singapore\(^8\) 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:

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\begin{align*}
\text{(1) } PSI_t &= \theta_1 FRP_t + \theta_2 FRP_t \times wind_t + \\
&\phantom{=} + \gamma_1 PSI_{\text{change}} t + \text{weather}_t \beta_1 + \alpha_t + \epsilon_t \\
\text{(2) } H_t &= \theta_3 PSI_t + \beta_2 \text{diarrhea}_t + \\
&\phantom{=} + \text{weather}_t \beta_3 + \alpha_t + \epsilon_t
\end{align*}
\]

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, \( PSI_{\text{change}} t \) is an indicator variable for the incorporation of PM2.5 into the

\(^7\) 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.
\(^8\) http://www.weather.gov.sg/home/
PSI after April 2014, $\text{weather}_t'$ is a vector of weather controls, $H_t$ is polyclinic attendances for ARTIs or AC, $\hat{PSI}_t$ is the predicted value of the PSI from the estimation of Equation (1), $\text{diarrhea}_t$ is the number of polyclinic attendances for acute diarrhea (a health trend control), and $\alpha_t$ 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 the 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.\footnote{See http://www.webmd.com.}

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 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.

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.

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 estimate the increases in PSI, upper respiratory tract infections, and acute conjunctivitis resulting from the fires. While the results presented in this paper are compelling, they are still suggestive. In ongoing work we test the robustness of the results to different specifications, to an alternative measure of fire, and to different sets of latitude and longitude coordinates. We also find evidence of averting behavior and estimate associated welfare costs (Sheldon and Sankaran, 2017). 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.

REFERENCES

in Indonesia.” *Demography*, 42(1): 109-129.


