

Article

Air Pollution and Long Term Mental Health

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Abstract: We study the long-term consequences of air pollution on mental health, using a natural experiment in Indonesia. We find that exposure to severe air pollution has significant and persistent consequences on mental health. An extra standard deviation in the pollution index raises the probability of clinical depression measured 10 years past exposure by almost 1%. Women in particular seem to be more affected, but some effects persist for men as well. Pollution exposure increases the likelihood of clinical depression for women and also the severity of depressive symptoms for both sexes. It is not clear if men are more resistant to pollution or they simply recover faster from it. Education, perceived economic status, and marriage seem to be the best mitigators for these negative effects.

Keywords: air pollution; mental health; depression; Indonesia

1. Introduction

Air pollution, especially fine particulate matter, has immediate negative consequences on health and causes a range of additional economic costs to society. These effects are well documented by the medical and economic literature. Air pollution is linked to respiratory problems in both infants and adults [1–3], infant health and mortality [4–9], lower labor supply [10–12], worker productivity [13,14], and even mental health and cognition [15]. While most of the existent literature focuses on the short-term effects, there is also some recent evidence of long lasting effects of air pollution on health [16] and on economic outcomes [17,18]. There is also evidence that humans are aware of these negative effects and are willing to pay to improve air quality [19].

Mental health, particularly depression, is an especially important outcome that needs careful consideration. Depression symptoms are very common, especially in older adults [20], and very problematic. Depression not only lowers quality of life, but is also a major risk factor for cardiovascular health and mortality [21–24]. Furthermore, in light of the fact that parental human capital is often influencing child outcomes [25], depression can have serious intergenerational consequences. Previous studies found infants of mothers with depressive symptoms at higher odds of being stunted or underweight [26,27], which can further have serious health and economic consequences. Similar links were also found between maternal depression and family food insecurity [28].

The links between air pollution and mental health are well documented by the medical literature, but virtually all of the previous studies are short cross-sectional studies that lack proper causal identification. There is a large set of papers documenting correlations between exposure to second-hand smoking and mental health issues such as depression, anxiety, ADD, etc. [29–32] and another set of papers showing links between long-term exposure to fine particulate matter, mostly related to road traffic, and mental health [33–36]. Depression is also linked to indoor air pollution from

cooking with biomass [37] and short-term exposure to air pollution [38]. All of these papers however, are correlational studies and present no efforts to demonstrate causality between air pollution and mental health. The only studies we are aware of that attempt to prove this causal link are studies based on laboratory tests on animals [39] and a recent study that controls for random effects and a large number of potential confounders [40].

It is also worth mentioning that some studies found no consistent evidence for an association between air pollution and depressive symptoms [41,42]. However, it is important to note here that some associations were found on certain sub-samples, and second that these studies are also purely correlational and lack any causal identification. This is further complicated by the fact that they used proxies for pollution exposure that are less than ideal, such as distance to the nearest major roadway, which is arguably correlated with many other confounders.

Our study contributes to the existent literature in a few distinct ways. We study the persistent (long term) effects of air pollution on mental health, focus on a short-lived but intense pollution shock, use longitudinal data and, most importantly, provide a credible identification source for the causal effects of air pollution on mental health: a natural experiment that occurred in Indonesia in 1997.

From September to November of 1997, large parts of Indonesia were blanketed in thick smoke caused by massive forest fires. The fires originated with slash-and-burn practices used by local farmers as a cheap way of clearing land, but got out of control due to the especially dry and windy season caused by El Niño. Since the exposure of people living in different parts of Indonesia to this pollution was due to natural phenomena such as lack of rain or wind direction and intensity, it can be considered as good as a random assignment. In fact, this episode has been widely used in the social science literature as an identification source for a range of studies involving air pollution [16,18,43–45].

We find significant effects of pollution on depression and depressive-like symptoms that persist even 10 years after exposure. Women seem to be more affected than men, or at least they recover slower than men do. The pollution shock of 1997 was found to increase the severity of mild depression-like symptoms in both sexes and also to increase the likelihood of experiencing severe clinical depression in women. Both these effects are observed in 2007, ten years after the pollution shock, which suggests not only that pollution has long-lasting effects, but also that the actual near-term effects and associated costs are much larger in magnitude. Unfortunately, due to data limitations, we cannot test the recovery hypothesis nor establish a clear significant link between pollution and clinical depression for men. The pattern observed in the results however, coupled with results from the existent literature, is highly suggestive of the fact that men are not immune to pollution, but they might recover faster from it.

2. Materials and Methods

We exploit data from the Indonesia Family Life Survey (IFLS). IFLS is a longitudinal survey spanning over 20 years and containing a representative sample of Indonesian households. The IFLS sample is representative for more than 80% of the Indonesian population, living in 13 of the country's 26 provinces. Some remote areas of Indonesia were not surveyed by IFLS. Detailed information on the sampling methodology can be found in [46]. The fourth wave of IFLS (IFLS4), which was fielded in 2007 and is primarily used in our study, interviewed 13,535 households and 44,103 total individuals—adults, children and elderly. IFLS collects a vast number of demographic and socio-economic indicators at the individual, household, and community level. The attrition rates are also very small in IFLS, which is ideal for our study, as it avoids potential attrition-related biases. The re-contact rate of the original IFLS1 dynasties was 93.6% in IFLS4, which is as high and even higher than most longitudinal surveys in the United States and Europe. IFLS data has been widely used in socioeconomic research [47–49].

Our main outcome variables are measures of depression based on the short form of the Center for Epidemiological Studies Depression Scale (CES-D). The 10-item questionnaire (CESD-10) was shown to be consistent and predictively accurate [50,51] when compared against the full-length 20-item version of the CES-D initially proposed by Radloff [52]. Based on respondents' answers to a series of 10 questions, and following the CES-D guidelines, we first computed a depression score for all

individuals in our sample. This score ranges from 0 to 30, with larger numbers representing more severe depressive symptoms. A well-established cutoff in the medical literature is that a score higher or equal to 10 represents severe depressive symptoms or clinical depression [50]. We therefore coded an indicator variable equal to 1 if a respondent's score was higher or equal to 10 and zero otherwise. We used this indicator and the raw depression score as our dependent variables in our study. The CES-D questionnaire was introduced in IFLS during the 2007 wave and so all our analyses refer to the persistent (long-term) effects of air pollution on depressive symptoms.

Since our focus is studying the effect of air pollution on depression, the main explanatory variable we use is the pollution level that respondents were exposed to during the 1997 fires. The IFLS provides the Global Positioning System (GPS) coordinates for each community and, following [18], we interpolate the Total Ozone Mapping Spectrometer (TOMS) data described in [44] using these GPS coordinates. The TOMS data was provided to us by Dr. Jayachandran. We use the aerosol index, which is calculated from the amount of light that is absorbed or reflected by different particulates. The aerosol index can take both negative and positive values, with positive values corresponding to particulate matter such as that contained by smoke from the forest fires. The aerosol index is a valid measure of pollution exposure that has been used widely in the literature. We then compute the pollution variable we use in all our regressions as the average monthly pollution over the September, October, and November months of 1997. For the monthly pollution we use the median of the daily values. Table 1 contains simple summary statistics describing the pollution levels and also the incidence of clinical depression among respondents.

Table 1. Summary Statistics.

Pollution Variable	Mean	Std. Dev.	Range	Sample Size
Pollution 1997	0.675	0.609	0.194–4.841	7969
Pollution 1996	0.091	0.081	−0.083–0.395	7969
Depression Score in 2007	Frequency	Percent	Males	Females
<10	7479	93.85%	3195	4284
≥10	490	6.15%	157	333
Total	7969	100%	3352	4617

Note: values greater than 0.75 in the pollution index are considered to be high levels of smoke.

The pollution index clearly increased from an average of 0.09 in 1996 to an average of 0.68 during the fires of 1997. For comparison purposes, the 1996 data represents the pollution average over the same months of September, October, and November corresponding to the 1997 fires. The aerosol index measures the amount of light absorbed and reflected by particulate matter and takes values between −2 and 7, with higher values indicating higher particulate matter pollution. Any value greater than 0.75 is considered to be a high level of smoke [44]. It is easy to see from the table that the pollution episode was extremely severe, with values of the aerosol index climbing as high as 4.8.

In terms of depressive symptoms, about 6.15% of the surveyed respondents are clinically depressed, with values of the CES-D score above 10. The incidence of depression seems to be higher for women than for men: About 7.2% of the women are significantly depressed, compared to only 4.7% of the men.

In addition, we also collect a number of socio-economic factors at the individual and household level that we use as controls in all our regressions. Although we argue that the exposure to pollution was due to a natural phenomenon and is therefore not likely correlated to any socio-economic indicators that could affect depression, these controls allow for a more robust estimation. We include controls such as respondents' age and age squared (to allow for non-linearities with respect to age), years of formal education, per capita expenditures (PCE), whether the household kitchen and water source are inside or outside the household (as this might affect pollution exposure), indicators for sex and marital

status, indicators for subjective (perceived) economic status, and initial general health status (before the pollution event).

Household income has been shown to be prone to systematic measurement errors [53], and household PCE is commonly used as a proxy for income. To account for SSS, a series of perceived income ladder indicators are constructed, based on respondents' answer to the following question: "Please imagine a six-step ladder where on the bottom (the first step) stand the poorest people, and on the highest step (the sixth step) stand the richest people. On which step are you today?" Since very few respondents chose the sixth step, we combined the fifth and sixth step.

Ideally, we would like to also control for the pre-pollution depressive symptoms, but this data was not collected by IFLS prior to 2007. However, since the pollution was an unprecedented and exogenous shock, it is unlikely to be correlated with the initial depressive symptoms and, furthermore, the initial general health status proxies to some degree for mental health too. The general health status (GHS) is a self-reported binary health measure which takes value 1 (Poor GHS) if respondents classify their own health as either "unhealthy" or "somewhat unhealthy", and value 0 (Good GHS) if respondents classify their health as "healthy" or "somewhat healthy". In spite of being somewhat vague and possibly suffering from subjective biases, GHS is an aggregate measure that proxies for a large variety of health issues and has been found to be a good predictor of future health [54–56]. Formally, the reduced form model can be therefore written as follows:

$$Depression_{ij}^{2007} = \beta Pollution_j^{1997} + \gamma Control_{ij} + \varepsilon_{ij}$$

where i denotes the respondent, j denotes the community, $Control$ is the vector of individual and household level control variables mentioned above, and ε_{ij} is the error term representing unobservables uncorrelated with the regressors.

3. Results and Discussion

Table 2 presents the estimated effects of pollution on the raw CES-D depression score. As mentioned before, this score takes values from 0 to 30, with larger figures representing more severe depressive symptoms. We control for a number of socio-economic indicators and for base-level health.

Table 2. The Effects of Pollution on Depressive Symptoms (OLS Regression Results).

Explanatory Variables	Full Sample		Men		Women	
	Coefficient	(St. Error)	Coefficient	(St. Error)	Coefficient	(St. Error)
Pollution in 1997	0.2690 ***	(0.0689)	0.2448 **	(0.1013)	0.2948 ***	(0.0928)
Age in 2007	−0.0538 **	(0.0249)	−0.1305 ***	(0.0392)	0.0029	(0.0333)
Age ² in 2007	0.0005 **	(0.0002)	0.0012 ***	(0.0003)	−0.000004	(0.00030)
Years of Education	−0.0598 ***	(0.0096)	−0.04995 ***	(0.0139)	−0.0683 ***	(0.0134)
Poor GHS in 1993	1.0368 ***	(0.1564)	0.6182 ***	(0.2131)	0.1.2904 ***	(0.2127)
Log PCE	−0.0898	(0.0637)	−0.0487	(0.0923)	−0.1177	(0.08698)
Income Ladder 2	−0.7396 ***	(0.2047)	−0.6413 **	(0.3149)	−0.7753 ***	(0.2688)
Income Ladder 3	−1.3745 ***	(0.1983)	−1.3318 ***	(0.3046)	−1.3720 ***	(0.2610)
Income Ladder 4	−1.6852 ***	(0.2146)	−1.8110 ***	(0.3205)	−1.5600 ***	(0.2882)
Income Ladder 5	−1.7928 ***	(0.3326)	−1.2737 ***	(0.4848)	−2.1026 ***	(0.4459)
Having Outside Kitchen	0.0547	(0.0766)	−0.1064	(0.1116)	0.1746 *	(0.1045)
Having Outside Water	−0.2583 ***	(0.0879)	−0.3745 ***	(0.1318)	−0.1676	(0.1175)
Married	−0.4257 ***	(0.1120)	−0.7415 ***	(0.2477)	−0.3119 **	(0.1312)
Male	−0.1537 *	(0.0800)	−	−	−	−
Constant	8.4143 ***	(1.0343)	10.2384 ***	(1.6112)	7.0444 ***	(1.3646)
Sample Size	7969		3352		4617	

Dependent variable: CES-D score in 2007. Robust standard errors in parentheses. * significant at 10% level

** significant at 5% level *** significant at 1% level.

Since the incidence of depression in women was found to be larger than in men, we estimated these effects for the entire sample and disaggregating by gender. The results in the table are estimated using ordinary least squares (OLS) with robust standard errors. For robustness purposes, ordered probit and ordered logit regressions were also performed, which yielded similar results.

We find that air pollution has negative consequences on the CES-D score that persist 10 years after exposure. These effects are statistically significant for both men and women, with slightly larger impacts for women. Besides the direct effect of pollution, our estimations also point to men being overall less depressed than women, to marriage and education being mitigating factors for depression, and somewhat interestingly, to the effects of subjective and objective economic well-being. While objective economic well-being (proxied by PCE) seems to have no significant effect, perceived economic well-being (proxied by the income ladder) is clearly and consistently mitigating depressive symptoms for both sexes. Perceiving yourself to be on a higher income ladder is generally associated with a lower CES-D score.

We further investigate the relationship between air pollution and depression by estimating the effects of pollution exposure in 1997 on the presence of severe (or clinical) depression in 2007, controlling for the same set of socio-economic indicators and base-level health status. The presence of clinical depression is signaled by a CES-D score higher or equal to 10 so the new dependent variable is an indicator that takes value 1 if the respondent's CES-D score is higher or equal to 10 and 0 otherwise. We again performed this estimation first for the entire sample, then separately for men and women. The results in Table 3 are that of a linear probability model estimated using ordinary least squares (OLS) with robust standard errors. For robustness purposes, we also performed logit and probit estimations and found similar results.

Table 3. The Effects of Pollution on Clinical Depression (OLS Regression Results).

Explanatory Variables	Full Sample		Men		Women	
	Coefficient	(St. Error)	Coefficient	(St. Error)	Coefficient	(St. Error)
Pollution in 1997	0.0121 **	(0.0050)	0.0082	(0.0067)	0.0150 **	(0.0071)
Age in 2007	−0.0031	(0.0019)	−0.0045	(0.0028)	−0.0024	(0.0027)
Age ² in 2007	0.00002	(0.00001)	0.00003	(0.00002)	0.00002	(0.00002)
Years of Education	−0.0011 *	(0.00007)	−0.0008	(0.0009)	−0.0014	(0.0009)
Poor GHS in 1993	0.0561 ***	(0.0122)	0.0122	(0.0149)	0.0813 ***	(0.0172)
Log PCE	0.0107 **	(0.0048)	0.0061	(0.0065)	0.0139 **	(0.0067)
Income Ladder 2	−0.0344 **	(0.0160)	−0.0255	(0.0230)	−0.0382 *	(0.0220)
Income Ladder 3	−0.0668 ***	(0.0153)	−0.0624 ***	(0.0218)	−0.0670 ***	(0.0213)
Income Ladder 4	−0.0702 ***	(0.0164)	−0.0773 ***	(0.0224)	−0.0624 ***	(0.0232)
Income Ladder 5	−0.0836 ***	(0.02199)	−0.0758 ***	(0.0294)	−0.0868 ***	(0.0310)
Having Outside Kitchen	−0.0006	(0.0055)	−0.0069	(0.0074)	0.0043	(0.0079)
Having Outside Water	−0.0066	(0.0065)	−0.0078	(0.00899)	−0.0052	(0.0092)
Married	−0.0249 ***	(0.0089)	−0.0269	(0.0191)	−0.0213 **	(0.0106)
Male	−0.0158 ***	(0.0056)	—	—	—	—
Constant	0.0972	(0.0776)	0.1909 *	(0.1126)	0.0245	(0.1069)
Sample Size	7969		3352		4617	

Dependent variable: Being clinically depressed in 2007. Robust standard errors in parentheses. * significant at 10% level ** significant at 5% level *** significant at 1% level.

We find that exposure to air pollution during the fires of 1997 significantly affects the probability of experiencing clinical depression ten years past exposure. This effect is however not statistically significant for men. While this lack of statistical significance might signal the fact that men do not get clinically depressed as a result of air pollution, another perfectly plausible and likely explanation is that this effect exists, but is not persistent. Men might recover from depression easier than women and the effects of the 1997 pollution shock might have disappeared over the 10 year lag in our data. Unfortunately, since IFLS only surveyed respondents about depressive symptoms in 2007, we cannot statistically test this hypothesis. There is some earlier literature however, that shows the effects of

pollution are persistent, but diminish over time. For instance [18] find that pollution exposure reduces hours worked both 3 years and 10 years past-exposure, but the magnitude of the 3 year effect is much larger. While theirs is not a study on mental health, the results signaling recovery are suggestive for a larger context. In addition, our previous results show that men have higher CES-D scores as a result of pollution, which proves that men are not immune to pollution. An important conclusion under this recovery hypothesis is that, while our estimation shows that women still suffer from depression caused by air pollution even 10 years after the event, the impact of this pollution could have arguably been much larger in magnitude in the immediate months and years after the fires.

As a potential mitigator of depression, it is worth noting that some previous research [57] found that exercise and physical activity has short- and long-term benefits for depression. Since men are generally more likely to engage in physical activities, this might be the channel responsible for their faster recovery. To that end, we coded an indicator variable equal to 1 for those respondents claiming their job requires them to engage in physical labor and included it in the estimations. Physical labor does not seem to be the channel responsible for men's recovery, although engaging in physical labor lowers the probability of depression. Specifically, when including the physical labor indicator in the men regression as an additional control, we find a statistically significant negative effect on depression (lower incidence of depression for men engaging in physical labor). However, when further disaggregating the sub-sample of men into those who performed physical labor and those who did not, we find the same insignificant effects of pollution on clinical depression for both sub-samples of men. This implies that even those men who did not engage in physical labor seem to have been recovered from clinical depression. So while exercise and physical labor are important mitigators for depression, they do not seem to be the responsible channels for men's faster recovery from clinical depression.

For robustness purposes, since the vast majority (over 93%) of the respondents in the sample cannot be classified as experiencing clinical depression according to the CES-D guidelines, we extend our analysis to study the effects of air pollution exposure on the intensity of mild depressive symptoms. To that end, we first restrict the sample to only those respondents with a CES-D score below 10, then estimate the effects of pollution exposure on the CES-D score itself, while controlling for the same socio-economic variables from our main regression. Table 4 presents the results of these OLS estimations, but ordered probit and ordered logit estimations were also employed and the results were found to be similar.

Table 4. The Effects of Pollution on Mild Depressive Symptoms (OLS Regression Results).

Explanatory Variables	Full Sample		Men		Women	
	Coefficient	(St. Error)	Coefficient	(St. Error)	Coefficient	(St. Error)
Pollution in 1997	0.1447 **	(0.0463)	0.1386 **	(0.0702)	0.1576 ***	(0.0617)
Age in 2007	−0.0269	(0.0182)	−0.0932 ***	(0.0308)	0.0246	(0.0224)
Age ² in 2007	0.00033 **	(0.00016)	0.00092 ***	(0.00027)	−0.00013	(0.0002)
Years of Education	−0.0486 ***	(0.0071)	−0.0403 ***	(0.0104)	−0.0555 ***	(0.0096)
Poor GHS in 1993	0.4705 ***	(0.1041)	0.5104 ***	(0.1614)	0.45997 ***	(0.1361)
Log PCE	−0.1919 ***	(0.0447)	−0.1169 *	(0.06896)	−0.2427 ***	(0.0586)
Income Ladder 2	−0.3604 ***	(0.1338)	−0.2940	(0.2013)	−0.40497 **	(0.1790)
Income Ladder 3	−0.7215 ***	(0.1299)	−0.6686 ***	(0.1948)	−0.7609 ***	(0.1742)
Income Ladder 4	−1.0098 ***	(0.1427)	−0.9881 ***	(0.2132)	−1.0267 ***	(0.1922)
Income Ladder 5	−0.9452 ***	(0.2626)	−0.3930	(0.4197)	−1.3023 ***	(0.3313)
Having Outside Kitchen	0.0534	(0.0549)	−0.0488	(0.08398)	0.1273 *	(0.0725)
Having Outside Water	−0.2242 ***	(0.0626)	−0.3042 ***	(0.0972)	−0.1636 **	(0.0819)
Married	−0.2681 ***	(0.0812)	−0.4881 ***	(0.1749)	−0.2013 **	(0.0950)
Male	−0.0166	(0.0571)	—	—	—	—
Constant	7.5446 ***	(0.7321)	8.5631 ***	(1.1942)	6.7945 ***	(0.9307)
Sample Size	7479		3195		4284	

Dependent variable: CES-D score in 2007. Robust standard errors in parentheses. * significant at 10% level ** significant at 5% level *** significant at 1% level.

These are nothing more than a reiteration of the estimations from Table 2, performed for those respondents who experience only mild depressive symptoms (CES-D scores below 10). We again estimated these for the whole sample first, then for men and women separately.

The results are robust to our previous estimations and show significant effects of pollution for both men and women, with slightly higher magnitudes for women. This strengthens the idea that men are not immune to pollution, but the effects are somewhat smaller. Whether that is because men are more resistant to depressive symptoms or because they recover faster from such symptoms remains an important question. Since the analysis is based on voluntary survey responses, it is also possible that men are simply less likely to report such symptoms even in the absence of any actual psychological or physiological differences between sexes.

While the results presented here are hard to interpret quantitatively due to the lack of measurement units for the aerosol index measuring pollution, they are highly suggestive from a qualitative perspective. The estimates are robust to alternative estimation strategies and show significant and persistent negative effects of exposure to air pollution on depression and depression-like symptoms. The fact that we are able to estimate effects that persist over a ten years period, suggests that the actual negative effects of pollution in the short-term are even larger and can have serious social and economic consequences.

4. Robustness Checks and Threats to Identification

Although natural experiments driven by meteorological phenomena like the Indonesian 1997 forest fires are plausibly fully exogenous, our estimates could be potentially biased by two factors specific to longitudinal data: attrition and migration. At the same time, the effects of pollution from smoke on mental health could be confounded with the effects of the fires on mental health. We briefly discuss these potential threats in this section.

Attrition and migration are usually valid reasons of concern in studies using longitudinal data that tracks people over the course of many years. If attrition or migration are systematic and driven by pollution, the estimates will be biased. Previous studies found however that the migration decision of IFLS respondents and also the sample attrition between 1993 and 2007 were not correlated with the pollution episode [18]. In other words, neither migration nor attrition were driven by the 1997 pollution shock. Furthermore, these studies note that even if this had occurred, it would have introduced a downward bias to the estimates which would only strengthen their qualitative results. The same argument can be applied for mental health: if pollution drives people out of the sample, the remaining sample is arguably in better health (both physical and mental) than the true population, which would render our results to be underestimated.

A more important issue specific to our study is the possibility that the damages to mental health are not truly caused by pollution but by the fires themselves, through their destructive power. If people lose their property or suffer physical injuries due to the fires, their mental health can suffer in response to these triggers, regardless of pollution. It is therefore important to estimate the effects of pollution on mental health for those households that did not experience any fires during the 1997 episode. It is important to note that while the fires were localized events, the smoke clouds were carried by the strong winds of El Niño throughout the region, even affecting some of the neighboring countries. So while some households were affected by both fires and smoke, others were only affected by smoke. We use this sub-sample of households to test whether our main results are primarily due to smoke or whether the effects of smoke are confounded with those of the fires.

One of the survey questions in IFLS asked respondents if they had experienced any fire or earthquake during the past 5 years. We used this question from the 2000 wave of IFLS to exclude the households that experienced fires. Out of our main sample of 7969 households, only 127 households experienced fires and 29 did not record any response. We excluded all these 156 households and re-estimated our main specification on the sub-sample of households that were not directly exposed to fires, but only to smoke. The results remain practically unchanged, which confirms that our estimates

measure mental health consequences of air pollution and not of other destruction caused by the fires. These estimates are reported in Table 5.

Table 5. Sub-sample analysis: Households exposed to smoke but not fires (OLS Regression Results).

Explanatory Variables	Clinical Depression Status		Mild Depressive Symptoms	
	Coefficient	(St. Error)	Coefficient	(St. Error)
Pollution in 1997	0.0128 **	(0.0051)	0.148 ***	(0.0467)
Age in 2007	−0.0027	(0.0019)	−0.0297	(0.0184)
Age ² in 2007	0.00002	(0.00001)	0.00036	(0.00016)
Years of Education	−0.0012 *	(0.00007)	−0.0468 ***	(0.0071)
Poor GHS in 1993	0.0585 ***	(0.0124)	0.466 ***	(0.1054)
Log PCE	0.0102 **	(0.0048)	−0.1948 ***	(0.0451)
Income Ladder 2	−0.0367 **	(0.0161)	−0.3540 ***	(0.1353)
Income Ladder 3	−0.0661 ***	(0.0154)	−0.7105 ***	(0.1314)
Income Ladder 4	−0.0710 ***	(0.0165)	−0.9956 ***	(0.1443)
Income Ladder 5	−0.0897 ***	(0.02104)	−0.9275 ***	(0.2641)
Having Outside Kitchen	0.0002	(0.0056)	0.0555	(0.0554)
Having Outside Water	−0.0065	(0.0066)	−0.2239 ***	(0.0634)
Married	−0.0241 ***	(0.0090)	−0.2747 ***	(0.082))
Male	−0.0175 ***	(0.0056)	−0.0188	(0.0575)
Constant	0.0923	(0.0785)	7.627 ****	(0.7397)
Sample Size	7813		7338	

Columns 2 and 3 present the effects of pollution on the likelihood of being clinically depressed (dependent variable: being clinically depressed in 2007). Columns 4 and 5 present the effects of pollution on the number of depressive symptoms, for respondents below the clinical depression threshold (dependent variable: CES-D score in 2007). The two models parallel those presented in Tables 3 and 4, respectively. Robust standard errors in parentheses. * significant at 10% level ** significant at 5% level *** significant at 1% level.

5. Conclusions

In this paper, we have provided evidence of significant and persistent negative effects of air pollution on mental health. Using a natural experiment in Indonesia, we find that exposure to severe air pollution significantly increases the incidence of depressive symptoms for both men and women and the incidence of clinical depression among women, even ten years after the pollution exposure. We also find robust significant effects of pollution on the severity of mild depressive symptoms that persist over time for both sexes. This pattern is consistent with a hypothesis of faster recovery times for men, but more research needs to be done to address this issue.

Another important avenue for future research is investigating the linkages and causal chains between mental health, general health, and economic outcomes in a context of air pollution exposure. In light of the results presented in this paper and those from previous research that link pollution to general health, labor supply, and earnings, it is important to understand the degree to which general health affects mental health (or vice-versa) and the degree to which both affect economic outcomes. If there are strong causal links, policies to mitigate the negative effects of pollution can be targeted towards the base of the causal chain. If however, these links are weak and pollution has separate and distinct negative effects on general health, mental health, and labor activities, then multiple policies need to be implemented to target these issues individually.

Also, since using aerosol index data to proxy for pollution exposure cannot provide meaningful quantitative estimates, better efforts have to be made to establish robust correlations of the aerosol index data with the ground-based pollution monitors. The qualitative implications of ours and other emerging results involving the persistence of the negative consequences of pollution over time are troubling and the economic costs that are often ignored by the medical literature are very high. But in the absence of robust quantitative measures of ground-level pollution, proper cost-benefit analyses cannot be performed and mitigating policies cannot be properly evaluated. Alternatively, studies that do use data generated by ground-level monitors need to be better formulated to control for many

potential confounders to ensure the magnitudes of the estimates are not biased and represent true causal inference.

Air pollution, particularly particulate matter pollution, is clearly affecting humans in a negative way and these negative effects seem to linger for years. It is therefore extremely important the scientific debate continues and more studies address the issue to better pinpoint the effects and best possible policies. In the meantime, education and economic stability seem to be the best and most consistent mitigators for these negative consequences and they need to be continuously improved, especially in developing countries that are resource constrained.

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