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Abstract

Smoke from forest fires blanketed the Indonesian islands of Kalimantan and Sumatra in late 1997. Population-based longitudinal survey data are combined with satellite measures of aerosol levels to assess the impact of the fires on adult health. To account for unobserved differences between haze and non-haze areas, we compare changes in health of individual respondents. Between 1993 and 1997, individuals exposed to haze experienced greater increases in difficulties with activities of daily living than their counterparts in non-haze areas. Results for respiratory and general health, though more complicated to interpret, suggest the haze had a negative impact on these dimensions of health.

INTRODUCTION

In late 1997 Southeast Asia experienced the worst forest fires on record. Large tracts of forest and arable land on the islands of Kalimantan and Sumatra were destroyed. Parts of those islands were blanketed with thick haze of smoke for several months, forcing President Soeharto to declare a state of emergency in September 1997. Analysis of SPOT images suggests that around 5 million hectares of land burned, of which 20% was forested (Liew et al. 1998).

The effects of the fires were felt throughout the region—in Brunei, Singapore, Malaysia, and as far afield as Thailand and Viet Nam. Early estimates suggested that the fires caused at least $4.5 billion in damage in the region (Schweithelm and Glover 1999). Most of these costs are attributed to the health consequences of the fires. Because the haze was heaviest and persisted for the longest over parts of Indonesia, several studies have concluded that the Indonesian population suffered the greatest health costs. Ruitenbeck (1999) bases his conclusions on data from hospitalizations and self treatments in Sarawak, Malaysia. Sastry (2002) examines the effects of the smoke on daily mortality in Kuala Lumpur and reports an increase in mortality for 65-74 year olds that lasted several weeks. He concludes that the results are "suggestive of wider short-term health impacts, particularly with respect to acute morbidity" and speculates that the effects of the smoke haze "in Indonesia itself are likely to be tremendous".

These conclusions are potentially flawed for two reasons. First, the degree of exposure to haze was substantially lower in Malaysia than in Kalimantan and Sumatra. It is unclear how to interpret extrapolation to the Indonesian population unless one assumes that the effects of haze on health are linear. Second, in poor economies, analyses of those who use health care likely miss the poorest and potentially most vulnerable part of the population.

This paper uses uniquely rich data from Indonesia to directly measure the short-term effects of the fires on the health status of the adults who were exposed to the most severe haze. Rather than rely on in-patient, out-patient, or mortality data to infer effects on health outcomes, we use longitudinal population-based household survey data, the second wave of which was collected at the time of the

Indonesian fires. We combine these survey data with satellite-based aerosol measures to produce a rich data source with which to examine the immediate effects of the fires.

In the following sections of the paper we describe the Indonesian fires and discuss what is known about the health consequences of exposure to particulates. Our data, the Indonesia Family Life Survey (IFLS), are described in conjunction with two important methodological issues. First, the health indicators that are examined are introduced and their interpretation is discussed. Second, comparisons of health status of adults living in areas that were exposed to haze in 1997 with the health of adults living in areas not exposed is shown to be contaminated by unobserved heterogeneity and overstates the impact of the fires on health. Exploiting the longitudinal dimension of IFLS, we develop a difference-in-difference approach to estimation. Specifically, health status reported several years prior to the fires is compared with health reported by the same person at the time of the fires. We then contrast changes among individuals exposed to the haze in 1997 with changes among individuals who were not exposed. The results indicate that exposure to fires has a negative and significant impact on the health of older adults and prime-age females but that much of the impact appears to be transitory.

THE INDONESIAN FIRES

The Indonesian fires have their origins in the ecologies and economies of Sumatra and Kalimantan—the two major islands on which the 1997 fires occurred. Population densities on these islands are low and tropical rain forest covers considerable portions of the land area. In some areas the forest floor is covered with a thick and exceptionally flammable layer of dried organic material.

On both Sumatra and Kalimantan small scale farmers have traditionally used controlled burns as a method of land clearing. Recent excavations have revealed sites where swidden (slash and burn) agriculture has been practiced for some 200 years (UNDP 1998; Lawrence and Schlesinger 2001). Used correctly, fire plays a valuable ecological role in swidden agriculture, because it makes available to future crops the nutrients bound up in plant material that has been cleared (UNDP 1998).

Over the last quarter century, the magnitude of fires on Sumatra and Kalimantan has increased dramatically, despite an ostensible ban on the practice put in place in 1984 and reaffirmed in 1997 (UNDP 1998; Ketterings et al. 1999). The increase in fires is a function of several phenomena. First, the amount of land under commercial control has risen as a result of timber and plantation concessions granted in the last three decades. These industries create more flammable debris and use fire for clearing over larger areas than do small-scale farmers. Second, when fires burn out of control, logged areas sustain more damage than primary forest (Siegert et al. 2001). Third, the Indonesian government's efforts to move people from the densely populated islands of Java and Bali to less settled areas have increased the numbers of small scale farmers—so much so that on Sumatra cultivation can no longer be called "shifting," although these farmers continue to use fire to clear land (Ketterings et al. 1999). Finally, conflicts over claims to land have increased, and fire is sometimes used as a weapon in such disputes (Glover and Jessup 1999).

In recent years the most damaging fires have occurred in 1982-1983, 1987, 1991, 1994, and 1997-1998. In all of these years, the fires were exacerbated by drought brought on by the El Nino Southern Oscillation (ENSO) (Jim 1999). In ENSO years the delay of the monsoon means that fires burn for several months longer than usual. Also, because the land is unusually dry, fires burn out of control more easily, sometimes escaping into peat forests, where they burn underground and may ignite shallow coal seams.

The forest fires of 1997-1998 were by far the largest in Indonesia's history, burning some 5 million hectares before they were eventually quenched by the rains in mid-to-late November (Ruitenbeck 1999). No sooner had the rains stopped than fires sprang up again on Kalimantan (but not on Sumatra) in early 1998.

One way to characterize the extent and consequences of the fires is through satellite imagery. Figure 1 displays locations of fires that occurred during the second half of 1997, identified by light emissions recorded by the DMSP-OLS satellite (Fuller and Fulk 2000).

The consequences of the fires, however, were not limited to the areas of burning. The fires produced visibility-limiting haze that caused transportation slowdowns and accidents, shutdowns of schools and businesses, and health problems. Easterly and south easterly winds spread haze from the fires over an area far larger than where the fires occurred.

This is reflected in Figure 2 which displays levels of haze on a particular day every two weeks from the start of the fires in early September 1997, to mid-November. Haze is measured using an aerosol index calculated with data from NASA's Total Ozone Mapping Spectrometer (TOMS). A value of zero indicates the air is crystal clear. NASA describes a value of four as corresponding to barely being able to see the midday sun, and aerosol index levels that are four and above are depicted by a black cloud in the figure. The figure highlights two important facts. First, the haze spread right across the southern part of Kalimantan (Borneo), covered all but the most northern part of the island of Sumatra, and spread up to Singapore and Malaysia for a short period of time. Estimates suggest the haze covered over 300 million square kilometers. Second, the figure clearly demonstrates that the areas with high levels of haze varied during this period with the haze building up in the last half of September, dissipating in early October and then, as the atmospheric pressure changed, both the area covered by haze and the intensity of the haze increased again until mid November, when the fires started dying out. Whereas Java, Bali, Lombok and Sulawesi were not affected by the haze, across Kalimantan and Sumatra, there is substantial variation in the timing, duration, and intensity of exposure to haze. This variation is important since it is exploited below in our analyses of the impact of the haze on health.

The magnitude of the 1997 fires is placed in a longer-term context in Figure 3 which reports the daily TOMS aerosol index from 1996 (when the satellite started recording data) through 2002. The capital cities of three provinces are selected because the provinces were blanketed with haze and they are included in the survey data used below. The figures illustrate a key point: 1997 was nothing short of a catastrophe. The TOMS aerosol index peaked very close to 6 in Sumatra and slightly over 5 in South Kalimantan. These levels are unprecedented in recent history. The figures also underscore the spatial and temporal heterogeneity in the haze.

Both Figures 2 and 3 indicate that haze levels in Kalimantan and Sumatra were significantly worse than the levels in Singapore and Malaysia. Other data corroborate this evidence. The most general ground-based measure of the hazard smoke presents for health, referred to as the PM_{10} measurement, reflects the number of particles with a diameter of less than 10 micrometers (a size that can enter the respiratory tract) per cubic meter of air ($\mu m/m^3$). Measurements in Jambi (on the west coast of Sumatra and marked on Figure 3) in early October document particulate concentrations of 1,864 $\mu m/m^3$ —a level three times higher than that at which the U.S. Environmental Protection Agency (EPA) warns people to use respirators during unavoidable outdoor activities (Kunii et al. 2002). Measurements taken a month later in Palembang, Sumatra indicate PM_{10} levels of 402, which generate EPA warnings that healthy people should curtail vigorous activities (Pinto and Grant 1999). In contrast, in Singapore and Malaysia PM_{10} levels in September averaged below 200 $\mu m/m^3$ (Emmanuel 2000; Sastry 2002).

HEALTH CONSEQUENCES OF EXPOSURE TO HAZE

Ambient air quality, which reflects the presence of both particulate matter and gaseous compounds, has been associated with increased risks of mortality and respiratory morbidity in numerous studies. Although the associations are strong, the precise biological pathways through which exposure to poor-quality air affects health are not fully delineated. Both the size of the particles and the chemical composition of the particles and the gasses appear to be relevant (Harrison and Yin 2000; Churg and Brauer 2000). With respect to size, all particles with a diameter of less than 10 micrometers (μm) can enter the respiratory tract, but those with a diameter of less than 2.5 μm ("fine" particles) are a particular concern because they are small enough to penetrate deeply into the lungs, enter the bloodstream, and be transported to other tissues (Malilay 1999; McClellan 2002). With respect to composition, attention has focused particularly on carbon monoxide, nitrogen dioxide, lead, sulfur dioxide, and polycyclic aromatic hydrocarbons. Less is known about the roles of aldehydes, free radicals, and volatile organic compounds.

Although the role of gaseous compounds is sometimes considered, particularly in studies of outdoor air pollution, we focus our discussion on the health implications of exposure to particulates, because most of the evidence from the Indonesian fires suggests that fine particulates were elevated to far more dangerous levels than were gaseous compounds (Pinto and Grant 1999; Kunii et al. 2002). Studies that consider the health impacts of exposure to particulates can be divided into three general types with respect to the source of exposure: outdoor air pollution resulting from routine activities that involve the combustion of fossil fuels, such as vehicular operation and manufacturing; indoor exposure from routine activities that involve the combustion of biomass fuels, such as cooking or heating; and exposure from a catastrophic event such as a forest fire, building fire, volcanic eruption, or an explosion. We discuss the literature on mortality and respiratory morbidity—the health outcomes on which most analyses focus.

Mortality

Exposure to particulates appears to elevate mortality risk. Most of the evidence for this relationship comes from studies of air pollution, which often has a chemical makeup similar to biomass smoke (because both involve combustion processes), although exposure to air pollution is generally at a lower level over a longer period of time.

Using data from the Harvard Six Cities Study, Dockery et al. (1993) find that Total Suspended Particulate (TSP) levels are significantly associated with increased mortality in each of six U.S. cities. Chay and Greenstone (2003) use variations in air quality attributable to the 1981-82 recession to identify the effects of pollution on infant mortality in the United States. They find that a 1 mg /m^3 reduction in particulates results in about 4-8 fewer infant deaths per 100,000 live births at the county level. Cropper et al. (1997) study the health effects of air pollution in Delhi, India. They present evidence of a positive relationship between particulate air pollution and daily nontraumatic deaths, but the impacts are smaller than those estimated for other countries. They attribute the lower impact to differences in distributions of age and cause of death. Most deaths in Delhi occur before the age of 65, from causes not strongly associated with air pollution.

Evidence of the impact of the Indonesian fires on mortality is mixed. Recent work by Sastry (2002) finds that daily increases in 1997 haze levels in two urban areas of Malaysia (Kuala Lumpur and Kuching) are associated with increased mortality rates for older individuals in these areas. For Singapore, however, Emmanuel (2000) finds no significant increase in mortality during the 1997 haze.

Respiratory Morbidity

Breathing air with a high level of particulates can damage both the upper and lower respiratory tract, resulting in inflammation of the airways and conditions such as coughs, bronchitis, difficulty breathing, reduced lung function, and ultimately more severe obstructive breathing disorders (Chretien and Nebut 1996). Most of the evidence about the respiratory consequences of exposure to intense levels of particulates comes from studies during or shortly after short-term exposure. Very little is known about the long-term effects of smoke exposure.

Nor is much known about respiratory morbidity in Indonesia during the 1997 fires. Comparisons of routine data collected from government health facilities reveal an increase in cases of Acute Respiratory Infection and bronchial asthma between September 1997 and June 1998, relative to the same period in 1995-1996 (Aditama 2000). A study based on a convenience sample of some 600 Indonesians in Jambi in September 1997 (when particulate levels far exceeded the EPA's "hazardous" rating) found high reported levels of respiratory problems (91% of interviewed respondents), shortness of breath when walking (44%), and shortness of breath with hard physical work (36%) (Kunii et al 2002).[1] Another study comparing 127 high school students in two areas of Central Kalimantan (one with twice the levels of particulates of the other) found that males in the area of poorer air quality performed significantly worse on physical assessments of lung function, although no difference emerged in prevalence of bronchitis or bronchial asthma (Santoso, cited in Aditama 2000).

[1] As discussed in more detail below, interpretation of self-reported morbidities is not straightforward. The Kunii et al. study was conducted during a period when particulate levels were more than five times higher than the Environmental Protection Agency's threshold for a hazardous rating, and so morbidities were likely to be elevated. Moreover, each respondent participated in a 15 minute interview which focused exclusively on health. This likely resulted in respondents "helping" the survey by responding affirmatively to questions about health problems, especially in the case of general questions like whether the respondent suffered from some respiratory problem. (See, for example, Sudman, Bradburn and Schwarz 1996, for a discussion.) Moreover, the authors report that many of the conditions reported were mild. The reported levels of health problems in this study are very high and, for these reasons, likely to be overstated.

Other studies consider respiratory health in Singapore and Thailand, where levels of particulates were also elevated by the Indonesian fires, but to a considerably lesser degree. In Singapore, increases in PM_{10} levels (from 50 to 150 µm /m^3) were associated with a 30% increase in haze-related health conditions (upper respiratory tract illness, asthma, and rhinitis) (Emmanuel 2000). In Thailand a comparison at the time of the haze of outpatient visits in southern Thailand (where air quality deteriorated) and northern Thailand (where it did not) revealed a relative increase in southern Thailand in both outpatient visits and inpatient admissions for respiratory conditions (Phonboon et al. 1999). In Malaysia, data from outpatient visits in Kuala Lumpur and Kuching indicate a rise in respiratory-related visits during the haze (World Health Organization 1998; Brauer and Hisham-Hashim 1998).

A number of studies in other settings consider the respiratory consequences of exposure to smoke from fires. Two conducted in California suggest that exposure is associated with immediate increases in respiratory morbidity (Lipsett et al. 1994; Shusterman et al. 1993). Another study of fire victims immediately and three months after exposure shows that while airway reactivity diminishes as duration since the fire increases, other aspects of lung function show no improvement (Kinsella et al. 1991).

Some analyses concentrate particularly on firefighters, who are regularly exposed to smoke. Generally studies of wildland firefighters (for whom exposure tends to be seasonal) point to an association between exposure to smoke and acute respiratory health, and to the persistence of some symptoms after the firefighting season ends (Brauer 1999). Studies are now underway of firefighters at the World Trade Center (WTC) site, a number of whom developed persistent coughs during their work at the bomb site (Prezant et al. 2002). Banauch et al. (2003) use data from a sample of firefighters exposed to the WTC disaster to show that for about 55% of workers who were highly exposed, lung dysfunction documented one or three months after the event was still present at six months.[2]

[2] Apart from this study and the Kinsella et al. (1991) study, almost no research assesses the duration for which exposure affects respiratory health, presumably because of the difficulties of assembling longitudinal data on post-exposure outcomes.

Exposure to indoor smoke from the combustion of cooking fuels also displays strong associations with both acute respiratory infections and acute lower respiratory infections (Bruce, Perez-Padilla, and Albalak 2000). Women and young children are particularly likely to be exposed as they tend to be indoors, especially when food is being cooked. In an extremely carefully executed observational study conducted in Kenya, Ezatti and Kammen (2001a; 2001b) constructed measures of exposure to particulates from biomass fuels, based on longitudinal data collected over a two year period. They show that time spent with both ARI and ALRI is an increasing concave function of daily exposure to PM_{10}. In an effort to directly address the issue of whether indoor air pollution affects respiratory illness, a controlled experiment is now underway in Guatemala, in which the respiratory health of individuals living in treatment households who have received a cookstove that has been shown to reduce the presence of particulates will be compared to health for individuals in control households in which open fires are used for cooking (Albalak et al. 2001; Smith 2004).

A substantial body of other work has considered the consequences for respiratory health of exposure to particulate air pollution (for an extensive review, see Pope et al. 1995). Exposure has been associated with increased hospitalization for respiratory disease, exacerbation of asthma, increased incidence and duration of respiratory symptoms, declines in lung function, and restricted lung activity.

Several difficulties complicate interpretation of the results described above. A well-documented issue with respect to the studies of mortality is the question of whether elevated particulate levels simply hasten death among frail individuals for whom the end is already near.

With respect to the consequences of biomass smoke for respiratory morbidity, most of the studies analyze groups that are select in various ways. Two of the studies of Indonesia rely on small samples chosen by convenience. Several studies analyze administrative data from health facilities. In contexts where access to health care is limited, however, the group who chooses to seek medical care may be quite different from the group who does not. Firefighters, of course, are likely to be a particularly fit group of individuals. Although the studies document increases in respiratory morbidity that accompany exposure to haze, the results do not necessarily generalize to broader populations.

DATA

We combine longitudinal household survey data collected in Indonesia in 1993, when there were no fires of note, and 1997, while the fires were burning, with information on the intensity of the smoke haze derived from satellite data. This combination provides unique opportunities to measure the effects of the fires on the health and well-being of the Indonesian population. We begin with a description of the household survey data and then turn to the measurement of smoke haze.

IFLS is an on-going longitudinal survey of individuals, households, communities, and facilities. The first wave, conducted between August and December, 1993, interviewed over 7,200 households in 321 enumeration areas on the islands of Sumatra, Java, Kalimantan, Sulawesi, Bali, and West Nusa Tenggarra. The survey represents 83% of the Indonesian population. Individual interviews were conducted with the household head, spouse, up to two children, and up to two other adults.

IFLS2, the first follow-up survey, was conducted in 1997. Between August and December, 1997 the 321 enumeration areas were visited, the original household was located, and all household members were re-interviewed. If a household or an individual interviewed in 1993 had moved nearby (within 30 minutes by public transportation), the interviewer would attempt to conduct the interviews at the new location. Longer distance movers were interviewed in late 1997 and early 1998 as long as their new location was in one of the 13 IFLS provinces included in IFLS. Over 94% of IFLS1 households were successfully re-interviewed in IFLS2.[3]

In addition to basic demographic and economic characteristics of respondents, the IFLS collects detailed information on health. Respondents are asked to report their general health status, whether they have difficulties with activities of daily living, and whether various symptoms were experienced in the month before the survey. Height and weight are measured as well. In 1997 additional physical assessments were conducted by trained healthworkers. Because these assessments are not available in

[3] See Frankenberg and Karoly (1995) for a description of IFLS1 and Frankenberg and Thomas (2000) for a description of IFLS2.

the 1993 data and data from two rounds are necessary to accurately assess the effects of the fires, we do not analyze the effect of the fires on the physical health assessments.

As discussed above, Indonesia's fires dramatically reduced air quality. Ground-based pollution monitors are one method of measuring air quality, but in Indonesia only a few cities have pollution monitors. Because of the limited coverage of ground-based monitors, we measure air quality with the Aerosol Index developed by NASA from the TOMS data.

The TOMS data offer several key advantages for this study. First, recent work shows that the aerosol index is linearly correlated with ground-level aerosol optical thickness (AOT), which in turn is highly correlated with levels of total suspended particulates (Brimblecombe 1995; Hsu et al. 1996; Hsu et al. 1999; Torres et al. 2002). Second, aerosol levels have been measured on a daily basis since 1978 (although instrument failure resulted in a lack of data for Indonesia between mid 1993 and mid-1996). Third, the geographic coverage of the TOMS data includes all of the locations of the households interviewed in the IFLS. We match the TOMS data to the IFLS data on the basis of the latitude and longitude of each IFLS enumeration area, which was recorded with a handheld global positioning system. Because the TOMS data are available over time, we can precisely capture each individual's exposure to the smoke on several dimensions: level of smoke inundation, duration of exposure, and timing of the exposure relative to the IFLS interview.

Figure 4 displays the location of IFLS enumeration areas and whether those areas were exposed to smoke. Following standard practice, we define an area to have experienced smoke if the TOMS aerosol index exceeded 1.5 for at least three days between July 1, 1997 and the interview date. Based on these criteria, exposure occurred in all the enumeration areas in Southern Kalimantan, Northern, Western, and Southern Sumatra as well as some areas in Lampung and West Nusa Tenggarra. About 25% of the IFLS respondents lived in "haze areas."

It is possible that the fires could elevate mortality or migration just before the survey. In fact, respondents in "haze areas" are no more likely either to die or to move in the three months preceding the interview date than are respondents in the “non-haze” areas. The fires do not appear to have induced differential attrition.

MEASUREMENT AND INTERPRETATION OF HEALTH

Health status is difficult to measure. It is multi-dimensional and an individual’s perception of each domain of his or her own health reflects a complex combination of physical, psycho-social, phenotype and genotype influences over the life course in conjunction with the individual’s expectations and information about health. Moreover, self-reported health is conditioned by levels of and knowledge about the health of the reference group used by the respondent. These complexities are inherent to all interview-based survey questions about health and have been subjected to extensive inquiry. (See the volume by Murray et al. 2002 for a state-of-the-art discussion of the issues and, for example, King et al. 2004, for some recent proposals for anchoring self-reported health in surveys.)

We examine three indicators of adult health status, each of which is potentially affected by exposure to haze from the fires and is measured in both the first and second waves of IFLS. The indicators are whether the respondent had difficulty carrying out strenuous tasks, a specific morbidity related to respiratory function, and a general measure of overall health.

Our first health indicator is whether the respondent has difficulty carrying a heavy load, one of a battery of questions about difficulties the respondent has with activities of daily living (ADLs). It has been argued that questions about ADLs are easy for a respondent to answer since they ask about specific activities, such as walking a certain distance, climbing stairs, or carrying a heavy load, which are well-defined and capture important dimensions of functional health. Moreover, ADLs have been shown to be predictive of later mortality (Reuben et al. 1992; Scott et al. 1997). Many of the standard ADLs are of greatest salience for the elderly, because they concern activities as basic as bathing. We focus on an item that is also relevant for prime-age adults and which provides information about the respondent's capacity to perform physically strenuous activities. If haze affects respiratory functioning, strenuous activities like carrying a heavy load are likely to be more difficult.

Adult respondents in IFLS were also asked whether they experienced a series of specific symptoms during the four weeks prior to the interview. Self-reported incidence of coughing, our second health measure, is indicative of respiratory problems which are affected by exposure to haze. The temporal framing of the questions likely points the respondent to comparing incidence at the time of the interview with incidence more than a month previously. (Sanchez-Paramo and Das 2003, provide an insightful discussion of the importance of the temporal frame when interpreting self-reported morbidities.)

Self-reported general health status (GHS), an indicator of overall health, is our third measure of health. Each adult respondent is asked to rate his or her own health as very good, good, fair, or poor. Whereas there is a clear mechanism through which exposure to haze will affect coughing and difficulty carrying a heavy load, examination of the impact on GHS is intended to capture the effects on a broader set of health domains. We focus on whether the respondent reported being in poor GHS, which has been shown to be a powerful predictor of subsequent mortality in a wide array of settings (see Idler and Benyamini 1997). This is true even after controlling physician reports of health problems, suggesting that GHS contains information that may not be readily observed by a physician. This might include, for example, an individual's health-related behaviors, own health history, and family health history.

The percentage of adult respondents age 30 and older who report having each health problem in the 1997 wave of IFLS is reported in the first column of Table 1. All three are common: one in five adults reports difficulty carrying a heavy load, one in six reports being in poor general health, and over one-third report coughing in the last month. Interpretation of any self-reported health indicator is complicated because the meaning of each question may vary across respondents. Several studies have shown that higher income (and arguably healthier) people report themselves as being in poorer health than lower income (less healthy) people. (See Murray and Chen 1996, and Sadana et al. 2002, for example.) In order to provide some insights into the quality and nature of the information contained in the three self-reported health indicators used in this study, we relate them to two physical health assessments. They are lung capacity (measured by a puff test, in which the respondent blows into a plastic tube), and the time it takes for the respondent to stand from a sitting position (repeated five times as fast as he or she can).[4] Lung capacity has been shown to be diminished by exposure to air pollution, and respiratory problems are likely to affect the timed sit-to-stand.

The second column of Table 1 presents results from a regression relating lung capacity to the three health indicators (and a control for gender of the respondent). Both lung capacity and timed sit-to-stand have been converted to z statistics so that the regression coefficients can be interpreted as standard deviations of change in the dependent variable. All three self-reported health indicators are significantly negatively correlated with lung capacity, and over one-third of the variation in measured lung capacity is explained by these three health indicators (and gender). The lung capacity of a respondent who has difficulty carrying a heavy load is 0.4 standard deviations lower than a respondent who has no such difficulty. This is significantly larger than the decline associated with being in poor GHS, which seems reasonable since lung capacity is likely to be more closely related to difficulty with strenuous activities than to overall health status. Having a cough has the smallest effect on lung capacity, which suggests coughing in the previous month is a transitory problem for most respondents. Results for the time it takes to stand from a sitting position, in the third column of the table, are qualitatively similar (a longer time indicates poorer health).

Both lung capacity and sit-to-stand assessments were conducted in the home by a trained healthworker, who was usually a nurse, and so are not contaminated by individual-specific self-reporting biases. However, both involve participation by the respondent, and people who are inclined to report themselves in poor health may also be inclined not to try as hard on these assessments. This would result in spurious correlations between the self-reported and physically assessed health indicators. In the final column, we turn to a health measure that involves no respondent participation at the interview and which is indicative of overall health status: whether or not the respondent is alive three years after the 1997 interview. All three self-reported health indicators are significant predictors of

[4] The physical health assessments were included for the first time in the 1997 wave of IFLS and so cannot be included in the analyses below which use both the 1993 and 1997 waves of the survey.

three-year mortality with difficulty carrying a heavy load continuing to be the best predictor. Coughing has only a modest effect, again suggesting that it is a transitory problem for most respondents. Clearly, all three self-reports of health contain information about the general health status of respondents as well as about specific domains that are related to exposure to haze.

The fact that difficulty carrying a heavy load is a better predictor of not only the physical health assessments but also three-year mortality suggests that it may be less subject to respondent bias than GHS. There is evidence in support of this interpretation. First, many studies have demonstrated that socio-economic status (SES) is a powerful predictor of multiple dimensions of health status including physical assessments and mortality. SES is also strongly predictive of ADLs, including having difficulty carrying a heavy load. However, SES is not as highly correlated with GHS and, in some studies, higher income individuals report themselves as being in worse general health than do lower income respondents. (See Strauss et al. 1993; Sadana et al. 2002; for discussions and Thomas and Frankenberg 2002, for evidence from IFLS.) One reason suggested for this observation is that relative to the concrete task of carrying a heavy load, GHS is less well-defined and the meaning of "poor" health likely depends on the reference population against which a respondent compares his or her own health. If the reference population is the entire population, the meaning of "poor" should be the same for everyone. However, if it depends on the people with whom one has contact, then higher SES respondents will tend to expect a higher standard of health.

The importance of information about health has been highlighted by Dow et al. (1997) who present evidence from two randomized experiments in which the user fees for health care services were changed for treatments relative to controls. One experiment was conducted in the United States, the other in Indonesia. In both cases, among those for whom the price of care was lower, use of health care services increased, ADLs improved, but GHS *worsened.* Dow et al. suggest that seeing a health professional likely changes information about one's own health, and possibly affects one's reference level of health, and this is reflected in GHS. ADLs are apparently less prone to these effects.

The role of changes in the health of a reference population is discussed in Thomas et al. (2004) who report results from another treatment-control experiment in Indonesia. Households were randomly assigned to receive either iron supplements or identical looking placeboes. After a year of supplementation, adults in the treated group were in better health relative to the controls. They had higher levels of iron in the blood, reported lower levels of fatigue, and less difficulty with ADLs including carrying a heavy load. Self-reported GHS, however, did not differ between the treatments and controls, suggesting that as the health of others in one's household (and community) changes, so one's own reference health level changes.

In sum, all three self-reported health indicators—difficulty carrying a heavy load, coughing, and poor GHS—are predictive of physical health and subsequent mortality. They clearly provide valuable information about the health of respondents. Their interpretation, however, is not straightforward and this will be taken up again below. We turn now to a discussion of the empirical methods and results.

METHODS AND RESULTS

The effect of exposure to haze from the fires on the health of adults age 30 and older is examined. The literature suggests that older people are more susceptible to the deleterious effects of smoke haze. Thus, we examine adults age 56 and older separately from prime-age adults (age 30 through 55 years). Among prime-age adults, women are more likely to have been exposed to indoor pollution (from cooking, for example) which might affect their susceptibility, whereas men are more likely to be working outdoors and in physically arduous tasks and so may be more exposed to the smoke haze. The analyses of these adults are stratified by gender.[5]

The relationship between exposure to haze and difficulty carrying a heavy load is reported in Table 2 for older adults. In 1997, over 50% of older adults who were exposed to haze reported such difficulties, but they affected less than 40% of those who were living in areas not affected by the fires.

[5] In addition to these *a priori* theoretical reasons, we have tested whether the groups can be pooled. There are no significant differences between older men and women in the models presented below and so they are pooled; pooling of prime-age females, prime-age males, and older adults is rejected in some models. To ease interpretation across models, all statistical analyses are presented separately for the three groups.

The difference between these is one potential measure of the effect of the haze on this dimension of health. It is both very large (15%) and significant. However, this estimate of the effect of the fires is predicated on the strong assumption that exposure to haze was spread randomly across the population.[6] The validity of this assumption can be tested. If differences in health status between the haze and non-haze areas reflect the impact of the haze, rather than other differences, then the incidence of difficulties carrying a heavy load as reported before the haze in 1993 should be the same for respondents in the haze and non-haze areas. As shown in the second row of Table 2, the assumption is false. Older people living in those areas affected by haze in 1997 reported themselves as being in worse health in 1993 than the rest of the older population.

The change in health in haze areas between 1993 and 1997, in the first column of the third row of the table, reflects the combined effect of aging of the respondents, exposure to haze, and any other changes that occurred during this period. The aging of the sample is common to both the haze and non-haze areas and, to the extent that other changes are similar, the difference between the change in health in haze areas and the change in health in non-haze areas yields an estimate of the effect of the fires on health that controls unobserved differences between the haze and non-haze areas. This "difference-in-difference" estimate is reported in the third column of the third row and indicates that 5.6% of the older population had more difficulty carrying a heavy load because of the fires.

That estimate may be contaminated by differences between respondents who are and are not exposed to haze. If all these differences are observed in the data, they can be controlled in a multivariate regression context. However, these estimates will also be biased if there are unobserved differences between respondents who are exposed and those not exposed. If the differences are fixed over time and they affect health outcomes in a linear and additive way, then inclusion of a person-specific fixed effect in the regression model will absorb their influence and the estimates will not be contaminated by this form of observed or unobserved heterogeneity. Intuitively, the change in health of

[6] Relative to respondents in areas not affected by the fires, those in the haze areas are slightly younger and better educated but have lower levels of household resources, as measured by *per capita* expenditure. Areas that were affected by smoke are more likely to be rural and tend to be at higher altitudes. In a multivariate context, it is better educated respondents living at higher altitudes who are more likely to be exposed to smoke.

an individual who was exposed to haze in 1997 is compared with the change in health of an individual not exposed, controlling all fixed observed and unobserved differences between these two individuals.

The fixed effects estimate of the effect of haze on difficulty carrying a heavy load is in the fourth row of the table. It is 5.3% and significant at a 5% size of test. The fact that this estimate is very close to the difference-in-difference estimate suggests that our identification strategy is robust to several sources of potential bias due to unobserved heterogeneity. In addition to controlling unobserved heterogeneity, the fixed effects difference-in-difference estimates have two important advantages. First, they are more efficient (as demonstrated in Table 2). Second, biases in self-reported health that arise from differences in the propensities of respondents to report themselves as being in poor health will be absorbed by the fixed effect as long as the individual's reporting propensity does not change over time.[7] The rest of the paper focuses on fixed effects estimates of the effect of the haze; difference-in-difference estimates are very similar in all cases.

Difficulty carrying a heavy load

Table 3 presents fixed effects estimates of the effects of haze for each of the three self-reported health indicators and for the three demographic groups. In each block, results for older adults are in the first column, for prime-age females in the second column, and for prime-age males in the third column. We begin with difficulty carrying a heavy load.

The regression in Panel A measures the effect of exposure to haze, controlling individual fixed effects as well as observed differences in household resources and location of the respondent. The first column in the first row repeats the estimate for older adults discussed above. For older adults and prime-age females, exposure to haze results in worse health as indicated by higher levels of reported difficulties carrying a heavy load.

Figure 2 highlighted the fact that the smoke and haze spread across Indonesia in two major waves. Some of the respondents who had been exposed to haze prior to the 1997 interview were no

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[7] Note that by including individual fixed effects in the models, changes in an individual's propensity to report poor health will be highlighted.

longer exposed by the time of the interview.[8] The regression in Panel B distinguishes those respondents who were exposed at the time of the interview, those who were interviewed at least a month after the haze and smoke had cleared, and those not exposed (the excluded group). Whereas older adults have more difficulty carrying a heavy load while exposed to the haze, there is no evidence of longer-term effects. In contrast, the effects on prime-age females persist even a month after the haze has cleared.

The regression in Panel C further disaggregates the timing of exposure to haze. We separately identify those respondents whose exposure to haze began no more than 30 days prior to the survey interview, those exposed at the time of the interview who had been exposed for at least a month, those not exposed at the time of the interview but who had been exposed within the prior 30 days, and those who had been exposed prior to the interview but more than 30 days ago. The key novel result from this specification is for prime-age males. They report more difficulty carrying a heavy load at the onset of haze, but the effect quickly disappears. There are at least two plausible interpretations. Either prime-age males become accustomed to the haze after a month of exposure, or they may adjust what they think of as being "difficult" if the exposure persists.

In sum, haze has a deleterious impact on ability to carry out strenuous tasks for all adults. Among prime-age males the effect is short lived, among older adults it persists until the haze has cleared, and among prime-age females the effect persists for at least a month after the haze has cleared.

Respiratory problems

The second block of Table 3 reports the fixed effects difference-in-difference estimates of the effect of exposure to haze on the incidence of coughing in the previous 30 days. The first row indicates

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[8] Interviews in IFLS were conducted by 26 teams of interviewers, each of which visited between 12 and 15 enumeration areas. Each province had at least one team of interviewers, and the most populous province had four teams. Within each province, enumeration areas were interviewed according to a sequence designed to minimize fieldwork costs, to avoid logistical difficulties so that teams did not work simultaneously in overlapping areas and to maximize the probability of finding movers (by visiting migration destinations towards the end of the fieldwork). The sequence was determined in early 1997, before the fires began. Interviews were conducted before, during, and after the haze had blanketed our enumeration areas. In a regression of the timing of interviews in each enumeration area, we find that, relative to not being blanketed with haze by the time of the interview, there is a 0.1% lower likelihood the area was blanketed with haze in the same week as the interviews (t=0.1) and a 2.4% higher likelihood that the area had been blanketed with haze prior to the interviews (t=1.4). We conclude that the timing of the interviews and the timing of the haze inundation are uncorrelated. By combining the timing of the interviews with the availability of daily measures of aerosol levels from TOMS, we are able to examine the time path of the relationship between haze and health.

that older adults who were exposed to haze prior to the 1997 interview were 10% less likely to report coughing, and prime-age adults were 5% less likely to report coughing. If respondents cough more when they are blanketed by haze, relative to before the haze or after it has cleared, then it will be important to distinguish those exposed at the time of the interview. This is particularly relevant for this health indicator, given that the temporal framing of the question suggests that respondents compare coughing at the time of the interview with coughing a month before the interview.

The regression in Panel B indicates that the lower levels of reported coughing among those exposed to haze arises because those people who were exposed to haze which cleared more than a month before the interview are much more likely to report less coughing than those who were not exposed to haze and those who were not exposed at the time of the 1997 interview.

The regression in Panel C demonstrates that there is a 8 to 9 % higher level of reported coughing among prime-age adults at the onset of haze. There is no difference between the effects on males and females, and when they are combined, the effect is significant at a 5% size of test. If respondents who are currently exposed to haze and have been exposed for at least a month compare their coughing in the last 30 days with coughing prior to that, they are not likely to be different from those not exposed to haze. This is reflected in the small and insignificant coefficients in the second row of Panel C. However, when the haze clears, the respondents apparently notice that they are coughing less and this is reported in the survey interview. We conclude that exposure to haze results in elevated levels of coughing but the effects are short-lived.

General health status

The effect of haze on whether the respondent reports him or herself as being in poor general health is displayed in the third block of Table 3. For older adults and prime-age females, exposure to haze results in fewer respondents reporting they are in poor general health. Haze has no impact on the GHS of prime-age males.

Panel C reports the time path of the estimated effects of the haze. Among prime-age females, reported GHS is no different for those who are exposed to haze at the time of the interview relative to those never exposed. However, after the exposure has ended, prime-age women are 10 % less likely to report they are in poor general health and the effect persists for at least a month after the haze has cleared. The results for older adults are similar except they are also less likely to report themselves as being in poor general health after they have been exposed for at least a month.

The lower rate of reported poor health, after the haze has cleared, is consistent with the evidence for coughing discussed above. The results suggest that these respondents compare their health at the time of the 1997 interview, when the haze has cleared, with their own health prior to the interview, when they were blanketed by haze and were in poorer health. Therefore, at the interview, they are less likely to report they are in poor health.

This interpretation suggests that people who have recently been exposed to haze should be more likely to report they are in poor general health. They do not. However, recall the discussion of self-reported health indicators in the previous section which suggested that GHS is likely to be influenced by both a respondent's own prior health experiences, and also by the health of those around him, and that the relative salience of these references is likely to shift as circumstances change.

At the onset of the haze, a good deal of discussion probably occurs in the community about its effects on health. Thus, when the haze is a relatively new phenomenon, the health of others in the community is likely to be particularly salient in one's assessment of one's own health. But because everyone in the community is likely to have been affected by the haze, on average, reported GHS will be no better or worse among individuals in communities affected by haze than among individuals in communities not affected by haze. In other words, within communities, individuals' relative positions with respect to general health have not changed, although absolute levels of health are lower in the haze communities than the non-haze communities, as indicated by increased difficulty with carrying a heavy load.

The simple comparisons of those exposed to haze and those not exposed, in Panel A of the table, suggest that the haze resulted in *improved* general health. A more nuanced examination of how reported general health status varies with the timing of exposure to haze indicates that the haze had a deleterious impact on GHS, which is consistent with our evidence on coughing and carrying a heavy load.

CONCLUSIONS

The fires in Indonesia in late 1997 were an environmental disaster. The effects of those fires on health have been difficult to quantify because of a paucity of survey data on health status of individuals. We combine information collected in health interviews in the IFLS with satellite measures of aerosol levels and examine the effects of haze exposure on three domains of health status.

We find that comparisons of the health of the population living in haze areas with the health of those in other areas substantially over-estimate the "effect" of the fires because of time-varying location-specific unobserved heterogeneity in health status. Consequently, we exploit the repeat observation nature of IFLS and compare changes in health between the two groups.

The haze had an immediate deleterious impact on physical functioning as measured by self-reported difficulty carrying a heavy load. The effect dissipates quickly for prime-age males, persists until the haze clears for older adults, and persists several months after the haze has cleared among prime-age females.

The incidence of reported coughing is higher at the onset of the haze and much lower a month after the haze has cleared, indicating that the haze has a substantial negative effect on respiratory health. Noting that the interpretation of GHS is likely to be influenced by both a respondent's own prior health and the health of those around him, we interpret the evidence on GHS as indicating that the fires resulted in substantially poorer general health among prime-age females and older adults.

In addition to shedding light on the health consequences of exposure to haze, the evidence presented in this paper provides insights into the nature of data necessary to measure the effects of changes in the environment—be they economic, social, ecological, or political changes. We have shown that comparisons of groups based on cross-sectional data is fraught with difficulties and can be seriously misleading. High-quality longitudinal survey data that can be matched with administrative or other data sources are of tremendous value in this context. It is also clear that interpretation of self-reported health status is not straightforward, and that the collection of physical health measures and biomarkers is likely to have substantial benefits.

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Table 1: Relationship between physical health and self-reported health status in 1997

	Percentage reporting (1)	Lung Capacity (2)	Sit-to-stand (Timed) (3)	Not alive (3 years later) (4)
Difficulty carrying a heavy load	19.9	-0.42	0.61	4.94
	(0.4)	(0.02)	(0.03)	(0.44)
Cough	37.6	-0.14	0.04	0.70
	(0.5)	(0.02)	(0.02)	(0.33)
Poor general health status	15.9	-0.25	0.23	3.65
	(0.4)	(0.02)	(0.03)	(0.47)
R^2		0.34	0.10	0.03

Notes: Sample includes 9,842 adult respondents in IFLS2. Percentage of respondents reporting each health problem (and associated standard error) is in column 1. Regression coefficients (and standard errors) in columns 2 through 4. Regression controls are indicator variables with value 1 if respondent reports having problem and 0 otherwise. Indicator variable for male included in each regression. Lung capacity measured by puff test. Sit-to-stand is time to stand from sitting position, repeated five times. Lung capacity and sit to stand expressed as z-scores.

Table 2: Difficulty carrying a heavy load and exposure to haze among older adults
Differences between those exposed and not exposed in 1997, in 1993 and change over time

	Exposure to haze from fires in 1997		
	Exposed (1)	Not exposed (2)	Difference (3)
Percentage of older adults who report difficulty carrying a heavy load			
(1) in 1997	54.3 (2.0)	39.4 (1.0)	14.9 (2.2)
(2) in 1993	26.9 (1.6)	17.6 (0.8)	9.3 (1.8)
(3) Change between 1993 and 1997	27.4 (2.5)	21.8 (1.3)	5.6 (2.8)
(4) Controlling time invariant unobserved heterogeneity (individual fixed effect estimate)			5.3 (2.4)

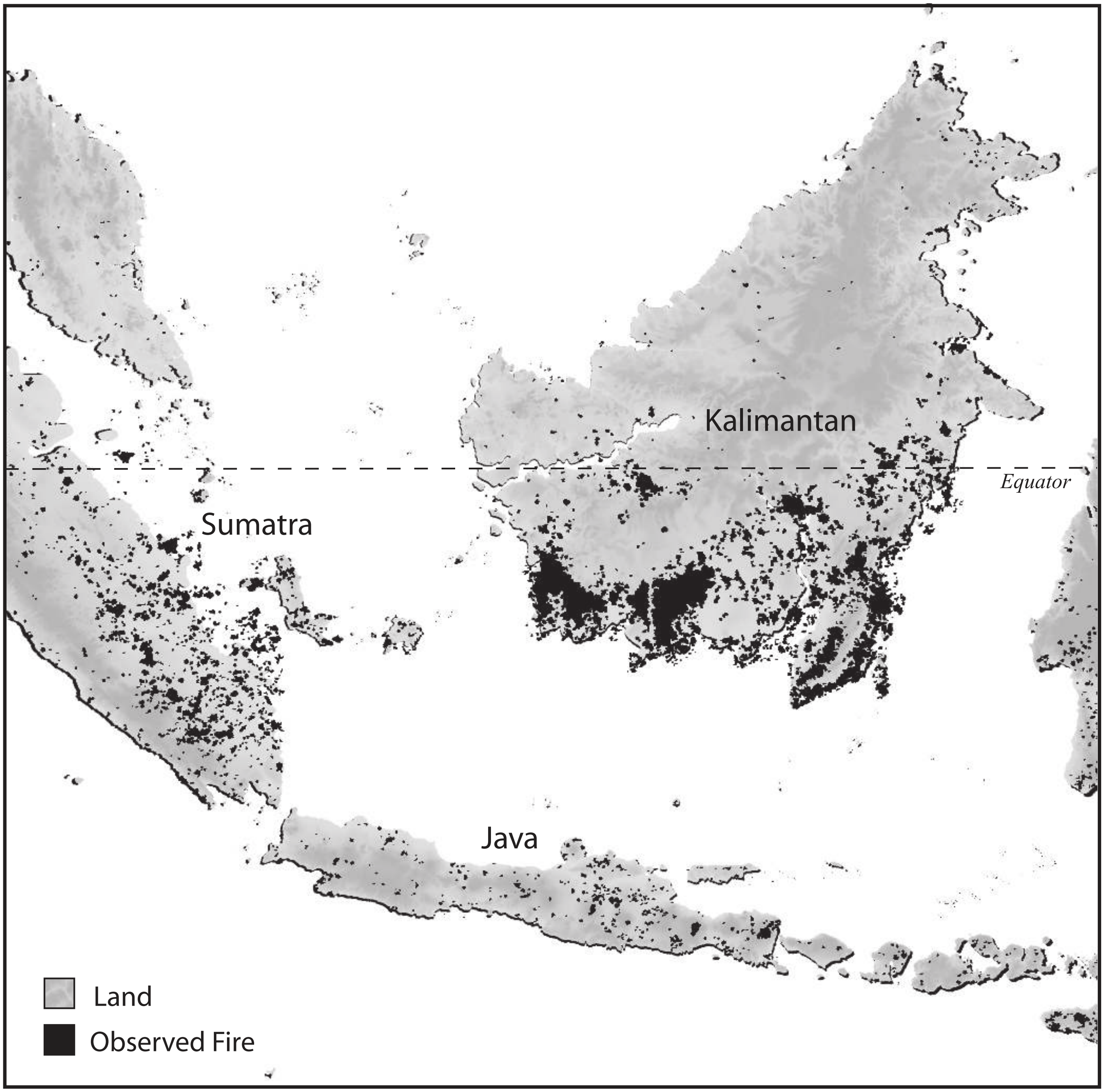
Notes: Sample includes 2,807 adults (age $\geq$ 56 years) interviewed in IFLS1 and IFLS2. Standard errors below percentages.

Table 3: Fixed effects estimates of impact of exposure to haze on adult health status

	Difficulty carrying heavy load			Cough in last 30 days			Poor general health status		
	Older Adults (1)	Prime Females (2)	Prime Males (3)	Older Adults (1)	Prime Females (2)	Prime Males (3)	Older Adults (1)	Prime Females (2)	Prime Males (3)
Panel A: (1) if exposed									
To haze prior to survey interview	5.33	4.86	1.41	-9.27	-4.77	-4.56	-10.52	-6.24	-0.82
	(2.40)	(1.56)	(0.95)	(2.87)	(2.23)	(2.52)	(2.40)	(1.52)	(1.44)
Panel B: (1) if exposure									
At time of interview or within last month	8.56	3.87	1.40	-5.50	-1.75	0.80	-11.48	-4.36	0.23
	(2.78)	(1.79)	(1.08)	(3.32)	(2.55)	(2.87)	(2.78)	(1.74)	(1.65)
Ended more than one month ago	-2.12	7.30	1.42	-17.94	-12.17	-17.33	-8.31	-10.85	-3.31
	(4.02)	(2.64)	(1.57)	(4.80)	(3.76)	(4.17)	(4.02)	(2.57)	(2.39)
Panel C: (1) if exposure									
Began within last month	11.75	6.59	7.85	-0.70	8.28	8.78	-0.99	2.60	2.83
	(6.20)	(3.77)	(2.37)	(7.41)	(5.38)	(6.28)	(6.20)	(3.67)	(3.60)
Began more than one month ago	6.29	-2.75	0.37	1.73	-2.66	5.42	-11.34	-0.70	2.91
	(4.17)	(2.63)	(1.55)	(4.98)	(3.75)	(4.10)	(4.17)	(2.56)	(2.35)
Ended within last month	9.39	9.29	-0.33	-14.27	-5.52	-7.88	-15.88	-11.30	-3.92
	(4.05)	(2.64)	(1.62)	(4.84)	(3.77)	(4.31)	(4.05)	(2.57)	(2.47)
Ended more than one month ago	-2.13	7.31	1.42	-17.95	-12.19	-17.33	-8.34	-10.88	-3.31
	(4.02)	(2.63)	(1.57)	(4.80)	(3.76)	(4.17)	(4.02)	(2.56)	(2.39)

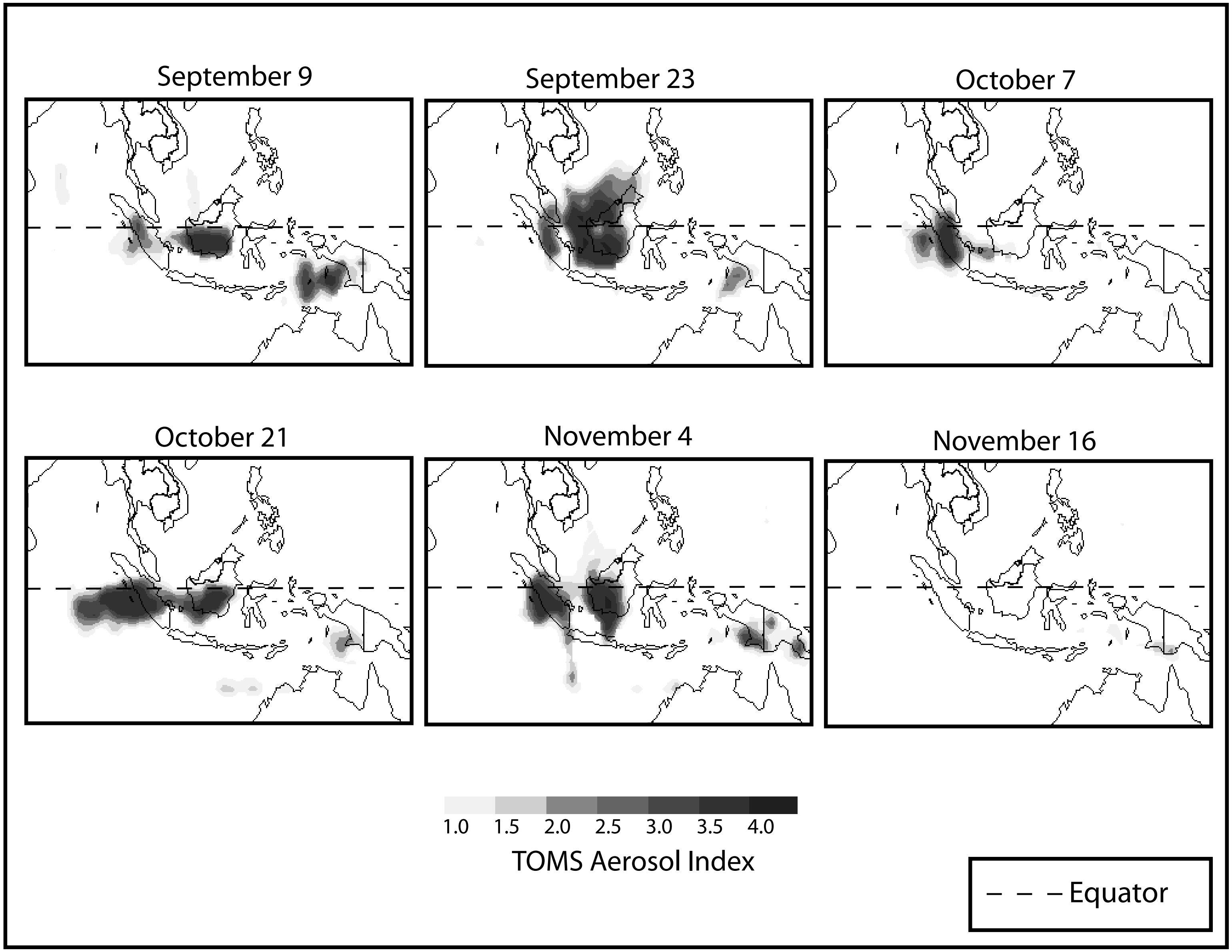
Notes: Samples include respondents interviewed in both IFLS1 and IFLS2. There are 2,807 older adults (age≥56) included in the regressions in column 1, 3,862 prime age females (age 30 to 55) in column 2 and 3,173 prime age males in column 3. Each panel reports a separate regression. Each regression also includes an individual-specific fixed effect, a time effect, spline in the logarithm of household *per capita* expenditure and an indicator for whether the respondent lives in an urban area. Standard errors are below regression coefficients.

Figure 1: Location of fires in Indonesia during the second half of 1997



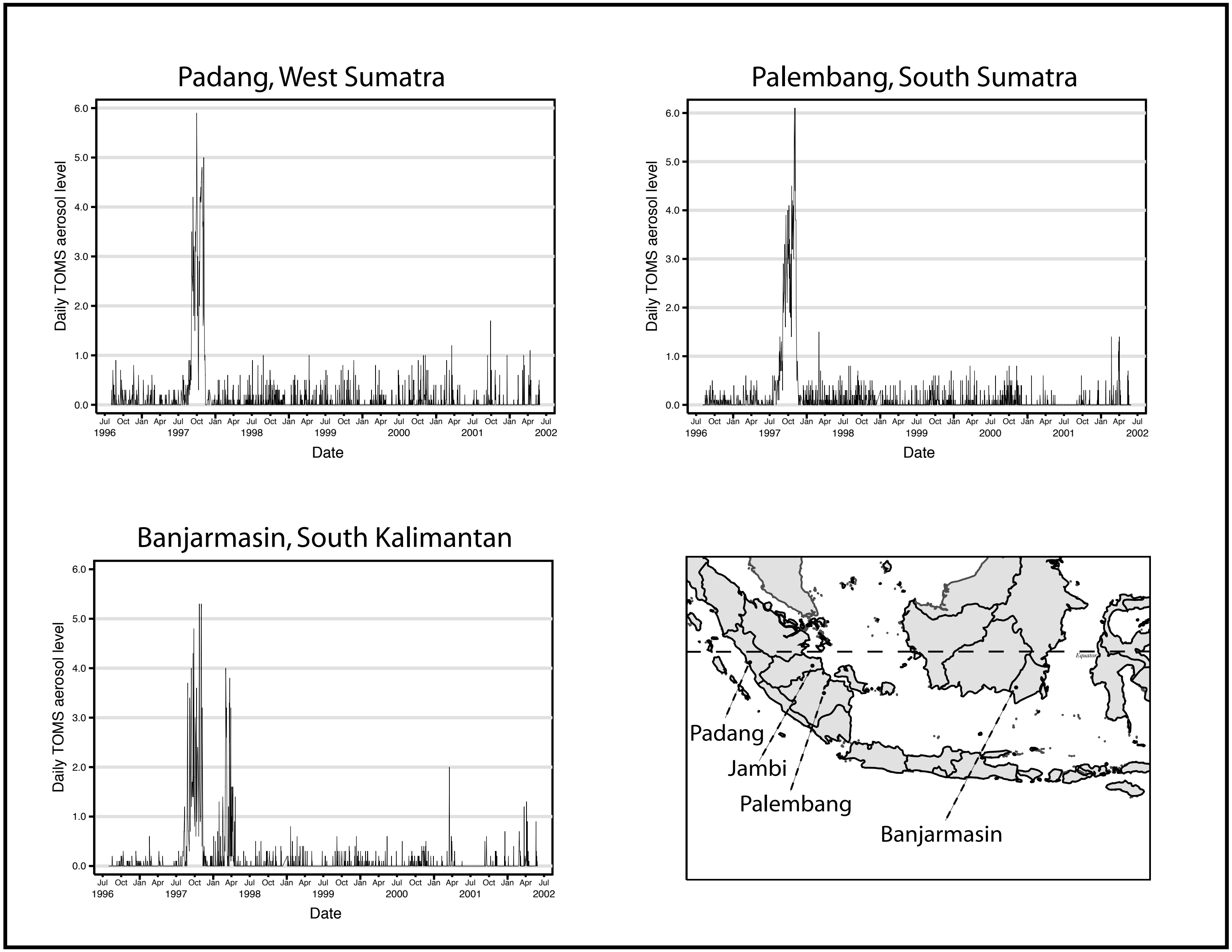
Source: DMSP-OLS measures of light emissions

Figure 2: TOMS Aerosol Index every two weeks between September 9 and November 16, 1997



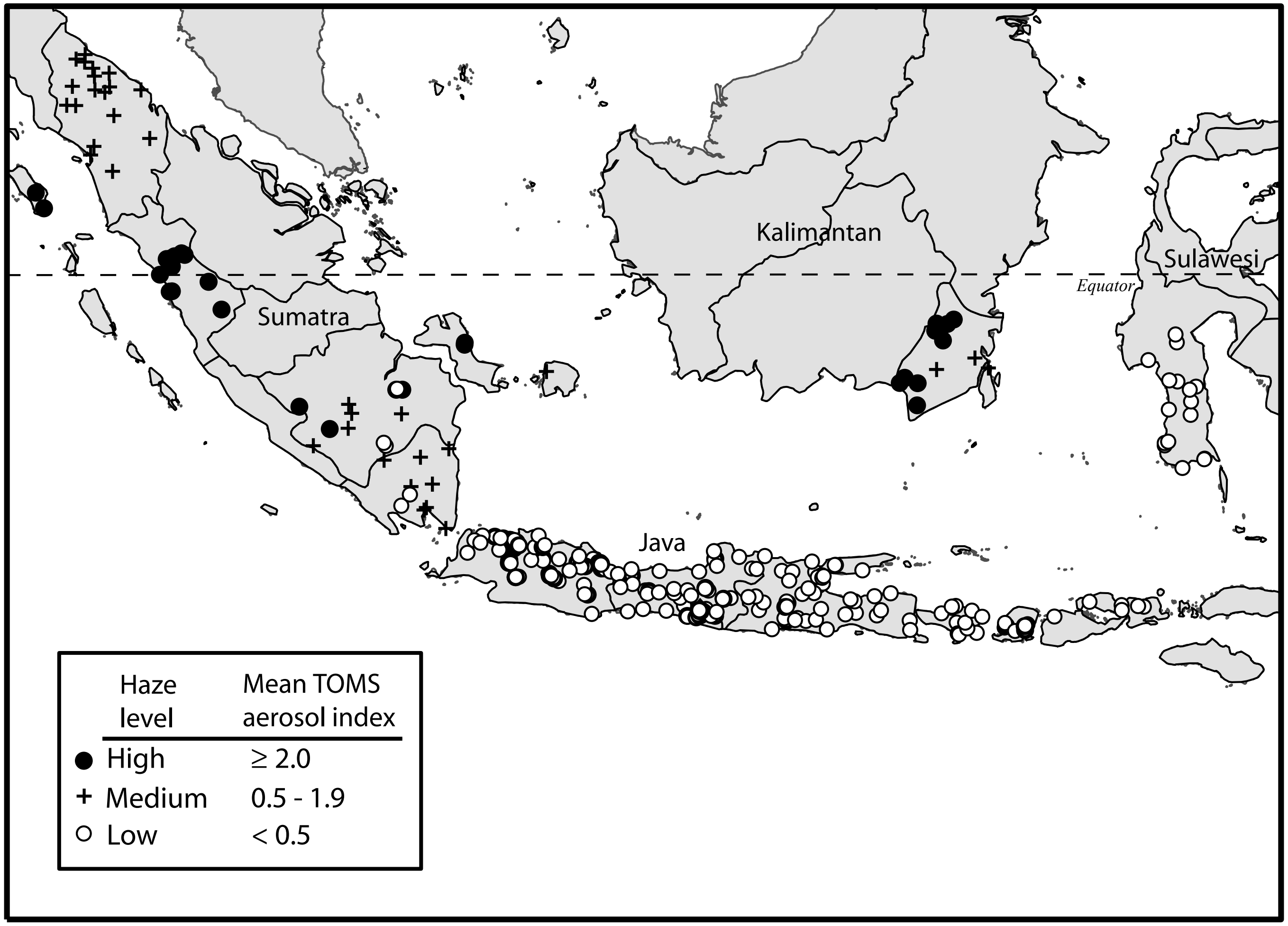
Source: NASA-TOMS

Figure 3: The TOMS Aerosol Index between July 1996 and July 2002 for major towns in three provinces included in IFLS



Source: NASA-TOMS

Figure 4: Average TOMS Aerosol Index in IFLS Enumeration Areas



Source: NASA-TOMS