

Transboundary Pollution in Southeast Asia: Welfare and Avoidance Costs in Singapore from the Forest Burning in Indonesia*

Tamara L. Sheldon^{†1} and Chandini Sankaran^{‡1}

¹Department of Economics, University of South Carolina

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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. Using a two-stage approach and 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 also estimate the change in electricity demand in Singapore attributable to the fires, finding that demand increases as people respond to haze episodes by staying indoors. We estimate partial health and avoidance costs of US\$333 million from January 2010 to June 2016. Our estimates suggest avoidance behavior is significant, accounting for over three quarters of our estimate.

Keywords: air pollution; health; avoidance behavior; externalities; forestry

JEL Classification Numbers: D62, I1, Q23, Q51, Q53

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[†]Tamara.Sheldon@moore.sc.edu

[‡]Chandini@moore.sc.edu

1 Introduction

Forest burning in Indonesia to clear land for cultivation of palm oil, the production of forestry products, and other ancillary industries has resulted in severe episodes of “seasonal haze” in neighboring Singapore, Brunei, Malaysia, and southern Thailand. These episodes of large-scale forest burning have occurred as early as the 1980s and as recent as 2016. In 2015 alone, NASA detected more than a hundred and twenty thousand forest fires in Indonesia (NASA, 2015a). The majority of these were deliberately set forest fires on the Indonesian islands of Sumatra, Indonesian Borneo, and Sulawesi. The neighboring “victim countries” experience 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 (NEA, 2016). The fires also emit greenhouse gases, with an estimated 1.6 billion tons of carbon dioxide emissions in 2015 from the Indonesian forest fires, larger than the average annual emissions from Japan (NASA, 2015b). With air pollution at unhealthy levels in Singapore in 2013 and 2015, school closures were ordered, school activities were cancelled, and limitations on outdoor activities were recommended by the Singaporean government (Straits Times, 2013; CNN, 2015).

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 (MOH, 2016). We offer the first causal analysis of the effects of the Indonesian forest burning on air quality and health outcomes in Singapore. Since the forest burning in Indonesia induces exogenous variation in Singaporean air quality, we are able to use fire data as an instrument for air pollution to estimate a causal relationship between the Indonesian forest fires and health outcomes independent of national health and macroeconomic trends.

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

typically look at reduced form impacts of changing air quality on health outcomes and do not account for averting behavior (Graff Zivin and Neidell, 2014). The first challenge is often addressed by using quasi-experiments, where researchers look at differences in health outcomes between a control group and a treatment group that has experienced a (usually non-random) shock to air pollution exposure (Ransom and Pope, 1995; Clancy et al., 2002; Chay and Greenstone, 2003; Lleras-Muney, 2010; Deschênes, Greenstone, and Shapiro, 2012; Rich et al., 2012; Chen et al., 2013). There is also growing literature attempting to quantify short run behavioral responses to air pollution and associated costs (Mansfield, Johnson, and Van Houtven, 2006; Graff Zivin and Neidell, 2009; Neidell, 2009; Moretti and Neidell, 2011). Though one study by Deschênes and Greenstone (2011) estimates the relationship between daily temperatures and annual mortality rates and daily temperatures and annual residential energy consumption in the United States, to our knowledge, no paper exists that uses a quasi-experimental approach to estimate impacts of air pollution both on health outcomes and on short run behavioral responses. This paper estimates direct health impacts (increase in polyclinic attendances), indirect health costs (losses in productivity), as well as short run behavioral responses (an increase in electricity usage due to avoidance behavior) in Singapore as a result of the forest fires in Indonesia. The estimates provided in this paper represent a lower bound of costs since we do not include some health costs such as mortality and only include one aspect of avoidance behavior.

Data on fire intensity and fire count from NASA’s Fire Information for Resource Management System allows us to clearly identify the severity and the number of Indonesian fires. The Indonesian forest fires cause exogenous variations in Singaporean air quality since they are independent of Singaporean macroeconomic trends, health trends, and policies. Due to the small size of Singapore¹ and the proximity of Singapore to Indonesia, the Indonesian fires have a similar impact on the Singaporean air quality, as measured through the Pollu-

¹The Republic of Singapore is a small island nation with a land area of approximately 277.6 square miles and a 2015 population of approximately 5,535,000; Singapore’s mainland measures approximately 31 miles from east to west and 16 miles from north to south (Department of Statistics Singapore, 2016).

tion Standards Index (PSI), throughout the country. Since there are no major differences in the air quality in different areas in Singapore, sorting behavior is unlikely. Furthermore, since Singapore is a small country, many Singaporean residents travel within the country on a daily basis as they commute from the suburbs to the city for work and recreational activities, resulting in similar exposure to the haze. The exogenous variation of air pollution and the lack of sorting issues allow for cleaner identification than a quasi-experiment that may be subject to non-random assignments. Using polyclinic attendances for acute respiratory illnesses and acute conjunctivitis as proxies for health allow us to observe the immediate short-term effects of the Indonesian fires on the health of Singaporeans.

The full disclosure and daily reporting of the Pollution Standard Index (PSI) in Singapore promotes averting behavior amongst Singaporeans. The Singaporean government has a “Haze Page”² and tweets out haze advisories, a screenshot of which is shown in Appendix Figure A.1. The daily and hourly PSI as well as haze health advisories are a major area of focus on the main pages of these websites. The PSI is also reported in daily television news reports. This extensive reporting often comes with recommendations to limit outdoor activity. Given that almost all Singaporeans have access to this information, averting behavior is expected during times of unhealthy air quality. Our study attempts to estimate averting behavior by estimating the relationship between energy use in Singapore and the Indonesian fires. Electricity demand is expected to increase during forest fires episodes as more Singaporeans choose to stay indoors to avoid exposure to the bad air quality.

Using satellite fire data from Indonesia as an instrument for air pollution, we use two-stage least squares to estimate the impact of air pollution on Singaporean polyclinic attendances for acute upper respiratory tract infections and acute conjunctivitis. We also estimate the increase in electricity demand induced by the fires as Singaporeans use air conditioners and stay indoors to reduce exposure to air pollution. We find that over the duration of our study period (January 2010 through June 2016) the Indonesian fires have resulted in direct health

²haze.gov.sg

costs of S\$19.9 million (US\$14.7 million), indirect costs due to missed work of S\$70.7 million (US\$52.3 million), and increased electricity costs (between 2012-2016) of S\$359.9 million (US\$266.3 million), for a total cost of S\$450 million (US\$333 million).³

This paper proceeds as follows. Section 2 provides a background on forest burning in Indonesia and the related seasonal haze issues in Singapore. The data used in this paper are described in Section 3, and Section 4 reviews the empirical strategy. We present our results in Section 5. Section 6 concludes the paper.

2 Background

Between 1990 and 2015, Indonesia lost nearly 25% of its forests, mostly due to intentional burning.⁴ Indonesian forest burning, primarily on the islands of Sumatra and Kalimantan, has resulted in seasonal haze episodes that last for several months in Indonesia, Malaysia, Singapore, Brunei, Southern Thailand and the Philippines (Sastry, 2002; Casson, 2002). Previous literature has identified several severe haze episodes in Southeast Asia caused by the Indonesian forest fires in the recent decades with the first episode dated from 1982-83, the second from 1991-1994, and the third episode from 1997-1998. “The burning in 1997 and 1998 alone devastated 1.7 million hectares in Sumatra, 6.5 million hectares in Kalimantan, 1.0 million hectares in Irian Jaya and 0.4 million hectares in Sulawesi” (Jones, 2006). The average emissions from fires in the region from 2000-2006 was 128 teragrams of carbon dioxide per year, with 58% of the emissions originating from southern Borneo, 38% from Sumatra (38%) and 1% from Sulawesi (van der Werf, 2008). While majority of the burning occurs on the islands of Sumatra and Kalimantan, forest fires are now being set on almost all the major Indonesian islands including Irian Jaya (West Papua). Significant transboundary haze pollution, as a result of the forest burning in Indonesia, has been an annual reoccurrence since

³The health costs estimated in this paper are the costs of treating acute upper respiratory tract infections and acute conjunctivitis. Since there may be additional health impacts and avoidance behaviors not captured in our data, our estimates should be viewed as a lower bound.

⁴According to the World Resource Institute.

2001 during the inter-monsoon dry seasons of February-March and July-October (Tacconi, Jotzo, and Grafton, 2006; Jones, 2006). According to NASA, the forest fires are becoming more severe over time, with the 2015 season being one of the most severe burning seasons that has been experienced by Indonesia in two decades (NASA, 2015b).

While fires have been used to clear forests to be converted for agricultural land for generations in Indonesia, the effects on regional air quality were inconsequential when small areas of land were cleared in the past for shifting agriculture. However, the amount of land clearing has increased in the last few decades as large-scale rubber and oil palm plantations use burning as an inexpensive method of clearing vast areas (Tomich et al., 1998). Virtually all Indonesian forest fires are now believed to be man-made, with the majority of them deliberately set by large landholders for land clearing to convert forested land to commercial agriculture, particularly oil-palm and timber plantations (Suyanto et al., 2004; Sastry, 2002; Persoon and Osseweijer, 2008; Aiken, 2004). Some authors have attributed up to 80% of the haze problems experienced in Southeast Asia in the 1997 to 1998 period to the forest burning in Indonesia for plantation development by multinational corporations (Applegate et al., 2003; Byron and Shepherd, 1998; Glover and Jessup, 1999). Logging can further exacerbate the problem by increasing forest flammability since fires can spread more rapidly in recently logged forests than undisturbed forests (Vayda, 2006). Once the forest fires are started, only the rains during the monsoon season are able to extinguish them (Sastry, 2002).

Transboundary pollution was recognized as an international issue as early as the 1960s when scientists demonstrated the interrelationship between sulphur emissions in continental Europe and the acidification of Scandinavian lakes (UNECE, 2016). This recognition of transboundary pollution resulted in the 1979 Geneva Convention on Long-range Transboundary Air Pollution, the first international legally binding instrument for controlling and reducing the damage to human health and the environment caused by transboundary air pollution. Since then, numerous studies have confirmed that air pollutants can cause damage thousands of miles from the pollution source (UNECE, 2016).

While regional discussions on the need for collaboration to combat the Indonesian forest burning were begun by 1990, the 1994 haze event motivated the Association of South East Asian Nations (ASEAN) Meeting on the Management of Transboundary Pollution in Malaysia in June 1995 to discuss smoke-haze pollution (Jones, 2006; Nguitragool, 2011). This meeting resulted in the Asean Cooperation Plan on Transboundary Pollution (ACPTP) in June 1995, which acknowledged that the smoke experienced by Southeast Asian countries was a result of the use of fires to clear land. Other actions taken by ASEAN countries to address the haze include The Regional Haze Action Plan in December 1997, national haze action plans by individual ASEAN nations, and the ASEAN Agreement for Transboundary Haze Pollution in June 2002 (commonly known as the Haze Treaty) (Haze Action Online, 2016). However, these measures are viewed as ineffective as the burning in Indonesia associated with the haze pollution has continued until today (Nguitragool, 2011).

Past research has recognized that emissions from the Indonesian forest fires not only have a strong and sustained regional impact on air quality and visibility, but also bring about adverse health consequences (Frankenberg et. al., 2005; Aiken, 2004). While common health grievances about the haze are lower visibility, eye irritation, and difficulty breathing, more serious health concerns can result. For example, the higher levels of pollution in Indonesia during the 1997 forest fires caused a 20% increase in under-three child mortality in Indonesia (Jayachandran, 2009). Higher ambient particulate matter concentrations increase the incidences of respiratory diseases, eye and skin disorders, upper respiratory tract infections, and asthma within the population, and increase morbidity from these diseases (Dockery and Pope, 1994; Bernard et. al., 2001; Ostermann and Brauer, 2001; Sastry, 2002; Jones, 2006; WHO, 2006). During the 1996-1997 haze event, five thousand people in the Malaysian state of Sarawak were treated for haze-related complaints in the month of September 1997 when the air pollution index was at the hazardous level (Shepherd, 1997). Health impacts depend on particle size, with smaller particles reaching deeper into the lungs and potentially being absorbed into the blood stream. The severity of the health impacts depends on the toxicity

of the compounds, how deeply they are deposited in one's respiratory system, the duration of exposure, and the individual's physical capacity to cope with the pollutants (Aiken, 2004; Dockery and Pope, 1994).

Literature on the transboundary impacts of the Indonesian forest fires is limited, especially studies of the more recent haze episodes. Previous research has attempted to quantify the direct and indirect costs of a specific haze to Singapore (Glover and Jessup, 1999; Quah, 1999), or has focused on analyzing mean data before, during, and after a specific Indonesian forest fire episode to assess the impact of the fire episode on the global carbon cycle and regional air quality (Nichol, 1997). One study conducted a regression analysis between air quality in Malaysia and mortality in Malaysia from 1994-1997 in an attempt to estimate the impact of the April to November 1997 haze (Sastry, 2002). The health impact in Brunei of the 1997-1998 haze has been assessed through surveys (Odihi, 2001). Emmanuel (2000) analyzed data from healthcare facilities to assess the impact in Singapore of the same haze incident.⁵ While these estimates are based on correlations between air quality and health outcomes, such as mortality, hospitalizations or polyclinic attendances within a specific country, they do not truly capture the transboundary impact of the Indonesian fires on regional air quality or health.

Studies on the 1997 haze have estimated the direct and indirect costs to Singapore alone at US\$69.3-US\$286.2 million, with losses in tourism accounting for the majority of these estimated costs (Glover and Jessup, 1999; Quah, 1999, Quah, 2000). Quah (1999) estimates US\$3.8-4.5 million total health damage from the 1997 episode, while Glover and Jessup (1999) estimate US\$4-13.5 million. These estimated health costs include direct cost of illness, self-medication expenses, loss in earnings/productivity, and preventative expenditures. A study of the 2013 haze in Singapore found decreases in tourist arrivals, increases in polyclinic attendances, and increases in household energy demand that correlated with increases in

⁵Utilizing data from public sector outpatient care facilities, accidents and emergency departments, public sector inpatient care facilities and national mortality data, Emmanuel (2000) found a 30% increase in outpatient attendance for haze-related conditions and increases of upper respiratory tract illness, asthma and rhinitis associated with an increase in PM10 during the 1997 haze event.

Singaporean PSI levels (Tan, 2014). Furthermore, previous studies have not established a direct causal relationship between the forest fires in Indonesia and air quality or health outcomes in neighboring countries.

A decrease in air quality, particularly due to an increase in fine particulate matter (PM2.5), may result in premature mortality, especially amongst susceptible populations, such as the elderly and those with asthma. A recent study found that the Indonesian fires caused 100,300 deaths in 2015 in Indonesia, Malaysia, and Singapore, more than double the fire-caused deaths in 2006 (Koplitz et al., 2016). The study found that in 2015, there were 600-3,800 fire-caused deaths in Singapore, up from 200-1,200 in 2006. While this study utilizes actual fire data combined with a chemical transport model to estimate population-weighted smoke exposure, the authors estimate mortality using a concentration response relationship that assumes a 1% increase in mortality for each 1 part per billion increase in annual average PM2.5 levels. This back-of-the-envelope mortality estimate does not utilize actual mortality data. Furthermore, these estimates implicitly assume no avoidance behavior, such as staying indoors, which might result in lower mortality due to haze episodes.

We provide the first econometric analysis to establish a causal relationship between the forest fires in Indonesia and the air quality and health outcomes in Singapore. We then proceed to estimate the direct and indirect health costs, as well as avoidance behavior,⁶ to Singapore as a result of the Indonesian fires. Our estimates of annual direct and indirect health costs are inline with past studies (Glover and Jessup, 1999; Quah, 1999) for the earlier years in our sample and larger (up to S\$33 million) in more recent years. Furthermore, our estimated avoidance costs are larger than the direct and indirect health costs, suggesting these costs are an important factor missing from other analyses and should be included as a cost of the Indonesian fires.

⁶We do not include estimates of premature mortality in our analysis due to lack of access to hospitalization and mortality data.

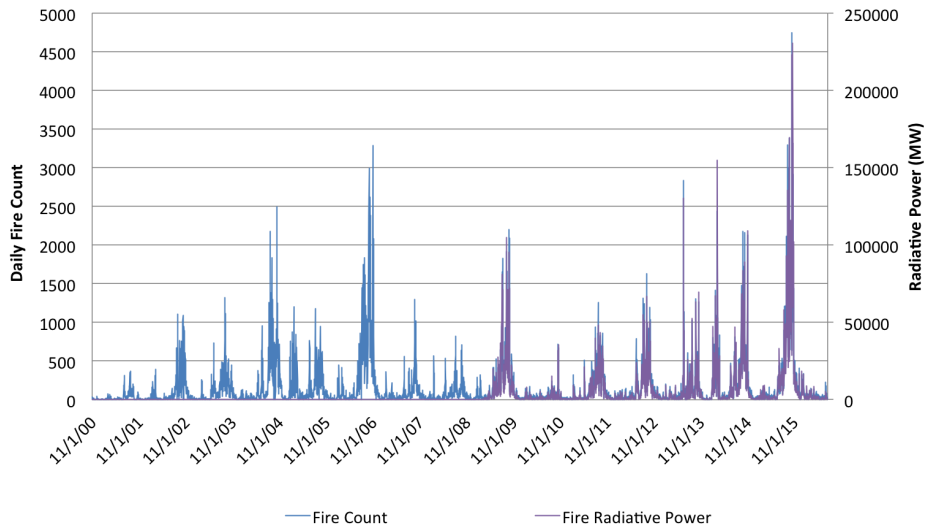
3 Data

NASA’s Fire Information for Resource Management System (NASA, 2016) provides a fire database collected by satellite, which includes the latitude and longitude of the center of fires that occur globally. This study utilizes data from NASA on Indonesian fires. The two variables that measure fires are fire counts and fire radiative power (FRP). Data on fire counts is available from November 2000 through June 2016; data on the fire radiative power is available from March of 2009 through June 2016. Fire radiative power is a measure of fire intensity and is measured in megawatts (MW). Our dataset includes all Indonesian latitudes and longitudes.⁷

Figure 1 shows both the number of fires and the total fire radiative power per day in Indonesia from November 2000 through June 2016. For a daily observation, we sum the radiative power of all fires on a given day. There tends to be more fires in late summer and early fall, the inter-monsoon dry season when the fires are less likely to be extinguished by rainfall. The number and intensity of Indonesian fires fluctuates from year to year, but does not appear to be decreasing over time. In fact, it can be observed from Figure 1 that the radiative power of the most recent fires in 2015 was higher than any of the previous fires since the beginning of the data in March 2009.

⁷Ideally we would interact fires with wind direction, however, our weather data do not include wind direction. We include all Indonesian latitudes and longitudes because, as shown in Appendix Figure A.2, there is no consistent prevailing wind direction. Depending on the time of day, the wind may blow in any direction.

Figure 1: Indonesian Fires



Daily data on air quality is obtained from Singapore’s National Environmental Agency (NEA, 2016). These data include daily readings of the Pollution Standards Index (PSI) from January 2010 through June 2016, as well as PM2.5 readings from September 2012 through March 2014, 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.

Singapore is a small country of 277.6 square miles, about half the size of Los Angeles and two-thirds the size of New York City. As such, air quality differs little across monitoring stations, and it is likely that pollution blown over from Indonesia is well mixed over Singapore. As shown in Table 1, 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. 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. The correlation between each station's PSI and the two measures of Indonesian fires 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.

From Singapore's Ministry of Health we obtain weekly data from January 2010 through June 2016 on polyclinic attendances for acute upper respiratory tract infections (ARTIs), acute conjunctivitis (AC), acute diarrhea, and chickenpox. The Singaporean National Government governs, manages, funds and administers Singapore's universal access to healthcare system through the Ministry of Health of Singapore. 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. In addition to the government subsidizing 80% of the healthcare bill at polyclinics, low income patients can receive full benefits for outpatient care in public polyclinics through the Medifund Endowment Program, with chronic or acute illnesses considered as qualifying conditions (Liu and Haseltine, 2016). Singapore's unique mix of private and public healthcare system allows for universal access to healthcare. According to the Primary Care Survey Report conducted by Singapore's Ministry of Health (2010), the market share split between the public polyclinics and private clinics for sick visits was 20% to 80%; the split between polyclinics and private clinics was more equal for those aged 65 and above with 47% visiting polyclinics and 53% visiting private clinics in 2010. While there is a variation in the type of patients seen at polyclinics and private clinics, with those in the lower income group (as proxied by patients living in public housing) being more likely to visit a polyclinic than those in the higher income group (as proxied by those living in private apartments or houses), patients in all income groups are seen at both facilities. Polyclinics see 28% of patients in the lower income groups, while the remaining 72% visited private

Table 1: Correlation between Air Quality at Various Measurement Stations and Indonesian Fires

	FRP	Fire Count	PSI North	PSI South	PSI East	PSI West	PSI Central	PSI Average
FRP	1							
Fire Count	0.99	1						
PSI North	0.71	0.70	1					
PSI South	0.70	0.69	0.98	1				
PSI East	0.68	0.67	0.98	0.99	1			
PSI West	0.72	0.71	0.98	0.98	0.97	1		
PSI Central	0.67	0.66	0.98	0.99	0.98	0.97	1	
PSI Average	0.70	0.69	0.99	0.99	0.99	0.99	0.99	1

clinics; polyclinics see 15% of patients in the higher income group while private clinics see 85%. The Primary Care Survey Report shows that the other demographics, such as sex and race of those who visit polyclinics and private clinics, appear similar. According to Dr. Meena Sundram, the Regional Director of the Jurong Polyclinics in Singapore, the people who visit the polyclinics tend to have similar health compared to the population that does not use the polyclinics.⁸

Figure 2 shows polyclinic attendances for ARTIs, daily counts of fires in Indonesia, and daily measurements of Singapore’s PSI taken at 4pm. When fire counts are high, the PSI also tends to be high. While the PSI tends to usually fall in the good or moderate range (under 100), it occasionally rises to unhealthy or very unhealthy levels particularly during Indonesian fire episodes. There does not appear to be an obvious correlation between fire counts or the PSI with ARTIs. This could be because other factors, such as general health trends, seasonality, and weather, that affect polyclinic attendances for ARTIs have not yet been taken into account.

⁸See interview transcript in Appendix B.

Figure 2: Acute Respiratory Tract Polyclinic Attendances, Indonesian Fire Count, and Singaporean Pollution Standards Index (PSI)

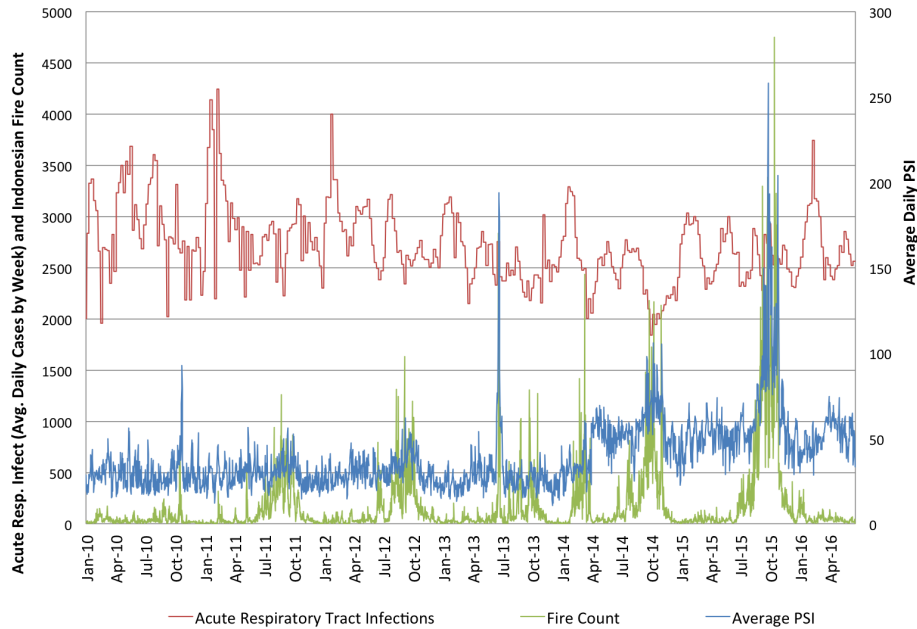


Table 2 shows the summary statistics of the key data used in our analysis. Singapore classifies a PSI under 50 as good air quality, 51-100 as moderate, 101-200 as unhealthy, 201-300 as very unhealthy, and above 300 as hazardous. On average, Singapore experienced good air quality between January 2010 and June 2016 with an average PSI at 4pm of 39.3 as shown in Table 2. However, the variation in daily air quality is large, with a minimum PSI of 10.6 and a maximum of 258.0. The daily average of fires in Indonesia from January 2010 to June 2016 was 165.3, with a minimum number of fires of 0 and a maximum of 4,750 in October 2015. The average fire radiative power during this time period was 7,190MW, with a minimum of 0MW and a maximum of 230,815MW observed in October 2015. The average daily number of ARTIs reported at polyclinics in Singapore was 2,711.7 with a minimum of 1,839.0 and a maximum of 4,240.8 in early February 2011, while the average daily cases of AC was 96.5 with a minimum of 62.0 and a maximum of 168.0 in early September 2014.

We obtain weather variables from Meteorological Service Singapore (2016) to use as

Table 2: Summary Statistics

	Mean	Std. Dev.	Min	Max
Average PSI (4pm)	39.3	20.8	10.6	258.0
Daily Fire Count	165.3	352.3	0	4,750.0
Total Daily Fire Radiative Power (MW)	7,190.0	17,521.2	0	230,815.4
Daily Electricity Demand (MWh)	133,393.2	8,923.5	2723	151,068.5
Average Daily Polyclinic Visits for:				
Acute Respiratory Tract Infections	2,711.7	368.9	1,839.0	4,240.8
Acute Conjunctivitis	96.5	17.0	62.0	168.0
Acute Diarrhea	472.5	57.1	267.8	652.0

For January 2010-June 2016.

controls in our estimation. These data include daily rainfall (mm), mean temperature ($^{\circ}\text{C}$), maximum temperature ($^{\circ}\text{C}$), minimum temperature ($^{\circ}\text{C}$), mean wind speed (kmh), and maximum wind speed (kmh) 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. Since the polyclinic data are reported weekly, all the weather data are averaged to the weekly level for our analyses. The final dataset used in the first step of our empirical analysis includes the weekly mean of daily rainfall, mean temperature, maximum temperature, mean wind speed, and maximum wind speed as weather controls and the total weekly fire count and the sum of the radiative power of all fires in a week as our measures of the Indonesian fires, and weekly polyclinic attendances for acute diarrhea as a control for general health trends. Mean wind speed over our sample is approximately 7kmh. At this speed, air pollution would travel roughly one hundred miles a day. This would allow smoke from Sumantra to reach Singapore in one to three days and smoke from West Kalimantan in four to five days. Therefore, we can expect air pollution from an Indonesian fire to reach Singapore within a week, which is our unit of analysis.

The second part of our empirical analysis attempts to measure averting behavior, hypothesizing that Singaporeans are likely to restrict outdoor activities and stay indoors during periods of bad air quality. For this analysis, we utilize data on historical electricity system demand for every half hour period (MW) from February 2012 through May 2016. This data

from the Energy Market Authority, Singapore’s power system operator, is published on Singapore’s Open Data Portal (2016). We aggregate the half hourly demand to daily demand. Average daily demand is 133,393MWh.

4 Empirical Strategy

The relationship between health and pollution is often described by the following health production function (Graff Zivin and Neidell, 2014):

$$H = f(P, A, E, S), \tag{1}$$

where H is a measure of health, P is a measure of pollution, E are environmental factors such as weather, A is avoidance behavior, and S are other factors affecting health, including socioeconomic as well as individual factors. Health outcomes are measured through polyclinic attendances for acute upper respiratory tract infections or acute conjunctivitis since numerous studies have shown the impact of air pollution on these diseases (Dockery and Pope, 1994; WHO, 2006; Delfino et. al, 2009; Alman et. al, 2016; Li, 2016). We use acute diarrhea as a measure of overall health trends (S). Since our analysis is at the aggregate level, there is no need to control for individual factors such as genetics. We estimate the impact of air pollution on ARTIs and AC using Indonesian forest fires as an instrument for air quality. Specifically, we estimate the following equations using a two-stage least squares approach and using the data described in Section 3:

$$PSI_t = \theta_1 fire_t + \theta_2 fire_t \times wind_t + \mathbf{weather}'_t \beta_1 + \gamma PSI\ change_t + \alpha_t + \varepsilon_t \tag{2}$$

$$H_t = \theta_3 \hat{PSI}_t + \beta_2 diarrhea_t + \mathbf{weather}'_t \beta_3 + \alpha_t + \varepsilon_t. \tag{3}$$

where

PSI_t : pollution standards index, a measure of air quality

H_t : health outcome (e.g., number of polyclinic attendances for ARTIs)

$fire_t$: number of fires or fire radiative power in Indonesia in week t

$fire_t \times wind_t$: interaction term between fire variable and mean wind speed

$\mathbf{weather}'_t$: vector of weather variables

$diarrhea_t$: number of polyclinic attendances for acute diarrhea

$PSI\ change_t$: binary variable equal to one after the incorporation of PM2.5 into the PSI in April 2014

α_t : monthly and yearly fixed effects

In our first stage estimation (Equation 2) we regress PSI on a measure of Indonesian fires. We then use the predicted values from the first stage in the second stage (Equation 3) in order to identify the causal impact of air pollution on health outcomes. This is a more accurate approach than the approach used in existing literature of regressing health outcomes directly on air pollution indices. Regressing health on pollution does not provide a precise estimate of the impact of air pollution on health outcomes as unobserved factors, such as macroeconomic trends, can influence both health outcomes and air quality. By using fire data, we are able to estimate the Indonesian fires as an exogenous shock to Singaporean health outcomes.

Our specifications assume that Indonesian forest clearing for palm oil production is exogenous to Singapore's air quality and economy. Since the Singaporean demand for Indonesian palm oil is negligible as Singapore is not a major market for Indonesian exports of palm oil (Van Gelder, 2004), the demand for palm oil originating from Singapore is unlikely to be a driver of Indonesian forest burning.⁹ Furthermore, the economies of Singapore and Indonesia

⁹Furthermore, out of the 18 major oil palm plantation groups in Indonesia, only one is owned by a Singaporean company (Van Gelder, 2004).

are vastly different. Singapore’s economic activities are largely driven by the service sector, whereas Indonesia’s economy is largely reliant on the agricultural and industrial sectors. According to the World Bank (2016), the value added of the service sector to Singapore’s GDP in 2014 was 75%, whereas the value added by the service sector to Indonesia’s GDP was only 42%. Agriculture contributed 13.34% to Indonesia’s GDP whereas it only contributed 0.03% to Singapore’s GDP. Since the production of palm oil contributes to the agricultural sector, and the demand for palm oil is largely driven by the industrial sector, the fact that the agricultural and industrial sectors combined in Singapore contribute only 25% to Singapore’s GDP indicates that trends driving the palm oil market are not likely to be correlated with the drivers of Singapore’s economy.

As of April 2014, the PSI index composition changed to incorporate PM2.5. This caused a vertical upwards shift in PSI. We use an indicator variable, the PSI change, in our analyses to account for this change. Year fixed effects account for health trends and month fixed effects account for seasonality of pollution and ARTIs. We do not include year by month fixed effects because they would reduce, if not eliminate, effects from the Indonesian fire episodes, 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 our health outcome estimations. Since diarrhea is an intestinal symptom presumably not affected by air pollution, it is sometimes used as a control variable in air pollution studies (Gordian et. al, 1996; Gajate-Garrido, 2003). For example, a patient with an upper respiratory illness as a result of a cold virus could experience diarrhea that is associated with this virus. A patient experiencing conjunctivitis as a result of a cold, rather than air pollution, might also experience symptoms of diarrhea (WebMD, 2016).

We analyze avoidance behavior separately in Section 5.2 using the following model with electricity demand, ED_t , as the dependent variable:

$$ED_t = \theta_3 fire_t + \mathbf{weather}'_t \beta_6 + \alpha_t + \varepsilon_t. \quad (4)$$

5 Results

The results section proceeds as following. In Section 5.1, we analyze the impact of the Indonesian fires on the Singaporean PSI and health outcomes. In Section 5.2, we analyze the impact of the fires on residential electricity use in Singapore. Section 5.3 monetizes the estimated health and electricity impacts to assess the partial welfare effects of the Indonesian fires on Singapore.

In our analysis, we use fire radiative power (FRP) as a measure of fire intensity because its correlation with PSI and PM2.5 are somewhat higher than fire count. However, our results are similar when using fire count instead of FRP. We do not use both measures of fire because they are collinear. For ease of interpretation of the results, we transform PSI, PM2.5, FRP, ARTI, and AC by dividing by their respective standard deviations.

5.1 Impacts of Indonesian Fires on Singaporean Health Outcomes

We use an instrumental variables approach, instrumenting for PSI with FRP. We include an interaction between FRP and mean windspeed, as windspeed is likely to affect the concentration of wildfire smoke blown to Singapore. A Cumby-Huizinga test¹⁰ for autocorrelation suggests there may 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.

Table 3 shows the first stage estimates, where Column 1 uses PSI as the dependent

¹⁰See Cumby (R.E. and Huizinga) for details.

Table 3: First Stage Results

	(1)	(2)
	PSI	PM2.5
FRP	1.425*** (0.261)	3.625** (1.418)
FRP*MeanWindSpeed	-0.0951*** (0.0252)	-0.371** (0.161)
PSI Change [†]	1.195*** (0.188)	
Constant	-1.261 (1.400)	3.169 (4.076)
Weather Controls	Y	Y
Year FE	Y	Y
Month FE	Y	Y
Observations	325	84
F-Stat	26.76	17.69

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

[†]Indicator for before/after PM2.5 was added to the PSI.
Additional lags and/or polynomials of PSI or PM2.5 are not significant and do not significantly change the above results.

variable and Column 2 uses PM2.5 as the dependent variable. Since the PSI data sample is larger, we consider the PSI estimates our headline estimates. The first stage F-statistics of 26 and 17 and the Cragg-Donald F-statistics are an order of magnitude larger than the critical values, suggesting FRP is a strong instrument for PSI and PM2.5. A one standard deviation increase in FRP increases PSI by 1.4 standard deviations and increases PM2.5 by 3.6 standard deviations. These results are statistically significant at the 1% and 5% levels, respectively. A one kilometer per hour increase in the mean wind speed reduces these impacts by 0.10 and 0.37 standard deviations, respectively, as higher wind speeds cause the fire smoke to blow through Singapore faster.

The results of a second stage regression of health outcomes on the predicted air quality are reported in Table 4. A one standard deviation increase in PSI causes a 0.35 standard deviation increase in ARTIs and a 0.29 standard deviation increase in AC cases. A one standard deviation increase in PM2.5 causes a 0.5 standard deviation increase in ARTIs and

Table 4: Second Stage Results

	(1) ARTI	(2) AC	(3) ARTI	(4) AC	(5) Chickenpox
PSI	0.351*** (0.0873)	0.290*** (0.0665)			0.0781 (0.110)
PM2.5			0.499*** (0.106)	0.334*** (0.0945)	
Acute Diarrhea	0.0100*** (0.000964)	0.00677*** (0.000937)	0.0102*** (0.00167)	0.00725*** (0.00172)	0.00337** (0.00168)
Constant	15.46*** (2.804)	5.808** (2.503)	20.54*** (3.036)	11.67** (4.842)	4.973 (3.313)
Weather Controls	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y
Month FE	Y	Y	Y	Y	Y
Observations	325	325	84	84	220
R^2	0.661	0.613	0.853	0.679	0.434

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Additional lags and/or polynomials of PSI or PM2.5 are not significant and do not significantly change the above results.

a 0.33 standard deviation increase in AC cases. These results are all statistically significant at the 1% level. Acute diarrhea, the proxy for general health trends, is highly significant in all models and positively related to ARTIs and AC.

As a falsification test, we estimate the two-stage regression using polyclinic attendances for chickenpox, since there is no medical evidence that air pollution impacts chickenpox. As shown in Table 4, we find no statistically significant impact of the Indonesian fires on chickenpox.

Table 5 reports the reduced form results. A one standard deviation increase in FRP increases ARTIs by 0.66 standard deviations and AC cases by 0.73 standard deviations. A one kilometer per hour increase in the mean wind speed reduces these impacts by 0.06 standard deviations as higher wind speeds cause the fire smoke to blow through Singapore faster.

Table 5: Reduced Form Results

	(1)	(2)
	ARTI	AC
FRP	0.668*** (0.222)	0.730*** (0.198)
FRP*MeanWindSpeed	-0.0513** (0.0235)	-0.0684*** (0.0220)
PSI Change	-0.0144 (0.276)	0.526 (0.411)
Acute Diarrhea	0.00988*** (0.00108)	0.00648*** (0.00107)
Constant	14.50*** (2.812)	5.645** (2.671)
Weather Controls	Y	Y
Year FE	Y	Y
Month FE	Y	Y
Observations	325	325

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Additional lags and/or polynomials of FRP are not significant and do not significantly change the above results.

5.2 Avoidance Behavior

The seasonal haze in Singapore caused by the Indonesian forest fires is pollution that can be directly observed by all Singaporeans. In addition to observing haze with the naked eye, the extensive reporting of the PSI on local television channels, newspapers, and websites, as well as the haze advisories provided by the Singaporean government, will likely lead to avoidance behaviors by individuals to minimize exposure to the pollution. While it is unlikely that Singaporeans will relocate to a different area within their country seeking better environmental quality due to the uniform impact of the haze throughout their small country, they might minimize their outdoor activities to reduce their exposure. Spending more time indoors would result in higher residential energy costs. It is important to estimate these behavioral responses since ignoring them will understate the welfare costs of pollution (Zivin and Neidell, 2014).

Table 6 shows the impact of the Indonesian fires on residential electricity demand in

Singapore. Linear and various polynomial models are estimated to investigate the nature of the relationship between the Indonesian fires and the Singaporean energy demand. Column 3 is our preferred specification, since there appears to be a cubic relationship but higher order polynomials are not significant. Column 3 shows that a one standard deviation increase in FRP causes a 0.14 standard deviation increase (with decreasing marginal effects) in day-ahead electricity demand and a 0.11 standard deviation increase (also with decreasing marginal effects) in two day-ahead electricity demand. One- and two-day lagged FRP has a statistically significant positive impact on electricity demand in Singapore. FRP_t and FRP_{t-3} and longer lags are not significant. It takes time for the fire smoke to blow from Indonesia to Singapore, which explains why FRP_t is not significant.

Since Singapore is located by the equator, this increase in energy demand is largely caused by an increase in air conditioner use as Singaporeans choose to stay indoors. Air conditioners also help filter out air pollution. In 2013, electricity use for air conditioning accounted for the largest amount of residential energy consumed at 36.7%, with the water heater, used mostly to heat water for showers, making up 20.9% of electricity consumed by all households (NTU, 2014). The air conditioner saturation in Singapore in 2003 was 72%, on par with the United States (Auffhammer, 2011). Taken together, these results imply that an increase in residential energy use as a result of the Indonesian fires could be a result of averting behavior as more Singaporeans choose to stay indoors and utilize air conditioners on the days of the fires.

5.3 Welfare Effects

Estimates of the welfare costs imposed on Singapore by Indonesia's forest fires can have important policy implications. We estimate welfare costs in two stages. First, using our results from Section 5.1, we predict how much lower the PSI and the number of ARTIs and AC cases in Singapore would be if there were no fires in Indonesia. Then, we estimate the direct health costs of treating the additional ARTI and AC cases as well as the indirect costs

Table 6: Impact of Fires (FRP) on Electricity Demand

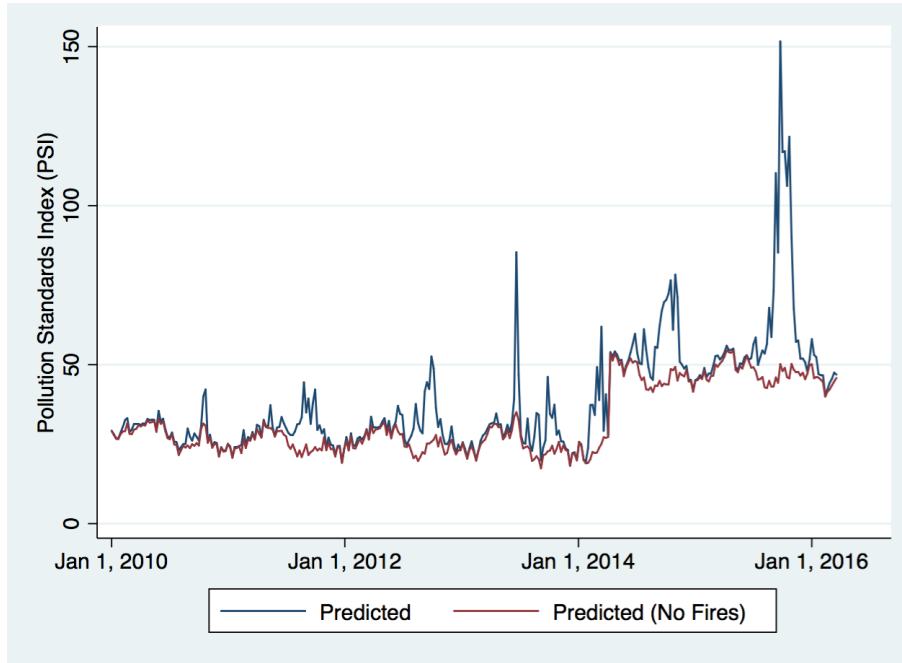
	(1)	(2)	(3)	(4)	(5)
FRP _{t-1}	0.0293** (0.0114)	0.0838*** (0.0284)	0.139** (0.0582)	0.102 (0.0970)	0.0656 (0.150)
FRP ² _{t-1}		-0.00817** (0.00354)	-0.0301* (0.0165)	-0.00640 (0.0465)	0.0270 (0.117)
FRP ³ _{t-1}			0.00175 (0.00111)	-0.00266 (0.00762)	-0.0134 (0.0357)
FRP ⁴ _{t-1}				0.000236 (0.000383)	0.00157 (0.00441)
FRP ⁵ _{t-1}					-5.54e-05 (0.000184)
FRP _{t-2}	0.0228** (0.0112)	0.0691** (0.0276)	0.114** (0.0518)	0.131 (0.0855)	0.213 (0.139)
FRP ² _{t-2}		-0.00795** (0.00343)	-0.0268** (0.0134)	-0.0363 (0.0424)	-0.123 (0.114)
FRP ³ _{t-2}			0.00162* (0.000862)	0.00325 (0.00730)	0.0329 (0.0351)
FRP ⁴ _{t-2}				-8.09e-05 (0.000377)	-0.00393 (0.00433)
FRP ⁵ _{t-2}					0.000164 (0.000181)
Constant	5.235*** (0.443)	5.398*** (0.437)	5.490*** (0.431)	5.476*** (0.430)	5.485*** (0.431)
Weather Controls	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y
Month FE	Y	Y	Y	Y	Y
Day of Week FE	Y	Y	Y	Y	Y
Observations	1,570	1,570	1,570	1,570	1,570
R ²	0.698	0.699	0.699	0.699	0.700

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Additional FRP lags are not significant and do not significantly change the above results.

Figure 3: Predicted PSI, with and without Fires

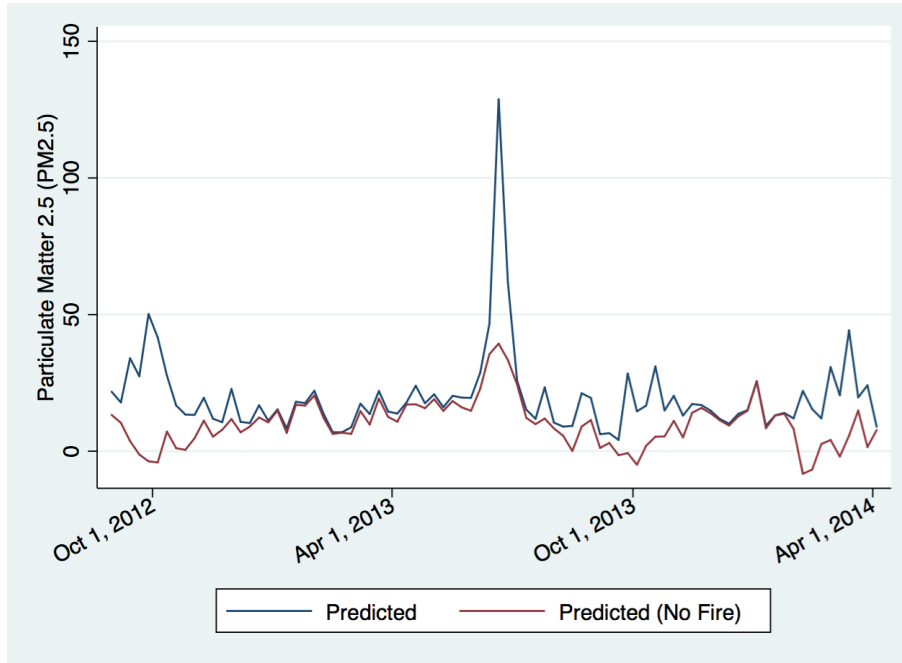


of lost productivity due to these illnesses. Lastly, we estimate the increase in electricity demand and associated costs that the Indonesian forest fires impose on Singapore.

Figure 3 shows PSI predicted using the estimation results from Column 1 of Table 3 using actual fire radiative power (blue) and assuming a counterfactual of no fires (red). Figure 4 shows similar predictions for PM_{2.5} using the estimation results from Column 2 of Table 3. According to the predictions in Figures 3 and 4, the PSI and PM_{2.5} were 16% and 49% higher on average, respectively, than they otherwise would have been without the Indonesian fires. As Table 7 shows, these percentages have been rising over time. 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).

Figure 5 shows weekly ARTI predictions using the estimation results from Column 1 of Table 5 using both actual fire radiative power (blue) and assuming a counterfactual of no fires (red). According to the predictions in Figure 5, 1.75% of infections over this time period

Figure 4: Predicted PM2.5, with and without Fires



were attributable to the Indonesian fires. As Table 7 shows, this percentage was lower in earlier years and has been rising over time to 4% in 2015.

Figure 6 shows weekly AC case predictions using the estimation results from Column 2 of Table 5 using both actual fire radiative power (blue) and assuming a counterfactual of no fires (red). According to the predictions in Figure 6, 1.5% of cases over this time period were attributable to the Indonesian fires. As Table 7 shows, this percentage was lower in earlier years and has been rising over time to over 3% in 2015.

Finally, using estimates from Column 3 of Table 6, we predict electricity demand using both actual fire radiative power and assuming a counterfactual of no fires. This allows us to estimate the increase in electricity demand from January 2012 to June 2016 attributable to the Indonesian fires. As shown in Table 7, the fires caused nearly a 0.9% increase in electricity demand over this time, with a maximal increase of 2.2% in 2015.

Table 8 shows the estimated direct and indirect health costs from ARTIs and AC cases, as well as the estimated costs from increased electricity use, as a result of the Indonesian

Figure 5: Predicted Acute Respiratory Tract Infections (ARTI), with and without Fires

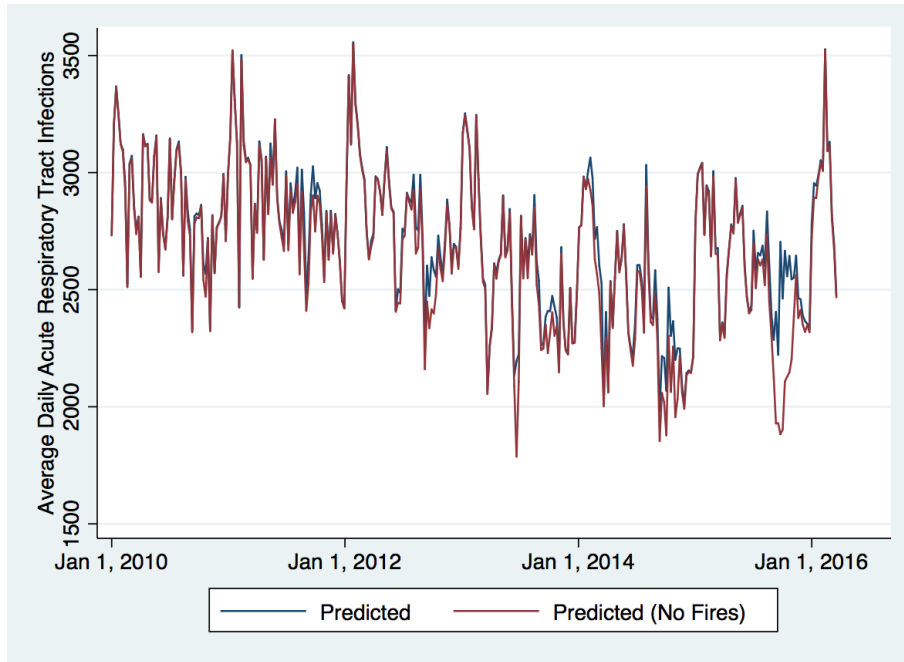


Figure 6: Predicted Acute Conjunctivitis (AC) Cases, with and without Fires

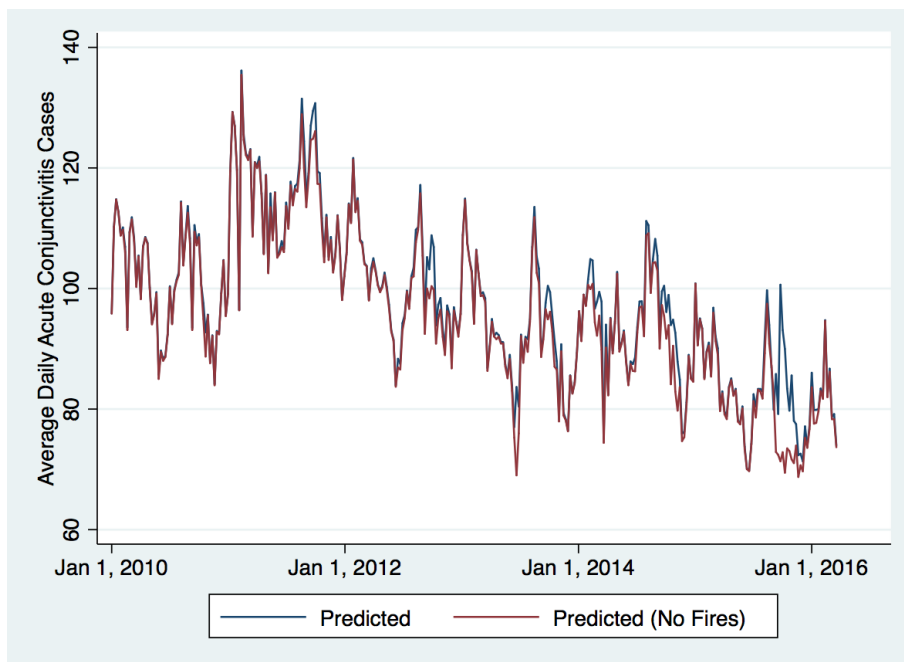


Table 7: Percent Increases Attributable to Fires

	PSI	PM2.5	ARTI	AC	Electricity Demand
2010	4.73%		0.39%	0.40%	
2011	13.54%		1.04%	0.76%	
2012	15.45%	69.05%	1.30%	1.15%	0.44%
2013	15.18%	36.06%	1.38%	1.31%	0.38%
2014	18.26%	74.40%	2.86%	2.32%	0.78%
2015	23.04%		4.13%	3.73%	2.21%
Full					
Sample	16.01%	49.47%	1.75%	1.50%	0.89%

forest fires. The second two columns of the top panel show the increase in ARTI and AC cases based on the estimates from Table 7. According to the Deputy Director of the Jurong Regional Polyclinics (see Appendix B), the total direct cost of treating an ARTI or a case of AC is approximately S\$50. Using this per case cost, we calculate the direct cost of treating ARTI and AC cases in the fourth column. Over our full sample, we estimate a direct ARTI and AC cost of just under S\$4 million.

Given the information provided by the Deputy Director of the Jurong Regional Polyclinics, we assume that each case of ARTI and AC results in two days of missed work for the patients of working age, which account for 40% of cases. Given average monthly earnings of S\$4,892,¹¹ we assume each of these illnesses results in (2 days)(S\$4,892 per month / 22 working days)=S\$444 of lost productivity. Thus we estimate the total indirect cost of ARTI and AC in the form of lost productivity over our sample of S\$14 million.

The last column in the top panel adds the direct and indirect cost of ARTI and AC cases. Given that polyclinics treat approximately 20% of cases, we scale our estimated total health costs up to 100% of the population by multiplying them by 5. Total health costs for 100% of the population are shown in the second column of the bottom panel of Table 8. Over all years in our sample, total health costs are estimated at S\$90. These are lower in earlier years and have been growing over time to nearly S\$33 million in 2015.

Assuming an electricity cost of 19.27 Singaporean cents per kWh,¹² we estimate total

¹¹According to International Labour Organization (ILO) at <http://www.ilo.org>, monthly average earnings in 2015 were S\$4,892.

¹²The rate in Singapore from July-September 2016 was 19.27 cents per kWh according to Singapore

increase in electricity costs due to the Indonesian fires in the second column of the bottom panel of Table 8. These costs have also been getting bigger over time, ranging from S\$35 million in 2012 to S\$210 million in 2015.

We estimate the total cost of the Indonesian fires in terms of direct and indirect health costs from an increase in ARTIs and AC cases as well as increased electricity usage due to avoidance behavior to be S\$450 million (US\$333 million) over our sample. Since the Indonesian forest burning has become more severe, these costs have been increasing over time and were S\$243 million (US\$179 million) in 2015 alone, just over 0.06% of Singaporean GDP. The indirect cost of ARTIs and AC due to lost productivity is more than three times the direct cost of treating these illnesses. Furthermore, the avoidance cost of increased electricity usage is approximately four times the combined direct and indirect ARTI and AC cost. This highlights the importance of considering indirect costs and especially avoidance behavior when estimating health impacts of air pollution.

These estimated costs should be viewed as a lower bound of the impacts of Indonesian forest burning on Singaporean health for several reasons. First, we only consider ARTIs and AC cases. There may be other illnesses and health impacts such as low birth weights and premature mortality.¹³ We do not have data on other health impacts and as such estimating these impacts is outside the scope of this analysis. Second, if individuals treated for ARTIs or AC are given extra medications, they may use these to treat a second illness or an illness in a family member, who could then avoid a trip to a polyclinic. Such illnesses would not be captured in the polyclinic attendance data. Third, there may be additional avoidance behaviors such as purchasing air filters or traveling out of Singapore during haze episodes.

Power's website. Singapore Power is the utility company that owns and operates Singapore's electricity and gas transmission and distribution networks.

¹³A full list of haze related ailments can be found in Glover and Jessup (1999).

Table 8: Costs Attributable to Indonesian Fires

	ARTI Cases	AC Cases	ARTI + AC Direct Costs	ARTI + AC Indirect Costs	Total Health Costs (20% Popltn)
2010	2,939	106	S\$152,286	S\$540,920	S\$693,206
2011	7,771	229	S\$400,011	S\$1,420,839	S\$1,820,850
2012	9,711	309	S\$501,033	S\$1,779,668	S\$2,280,701
2013	9,226	317	S\$477,146	S\$1,694,821	S\$2,171,967
2014	18,318	567	S\$944,243	S\$3,353,950	S\$4,298,192
2015	28,144	809	S\$1,447,687	S\$5,142,185	S\$6,589,872
Full Sample	77,234	2,379	S\$3,980,634	S\$14,139,212	S\$18,119,846
	Total Health Costs (100% Popltn)	Electricity Costs	Total Cost	Total Cost (USD)	Total Cost (% of GDP)
2010	S\$3,466,030		S\$3,466,030	\$2,564,862	0.001%
2011	S\$9,104,252		S\$9,104,252	\$6,737,147	0.002%
2012	S\$11,403,505	S\$35,791,494	S\$47,194,998	\$34,924,299	0.012%
2013	S\$10,859,835	S\$34,068,240	S\$44,928,075	\$33,246,775	0.011%
2014	S\$21,490,961	S\$73,598,944	S\$95,089,906	\$70,366,530	0.023%
2015	S\$32,949,362	S\$210,072,421	S\$243,021,783	\$179,836,120	0.061%
Full Sample	S\$90,599,231	S\$359,889,848	S\$450,489,080	\$333,361,919	

6 Conclusion

This study performs the first causal analysis of the effects of the Indonesian forest burning on air quality and health outcomes in Singapore. Using satellite fire data from Indonesia as an instrument for air pollution, we use two-stage least squares to estimate the impact of air pollution on Singaporean polyclinic attendances for acute respiratory tract infections and acute conjunctivitis. The Indonesian 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 challenge attempts to quantify air pollution impacts. We find a one standard deviation increase in the Pollution Standards Index increases polyclinic attendances for acute upper respiratory tract infections and acute conjunctivitis by 0.35 and 0.29 standard deviations, respectively.

We use our estimation results to predict polyclinic attendances for acute upper respiratory tract infections and acute conjunctivitis assuming a counterfactual of no Indonesian fires. We monetize these values by combining them with various cost estimates. We find that from

January 2010 through June 2016 the Indonesian fires have resulted in direct health costs of S\$19.9 million (US\$14.7 million) and indirect costs due to missed work of S\$70.7 million (US\$52.3 million).

While our study uses polyclinic attendances for acute upper respiratory tract illnesses and acute conjunctivitis, future research using other estimates of health costs, such as hospital admittances and mortality rates from haze related diseases, can provide more extensive estimates of direct costs from the Indonesian fires. Our estimates should thus be viewed as a lower bound.

Few air pollution studies examine avoidance behavior in conjunction with health costs. We estimate the increase in electricity demand induced by the fires as Singaporeans use air conditioners and stay indoors to reduce exposure to air pollution. Results indicate that a one standard deviation increase in fire radiative power increases one and two-day ahead electricity demand by more than 0.1 standard deviations. We find that from January 2012-June 2016 the Indonesian fires have resulted increased electricity costs of S\$359.9 million (US\$266.3 million). This estimate should also be viewed as a lower bound, since it does not include additional averting behaviors such as traveling out of the country.

The cost of this avoidance behavior is roughly four times our estimate of health costs. While both estimates are lower bounds, the relative magnitudes emphasize the importance of considering the costs of averting behavior in addition to health costs from exposure to air pollution. Negotiations on transboundary pollution policies should therefore consider not only health impacts but also behavioral responses to pollution episodes.

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A Additional Haze Background

Figure A.1: Screen Shot of Singaporean Government Haze Website

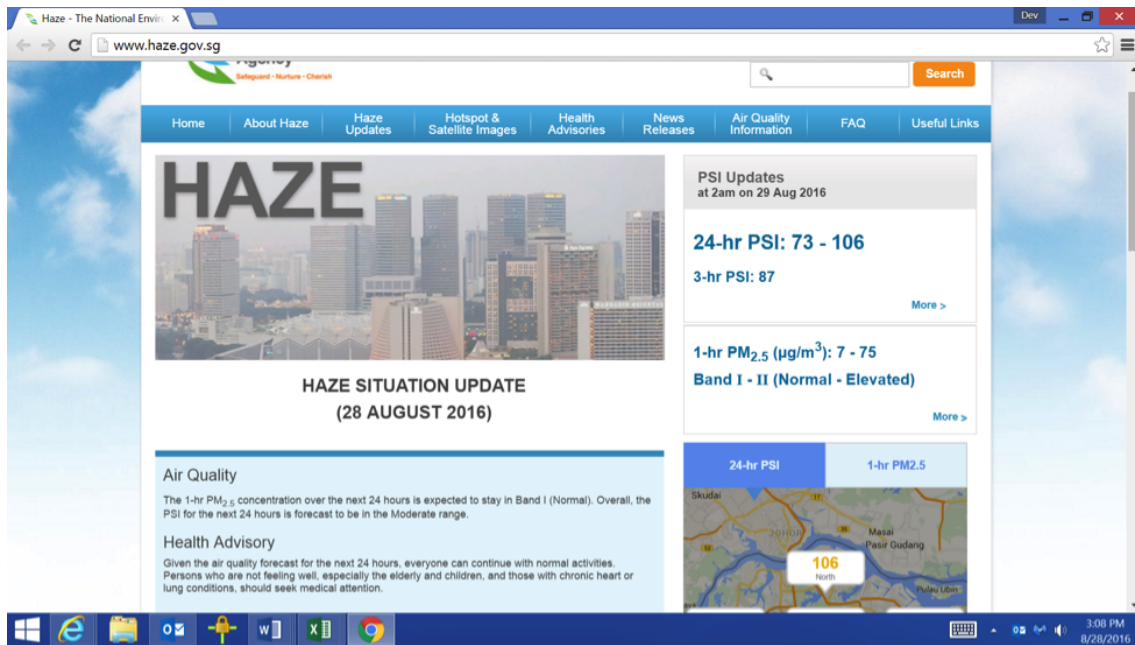
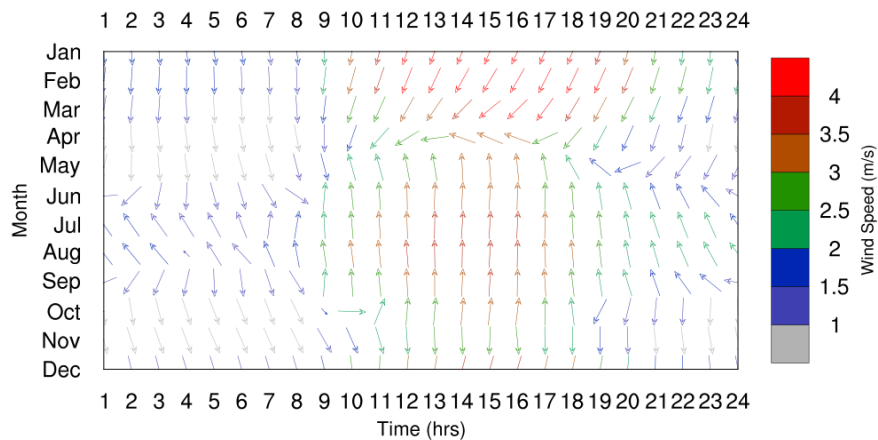


Figure A.2: Hourly Variation of Surface Wind Speed in Singapore



Source: <http://www.weather.gov.sg/climate-climate-of-singapore/>

B Interview with Dr. Meena Sundram, Regional Director, Jurong Polyclinics, Singapore

1. *Treatment of acute respiratory tract infections*¹⁴

- (a) How much does it cost the polyclinic to treat this illness? “MOH will have more accurate data but I can estimate that this is under 20 Singapore dollars as polyclinics are subsidized.”
- (b) Can you provide an estimate of how it would cost the polyclinic to treat this illness if it was not subsidized? “\$40-\$50 (Singapore dollars)”
- (c) How long does the average person typically stay home for recovery? “2 days”

2. *Treatment of acute conjunctivitis*

- (a) How much does it cost the polyclinic to treat this illness? “MOH will have more accurate data but I can estimate that this is around 15 Singapore dollars as polyclinics are subsidized.”
- (b) Can you provide an estimate of how it would cost the polyclinic to treat this illness if it was not subsidized? “\$40-\$50 (Singapore dollars)”
- (c) How long does the average person typically stay home for recovery? “2 days”

3. *Polyclinic visitors*

- (a) Who tends to visit the polyclinics? “Everyone as is it subsidized.”
- (b) Do these people tend to have better, worse, or similar health than the population that does not use the polyclinics? “Similar”

¹⁴The cost of treating URTI and AC of \$50 per case quoted by Dr. Meena Sundram is the same as the upper bound treatment cost of these diseases, and the estimation of 2 lost workdays provided by Dr. Sundram is the same as the lower bound lost days, used by Glover and Jessup (1999).

- (c) Approximately what percentage of the patients who visit polyclinics for acute upper respiratory tract infections (and conjunctivitis) are of working age? “Approximately 40%. Children and NS [National Service] boys around 20%, 40% adults below 65. The rest would be above 65.”

4. *Polyclinics*

- (a) How many polyclinics are there and how far must people travel to get there? “18 all over the island. Located very conveniently so travel would be under 20 minutes.”
- (b) What are the average wait times at the polyclinics? “With an appointment can be under one hour but peak times 2-3 hrs especially Monday morning.”