Supplementary appendix

This appendix formed part of the original submission and has been peer reviewed. We post it as supplied by the authors.

Supplement to: Qiu X, Danesh-Yazdi M, Wei Y, et al. Associations of short-term exposure to air pollution and increased ambient temperature with psychiatric hospital admissions in older adults in the USA: a case–crossover study. Lancet Planet Health 2022; 6: e331–41.
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Methods

In a case-crossover setting described in the study design section, only covariates that changed from day to day in the short-term can be confounders. Individual-level covariates and zip code – level covariates that did not vary day to day (i.e., age, sex, race/ ethnicity, population density, socioeconomic status and behavioral risk factors) were not considered to be confounders as they remained constant when comparing case days vs control days.

A natural cubic spline splits the range of exposure into several pieces and fits a separate polynomial for each piece, so e.g. the shape of the low exposure relationship does not influence the shape of the high exposure relationship. The polynomials are constrained to meet up at the split points, and to be linear at the extremes of exposure, where data is sparse. (1)

Based on the preliminary results using DL models, in the final models, we used moving averages of lag02 for PM$_{2.5}$ and NO$_{2}$ in the models for depression, moving averages of lag36 for PM$_{2.5}$ and moving averages of lag02 for NO$_{2}$ in the models for schizophrenia, and moving averages of lag36 for PM$_{2.5}$ in the models for bipolar disorder. Temperature was fitted with a moving average of lag 0 to lag6 days for all outcomes. Ozone as not associated with any outcome in preliminary models and was not included in the multi-pollutant models.

Bonferroni correction is usually applied when there is an increased risk of a type I error when making multiple statistical tests to test the same hypothesis. (2) It is not commonly used in air pollution epidemiology studies to test the association with different air pollutants, as they differ in physical and chemical aspects and hence are different hypotheses.

In our series of interaction analyses we applied to detect if any of the personal or community factors modifies the associations between ambient exposures and psychiatric mental admission risk, we have a universal null hypothesis, that none of them modified our exposure-outcome associations. Therefore, we thought it would be appropriate to apply a Bonferroni correction to see if the observed $P$ is still significant after the correction.

But otherwise, if we instead focus on the testing using a separate hypothesis for each effect modifier, i.e. “does education level interacts with the exposure on the outcome” is an independent hypothesis from “does community Hispanic level interacts with the exposure on the outcome”. Then, Bonferroni may not be considered appropriate. In the results, we presented the non-corrected confidence intervals in the first place in the forest plots, but also presented how significance can change after applying a Bonferroni correction if we want to investigate if there is any effect modifier across the comparisons.

Detailed steps of model building:

The following procedures were conducted separately for depression, schizophrenia and bipolar disorder hospitalization.

1) We created a case-crossover dataset with case days being the day where we observed a hospitalization with primary diagnosis of each of the targeted psychiatric disorders. Control days were matched with case days in a time-stratified bidirectional way by same day of week, month and year for the same person.

2) Air pollution predictions as well as meteorological conditions were merged to each case and control days for that date as well as lag periods before the event day.

3) We conducted single-exposure cubic constrained distributed lag (DL) models to observe the distributed lag pattern as well as cumulative effects of each of air pollutants and warm/cold season temperature on disorder-specific psychiatric admission risk.
Further, the constrained DL models were extended to include multiple pollutants in the same model including all lag day exposures for the exposures of interest (PM$_{2.5}$, temperature, and NO$_2$ – ozone was not included due to its consistent null associations across the lag days on psychiatric admission risk from the previous step). This step was conducted to allow for mutual adjustment of the co-exposures to reduce estimation bias, and to further assist the detection of significant lag windows for each exposure.

Then, based on the single-exposure as well as multi-exposure distributed lag pattern, we identified the critical lag windows for each of the exposures on disorder-specific psychiatric admission risk.

In the main conditional logistic regression model sets, we used moving averages of lag02 for PM$_{2.5}$ and NO$_2$ in the models for depression, moving averages of lag36 for PM$_{2.5}$ and moving averages of lag02 for NO$_2$ in the models for schizophrenia, and moving averages of lag36 for PM$_{2.5}$ in the models for bipolar disorder. Temperature was fitted with a moving average of lag 0 to lag6 days for all outcomes because its effect was persistent across the lag0-lag6 period based on preliminary analysis. Ozone as not associated with any outcome in preliminary models and was not included in the multi-pollutant models.

Increases in temperature may have different effects in the warm and cold season, so we examined the temperature effect separately in warm and cold season. To detect possible non-linearity for the temperature effect, temperature-response curves were generated via fitting natural cubic spline with 3 degrees of freedom for warm and cold season temperature. Examining those curves we found a close-to-linear relationship between temperature and psychiatric hospital admission risk for cold season, and null association for warm season, indicating linear terms could be applied for temperature. Linear terms were also used for pollutants since a large number of studies have reported close-to-linear associations between pollutants and various health outcomes in US nationwide or across cities investigation.

All the models were adjusted for precipitation using a natural cubic spline with 3 degrees of freedom for moving averages of lag0 to lag6, similar to temperature to allow for flexibility in its relationship with the outcomes. Detail reasons for why we chose to adjust for precipitation has been provided in the responses to your first detailed comments. Briefly, evidence has shown that precipitation matters for people’s mental health and feelings and we are focusing on psychiatric health outcomes in this study rather than physical health outcomes or mortality. We have cited papers to justify the interest in precipitation.

The final conditional logistic regression models included moving averages of the lags of choice for each pollutant of interest, linear partitioned warm/cold season temperature and a natural spline of df=3 for precipitation based on preliminary analyses.

Similar regressions were applied to the low-level air pollution setting.

Regional analyses (Midwest, Northeast, South and West) were applied for cold season temperature to account for adaptation to baseline temperature or climate zone.

Interactions between pollutants and ambient temperature were examined by fitting multiplicative interaction terms between them in the final multi-exposure models.

Modification of the association of interest by individual covariates (sex, race, Medicaid coverage) and contextual covariates (population density, Hispanic people proportion, median household income, poverty proportion, education level) was also examined via multiplicative interaction terms. Population density was chosen as a proxy for urbaniy level, other variables were chosen as key elements of community socio-economic status. Hispanic people proportion was chosen separately to investigate the Hispanic community modification effect. Medicaid coverage was chosen as a proxy for personal poverty level. We also included two key demographical variables (sex and race).

The robustness of the estimates was assessed with respect to 1) moving averages of lag day of choice; 2) residual confounding (e-value); 3) alternative adjustment of specific humidity; 4) alternative adjustment of moving average of lag0-3 day temperature exposure; 5) temperature only modeling.

- **Results**

Cold temperature had a close to linear dose-response relationship with acute hospital admission relative risk of depression and schizophrenia across the range of values and a close to linear dose-response relationship with the risk of bipolar disorder when temperature was lower than 10 ° C.
For example, areas with a higher Hispanic population (>=75th of the total area Hispanic proportion) and with low education level (>=75th people with <= high school education) were associated with a lower but non-significant risk of hospitalization for bipolar disorder when exposed to the same increased levels of PM$_{2.5}$ (medium to low Hispanic population: 1.66% (0.84%, 2.48%) vs. high Hispanic population: -0.26% (-2.05%, 1.56%); high education: 1.73% (0.87%, 2.59%) vs. lower education: 0.04% (-1.68%, 1.78%); interaction: $P=0.021$; $P=0.029$; respectively). NO$_2$ exposure was also associated with a lower and non-significant percent increase in admission risk for schizophrenia in areas with a high Hispanic population (medium to low Hispanic population: 1.02% (0.46%, 1.58%) vs. high Hispanic population: 0.04% (-1.01%, 1.11%); interaction: $P=0.035$). Increased levels of cold season ambient temperature were significant associated with an increased risk of all of the investigated mental outcomes in this study. The observed associations remained significant in different subgroups of people. Specifically, areas with low education amplified the association between cold season temperature increase and hospital admission for depression while areas with high population density weakened the link between cold season temperature increase and admission of bipolar disorder. However, after applying a Bonferroni correction, none of the interactions remained significant (Bonferroni corrected p value threshold was set at 0.05/8=0.00625).

**Discussion**

We also found a significant negative interaction between NO$_2$ and cold season temperature on the acute admission risk for schizophrenia. We reported a lower distribution range of cold season temperature in the schizophrenia population compared with the depression and bipolar disorder populations, indicating the schizophrenia population experienced a colder climate in cold seasons in general (Table 1). The interaction effect we identified here could be due to that when people were exposed to lower ambient temperature, they were also exposed to a lowered atmospheric mixing height. The lowered mixing height further compressed the concentrations of surface air pollutants (especially for traffic emissions that are in high correlation with NO$_2$, such as PAHs and ultrafine particles). As a possible consequence, the admission risk for schizophrenia got more elevated because people were also exposed to elevated levels of companion traffic source pollutants. This increase in the NO$_2$ effect with colder temperatures would appear as a negative interaction with temperature increases. Another possible reason is that due to the heavier use of combustion power plants for wintertime residential heating, we actually observed higher levels of NO$_2$ in the cold season with colder temperature leading to excess emission of heating related NO$_2$. The negative interaction between PM$_{2.5}$ and NO$_2$ on depression admission is also interesting. However, it remains unclear why we additionally observed this negative gas-particle interaction. It could be that the effect interaction between PM$_{2.5}$ and NO$_2$ is antagonistic in triggering the depressive episode. Another proposed hypothesis is that when NO$_2$ level is high (usually in the cold season), the particulate matter in the air tends to be primary particles that are emitted directly from the sources, such as power plants or heating or traffic (what happens in the winter when mixing heights and photochemistry are low). When NO$_2$ level is low (usually in the warm season), temperature tends to be higher and results in more photochemical reactions of the air. Therefore, secondary particles are at a higher proportion of particles in the warm seasons. It could be that secondary particles, in comparison with primary particles, are more harmful for the brain and related mental outcomes. However, related evidence on the different toxicities of primary and secondary particles is still lacking. Further studies are needed to test this gas-particle interaction on mental health outcomes.

Area education level is another potential modifier. We have shown that areas with higher proportions of people <=high school education (less sufficiently educated areas) experienced a much higher risk of depression admission when exposed to same levels of cold season temperature increase. However, on the contrary, it appeared to weaken the positive association between PM$_{2.5}$ and hospitalization for bipolar disorder. Besides, community income levels as well as population density also shifted the effect estimates between different subgroups.

The fact that psychiatric hospitalization risk (we focused on hospitalization) appeared to be stronger in high education and low poverty communities than in low education and high poverty communities could be related to the differences in the underlying healthcare seeking awareness in high SES vs. low SES areas. For example, psychiatric patients who lived in a poor neighborhood or less educated area may also have less chance of being...
hospitalized to take care of their mental outbreak even if they actually need one because their neighbors or family, community members are less likely to recognize the severity of the mental conditions and take them to the hospital for inpatient care due to limited mental healthcare seeking awareness. More studies are needed to validate and explain these effect modification findings.

Recent evidence has shown that, while the first onset is usually at early life stage for schizophrenia, schizophrenia hospitalizations were actually most prevalent for middle age individuals aged 45-64 yrs. (38.8%) based on the Nationwide Inpatient Sample data during 2005-2014. (3) Further, people aged 65 and above accounted for 28.81% of all schizophrenia hospitalizations. Because we are studying short-term acute admissions of each of the three mental disorders in this study, what we were investigating is not the onset of the disease, but rather an acute episode of them, whether that is for an incident case or an existing prevalent case. While there may be some misdiagnosis based on medication alone, we believe that a discharge diagnosis of schizophrenia after a hospital admission is likely to be based on symptomatology and medical record and hence reasonably accurate. In addition, evidence has shown that the neurodegenerative process may be etiologically relevant to psychosis with onset in late life. (4) Therefore, having incidence cases in later ages is also possible. Higher prevalence of psychosis, including schizophrenia, has been observed in the American black population for a long time. Research has found that black people are about 3 to 4 times more likely than white people to receive a schizophrenia diagnosis. (5) In addition, the lifetime prevalence of self-reported psychotic symptoms is the highest in black Americans (21.1%) compared to white Americans (13.1%). (6) There are several possible reasons for this. First, there might be genetic susceptibility that predisposes the black population to be at higher risk of schizophrenia. (7, 8) Second, it is also possible that the relatively low socio-economic status along with higher psychosocial stress experienced among blacks increases the risk of severe mental health problems including schizophrenia. Third, it has been reported that the psychiatric diagnosis system has a tendency to over-diagnose black people with schizophrenia. (9)

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eTable 1. National and Regional Percent Increase and 95% Confidence Intervals (CI) of Psychiatric Admission Rate per 5 °C Increase in Cold Season Temperature.

| Outcome       | Region  | Percent Increase, % (95% CI) |
|---------------|---------|------------------------------|
| Depression    | Nation  | 3.66 (3.06, 4.26)            |
|               | West    | 2.37 (0.57, 4.20)            |
|               | South   | 3.97 (2.97, 4.98)            |
|               | Northeast | 4.69 (3.50, 5.89)         |
|               | Midwest | 2.70 (1.59, 3.83)            |
| Schizophrenia | Nation  | 3.03 (2.04, 4.02)            |
|               | West    | 5.13 (2.41, 7.92)            |
|               | South   | 2.81 (1.03, 4.61)            |
|               | Northeast | 2.18 (0.42, 3.96)         |
|               | Midwest | 3.33 (1.39, 5.30)            |
| Bipolar Disorder | Nation | 3.52 (2.38, 4.68)           |
|               | West    | 1.25 (-1.80, 4.40)           |
|               | South   | 3.43 (1.33, 5.58)            |
|               | Northeast | 4.61 (2.47, 6.80)       |
|               | Midwest | 3.48 (1.36, 5.65)            |

* Percent Increase % and its 95% Confidence Interval (CI).
eTable 2. Model Interaction Results between Pollutant and Temperature.

| Outcome              | Exposure Interaction          | Beta Coefficient | Standard Error | P value<sup>a</sup> |
|----------------------|-------------------------------|------------------|----------------|----------------------|
| Depression<sup>b</sup> | PM<sub>2.5</sub> × Temperature (Warm) | -4.02E-05        | 3.55E-05       | 0.258                |
|                      | PM<sub>2.5</sub> × Temperature (Cold) | 7.74E-06         | 5.05E-05       | 0.878                |
|                      | NO<sub>2</sub> × Temperature (Warm) | -1.78E-05        | 3.02E-05       | 0.557                |
|                      | NO<sub>2</sub> × Temperature (Cold) | -3.65E-05        | 3.29E-05       | 0.268                |
|                      | PM<sub>2.5</sub> × NO<sub>2</sub> | **-4.74E-05**    | **1.81E-05**   | **0.009**            |
| Schizophrenia<sup>c</sup> | PM<sub>2.5</sub> × Temperature (Warm) | -4.78E-06        | 6.40E-05       | 0.941                |
|                      | PM<sub>2.5</sub> × Temperature (Cold) | 6.15E-05         | 8.26E-05       | 0.457                |
|                      | NO<sub>2</sub> × Temperature (Warm) | 4.45E-05         | 4.42E-05       | 0.313                |
|                      | NO<sub>2</sub> × Temperature (Cold) | **-1.80E-04**    | **4.67E-05**   | <0.0001              |
|                      | PM<sub>2.5</sub> × NO<sub>2</sub> | 3.45E-05         | 3.78E-05       | 0.361                |
| Bipolar Disorder<sup>d</sup> | PM<sub>2.5</sub> × Temperature (Warm) | -1.34E-06        | 6.98E-05       | 0.985                |
|                      | PM<sub>2.5</sub> × Temperature (Cold) | 1.62E-04         | 1.18E-04       | 0.171                |
|                      | PM<sub>2.5</sub> × NO<sub>2</sub> | -2.53E-05        | 3.56E-05       | 0.477                |

<sup>a</sup> P value is model p value for interaction terms;
<sup>b</sup> for depression, based on significant lag period, moving average of lag0 to lag2 day PM<sub>2.5</sub> and NO<sub>2</sub> exposure was applied;
<sup>c</sup> for schizophrenia, based on significant lag period, moving average of lag3 to lag6 day PM<sub>2.5</sub> and of lag0 to lag2 day NO<sub>2</sub> exposure was applied;
<sup>d</sup> for bipolar disorder, based on significant lag period, moving average of lag3 to lag6 day PM<sub>2.5</sub> was applied, and in the examination of pollutant interaction, same lag period of lag3 to lag6 day NO<sub>2</sub> exposure was applied.
### Table 3. Percent Increase and 95% Confidence Intervals (CI) of Psychiatric Admission Rate per 5 Units Increase in PM$_{2.5}$, NO$_2$ and Cold Season Temperature (Subgroup Results).

| Exposure | Subpopulation | Depression | Schizophrenia | Bipolar Disorder |
|----------|---------------|------------|---------------|-----------------|
|          | Percent Increase, % (95% CI)* | Interaction $P$ | Percent Increase, % (95% CI) | Interaction $P$ | Percent Increase, % (95% CI) | Interaction $P$ |
| PM$_{2.5}$ (µg/m$^3$) | Male Gender | 0.37 (-0.30, 1.05) | ref | 0.81 (-0.37, 2.01) | ref | 0.57 (-0.70, 1.86) | ref |
| | Female Gender | 0.75 (-0.32, 1.83) | 0.376 | 0.75 (-1.09, 2.63) | 0.933 | 1.46 (-0.53, 3.50) | 0.257 |
| | Caucasian | 0.66 (0.24, 1.07) | ref | 0.84 (0.05, 1.64) | ref | 1.26 (0.52, 2.02) | ref |
| | African American | 0.02 (-1.60, 1.66) | 0.430 | 0.07 (-1.68, 1.84) | 0.333 | 1.02 (-1.69, 3.81) | 0.856 |
| | Other Race | 0.82 (-1.28, 2.97) | 0.878 | 2.84 (-0.18, 5.96) | 0.181 | -0.29 (-4.17, 3.74) | 0.435 |
| | Median-Low Hispanic | 0.60 (0.14, 1.06) | ref | 0.52 (-0.26, 1.30) | ref | 1.66 (0.84, 2.48) | ref |
| | High Hispanic | 0.61 (-0.40, 1.62) | 0.991 | 1.55 (-0.14, 3.26) | 0.180 | -0.26 (-2.05, 1.56) | 0.021* |
| | Median-Low Population Density | 0.63 (0.15, 1.11) | ref | 0.56 (-0.25, 1.37) | ref | 1.30 (0.45, 2.16) | ref |
| | High Population Density | 0.47 (-0.50, 1.45) | 0.719 | 1.28 (-0.36, 2.94) | 0.324 | 0.80 (-0.93, 2.56) | 0.517 |
| | No Medicaid Coverage | 0.72 (0.27, 1.18) | ref | 0.74 (-0.38, 1.88) | ref | 1.28 (0.41, 2.17) | ref |
| | With Medicaid Coverage | 0.34 (-0.65, 1.35) | 0.403 | 0.79 (-0.99, 2.60) | 0.948 | 1.02 (-0.68, 2.76) | 0.733 |
| | High-Median Income | 0.90 (0.44, 1.35) | ref | 0.89 (0.10, 1.68) | ref | 1.20 (0.38, 2.04) | ref |
| | Low Income | -0.15 (-1.14, 0.86) | 0.022* | 0.47 (-1.18, 2.16) | 0.582 | 1.16 (-0.62, 2.97) | 0.954 |
| | Median-Low Poverty | 0.71 (0.26, 1.16) | ref | 0.66 (-0.11, 1.44) | ref | 1.26 (0.44, 2.08) | ref |
| | High Poverty | 0.34 (-0.66, 1.36) | 0.432 | 1.13 (-0.56, 2.85) | 0.547 | 0.99 (-0.81, 2.82) | 0.744 |
| | High Education | 0.84 (0.37, 1.32) | ref | 0.80 (0.00, 1.62) | ref | 1.73 (0.87, 2.59) | ref |
| | Low Education | 0.10 (-0.86, 1.07) | 0.085 | 0.71 (-0.91, 2.37) | 0.900 | 0.04 (-1.68, 1.78) | 0.029* |
| NO$_2$ (ppb) | Male Gender | 0.52 (-0.02, 1.07) | ref | 0.54 (-0.22, 1.30) | ref | - | - |
| | Female Gender | 0.26 (-0.60, 1.12) | 0.440 | 0.70 (-0.50, 1.91) | 0.743 | - | - |
| | Caucasian | 0.40 (0.06, 0.74) | ref | 0.79 (0.25, 1.34) | ref | - | - |
| | African American | 0.12 (-1.09, 1.35) | 0.639 | 0.22 (-0.91, 1.36) | 0.257 | - | - |
| | Other Race | -0.13 (-1.57, 1.33) | 0.458 | 0.87 (-0.92, 2.69) | 0.933 | - | - |
| | Median-Low Hispanic | 0.43 (0.03, 0.83) | ref | 1.02 (0.46, 1.58) | ref | - | - |
| | High Hispanic | 0.24 (-0.52, 1.01) | 0.579 | 0.04 (-1.01, 1.11) | 0.035* | - | - |
| | Median-Low Population Density | 0.58 (0.14, 1.02) | ref | 0.58 (-0.01, 1.18) | ref | - | - |
| | High Population Density | 0.17 (-0.60, 0.94) | 0.210 | 0.73 (-0.33, 1.81) | 0.734 | - | - |
| | No Medicaid Coverage | 0.29 (-0.08, 0.66) | ref | 0.67 (-0.10, 1.43) | ref | - | - |
| | With Medicaid Coverage | 0.51 (-0.29, 1.31) | 0.542 | 0.63 (-0.56, 1.85) | 0.948 | - | - |
| | High-Median Income | 0.42 (0.07, 0.78) | ref | 0.60 (0.09, 1.12) | ref | - | - |
| | Low Income | 0.02 (-0.81, 0.86) | 0.293 | 0.76 (-0.34, 1.88) | 0.748 | - | - |
| | Median-Low Poverty | 0.38 (0.02, 0.75) | ref | 0.68 (0.15, 1.22) | ref | - | - |
| | High Poverty | 0.25 (-0.55, 1.05) | 0.709 | 0.57 (-0.51, 1.65) | 0.805 | - | - |
| | High Education | 0.33 (-0.67, 0.70) | ref | 0.67 (0.13, 1.26) | ref | - | - |
| | Low Education | 0.40 (-0.40, 0.20) | 0.844 | 0.60 (-0.47, 1.69) | 0.896 | - | - |
| Cold Season Temperature ($^\circ$ C) | Male Gender | 3.46 (2.45, 4.49) | ref | 2.74 (1.05, 4.47) | ref | 1.92 (-0.10, 3.97) | ref |
| | Female Gender | 3.76 (2.15, 5.40) | 0.638 | 3.17 (0.49, 5.91) | 0.691 | 4.24 (1.05, 7.54) | 0.064 |
| | Caucasian | 3.71 (3.08, 4.34) | ref | 3.11 (1.93, 4.29) | ref | 3.69 (2.48, 4.92) | ref |
| | African American | 2.49 (0.05, 4.98) | 0.318 | 3.34 (0.77, 5.97) | 0.845 | 1.43 (-2.84, 5.88) | 0.294 |
| Category                          | Estimate (SE) | Percent Increase | 95% CI       | P value |
|----------------------------------|---------------|------------------|--------------|---------|
| Other Race                       | 4.69 (1.55, 7.93) | 0.535 | 0.87 (-3.41, 5.35) | 0.305 | 3.81 (-2.35, 10.36) | 0.971 |
| Median-Low Hispanic              | 3.81 (3.11, 4.52) | ref | 3.59 (2.43, 4.76) | ref | 3.98 (2.62, 5.35) | ref |
| High Hispanic                    | 3.26 (1.77, 4.78) | 0.423 | 1.63 (-0.80, 4.11) | 0.080 | 2.32 (-0.49, 5.20) | 0.198 |
| Median-Low Population Density    | 3.77 (3.05, 4.50) | ref | 3.41 (2.22, 4.60) | ref | 4.41 (3.00, 5.84) | ref |
| High Population Density          | 3.45 (1.99, 4.94) | 0.624 | 2.21 (-0.18, 4.66) | 0.270 | 1.79 (-0.93, 4.58) | 0.033* |
| No Medicaid Coverage             | 3.59 (2.90, 4.29) | ref | 3.07 (1.42, 4.75) | ref | 3.48 (2.07, 4.90) | ref |
| With Medicaid Coverage           | 3.86 (2.33, 5.42) | 0.698 | 3.00 (0.39, 5.68) | 0.950 | 3.60 (0.84, 6.44) | 0.921 |
| High-Median Income               | 3.57 (2.89, 4.26) | ref | 3.38 (2.24, 4.53) | ref | 3.01 (1.71, 4.33) | ref |
| Low Income                       | 3.97 (2.42, 5.55) | 0.579 | 1.99 (-0.48, 4.53) | 0.228 | 5.20 (2.19, 8.29) | 0.115 |
| Median-Low Poverty               | 3.49 (2.81, 4.19) | ref | 3.30 (2.15, 4.46) | ref | 3.28 (1.96, 4.62) | ref |
| High Poverty                     | 4.18 (2.64, 5.74) | 0.334 | 2.31 (-0.13, 4.82) | 0.381 | 4.22 (1.30, 7.22) | 0.483 |
| High Education                   | 3.21 (2.53, 3.89) | ref | 3.56 (2.42, 4.72) | ref | 3.43 (2.13, 4.75) | ref |
| Low Education                    | 5.14 (3.57, 6.74) | 0.007* | 1.49 (-0.96, 4.01) | 0.070 | 3.78 (0.80, 6.83) | 0.803 |

*a Percent Increase % and its 95% Confidence Interval (CI);
*b Reference group.

P value marked with * indicated a significant difference between estimates in the contrasting subgroups (P < 0.05, without Bonferroni correction).
Table 4. Model Coefficient, Significance and Percent Increase (95% Confidence Interval, CI) in Targeted Psychiatric Admission Rate per 5 Units Increase in PM$_{2.5}$ (μg/m$^3$), NO$_2$(ppb) and Warm/Cold Season Temperature ($^\circ$C) (Fully Adjusted Model Results).

| Outcome     | Exposure | Coefficient | SE$^a$ | P$^b$ | Percent Increase, % (95% CI) |
|-------------|----------|-------------|--------|-------|-----------------------------|
| Depression  | pm25lag02$^d$ | 0.001300   | 0.000406 | 0.001 | 0.65 (0.25, 1.05) |
|             | pm25lag36$^e$ | 0.000083   | 0.000445 | 0.852 | 0.04 (-0.39, 0.48) |
|             | no2lag02$^f$ | 0.000738   | 0.000326 | 0.024 | 0.37 (0.05, 0.69) |
|             | no2lag36$^g$ | -0.000445  | 0.000362 | 0.219 | -0.22 (-0.58, 0.13) |
|             | warmtemp$^h$ | 0.000593   | 0.000765 | 0.438 | 0.30 (-0.45, 1.05) |
|             | coldtemp$^i$ | 0.007219   | 0.000590 | <0.001 | 3.68 (3.08, 4.28) |
| Schizophrenia | pm25lag02 | 0.000025   | 0.000690 | 0.972 | 0.01 (-0.66, 0.69) |
|              | pm25lag36 | 0.001460   | 0.000758 | 0.054 | 0.73 (-0.01, 1.48) |
|              | no2lag02 | 0.001260   | 0.000502 | 0.012 | 0.63 (0.14, 1.13) |
|              | no2lag36 | 0.000122   | 0.000559 | 0.827 | 0.06 (-0.49, 0.61) |
|              | warmtemp | -0.001452  | 0.001265 | 0.251 | -0.72 (-1.95, 0.51) |
|              | coldtemp | 0.005960   | 0.000977 | <0.0001 | 3.03 (2.04, 4.02) |
| Bipolar Disorder | pm25lag02 | -0.000846  | 0.000737 | 0.251 | -0.42 (-1.14, 0.30) |
|              | pm25lag36 | 0.002908   | 0.000797 | <0.0001 | 1.46 (0.68, 2.26) |
|              | no2lag02 | 0.000910   | 0.000567 | 0.109 | 0.46 (-0.10, 1.02) |
|              | no2lag36 | -0.000657  | 0.000629 | 0.296 | -0.33 (-0.94, 0.29) |
|              | warmtemp | -0.000760  | 0.001279 | 0.552 | -0.38 (-1.62, 0.88) |
|              | coldtemp | 0.006894   | 0.001134 | <0.0001 | 3.51 (2.36, 4.66) |

$^a$ Standard error (SE) of model coefficient for each exposure;
$^b$ Model coefficient significance p value generated for each exposure;
$^c$ Percent Increase % and its 95% Confidence Interval (CI);
$^d$ Moving average of lag0 to lag2 day PM$_{2.5}$ exposure;
$^e$ Moving average of lag3 to lag6 day PM$_{2.5}$ exposure;
$^f$ Moving average of lag0 to lag2 day NO$_2$ exposure;
$^g$ Moving average of lag3 to lag6 day NO$_2$ exposure;
$^h$ Moving average of lag0 to lag6 day temperature exposure in warm season (Month: 4-9);
$^i$ Moving average of lag0 to lag6 day temperature exposure in cold season (Month: 1-3, 10-12).
**Table 5. E-values (95% Confidence Interval) at Risk Ratio Scale for Estimation of Associations in Main Analyses.**

| Outcome       | Exposure  | Relative Risk (95% CI) | Percent Increase, % (95% CI) | E-value (95% CI) |
|---------------|-----------|------------------------|-----------------------------|-----------------|
| **Depression**| PM<sub>2.5</sub> | 1.0062 (1.0023, 1.0102) | 0.62 (0.23, 1.02)           | 1.0852 (1.0503, -) |
|               | NO<sub>2</sub> | 1.0035 (1.0003, 1.0066) | 0.35 (0.03, 0.66)           | 1.0628 (1.0176, -) |
|               | Temperature (warm) | 1.003 (0.9956, 1.0106)  | 0.30 (-0.44, 1.06)          | 1.0579 (1.0000, -) |
|               | Temperature (cold) | 1.0366 (1.0306, 1.0426) | 3.66 (3.06, 4.26)           | 1.2314 (1.2082, -) |
| **Schizophrenia** | PM<sub>2.5</sub> | 1.0077 (1.0011, 1.0144) | 0.77 (0.11, 1.44)           | 1.0958 (1.0343, -) |
|               | NO<sub>2</sub> | 1.0064 (1.0020, 1.0108) | 0.64 (0.20, 1.08)           | 1.0867 (1.0468, -) |
|               | Temperature (warm) | 0.9928 (0.9807, 1.0051) | -0.72 (-1.93, 0.51)         | 1.0927 (-, 1.0000) |
|               | Temperature (cold) | 1.0303 (1.0204, 1.0402) | 3.03 (2.04, 4.02)           | 1.2070 (1.1648, -) |
| **Bipolar Disorder** | PM<sub>2.5</sub> | 1.0119 (1.0049, 1.019)  | 1.19 (0.49, 1.90)           | 1.1216 (1.0751, -) |
|               | Temperature (warm) | 0.9957 (0.9834, 1.0081) | -0.43 (-1.66, 0.81)         | 1.0702 (-, 1.0000) |
|               | Temperature (cold) | 1.0352 (1.0238, 1.0468) | 3.52 (2.38, 4.68)           | 1.2261 (1.1799, -) |

-a E-value defined as the minimum strength of association on the risk ratio scale that an unmeasured confounder would need to have with both the treatment and the outcome to fully explain away a specific exposure-outcome association, conditional on the measured covariates. (https://cran.r-project.org/web/packages/EValue/index.html; VanderWeele, T. J., & Ding, P. (2017). Sensitivity analysis in observational research: introducing the E-value. Annals of internal medicine, 167(4), 268-274.)

-b 95% confidence interval of E values, some missing upper bound and some missing lower bound, depending on the direction of associations.
**eTable 6. Percent Increase (95% Confidence Interval, CI) in Admission Rate for Targeted Psychiatric Disorders per 5 Units Increase in PM$_{2.5}$ ($\mu$g/m$^3$), NO$_2$ (ppb) and Warm/Cold Season Temperature (°C) Based on Multi-Pollutant-Temperature Model (Main Adjustment, Alternative Adjustment for Specific Humidity, Moving Average of Lag0 to Lag3 Day Temperature)**

| Outcome          | Exposure | Percent Increase $^a$, % (95% CI) | Percent Increase $^b$, % (95% CI) | Percent Increase $^c$, % (95% CI) |
|------------------|----------|----------------------------------|----------------------------------|----------------------------------|
| **Depression**   | PM$_{2.5}$ | 0.62 (0.23, 1.02)                | 0.63 (0.24, 1.03)                | 0.58 (0.19, 0.97)                |
|                  | NO$_2$   | 0.35 (0.03, 0.66)                | 0.37 (0.05, 0.69)                | 0.32 (0.00, 0.63)                |
| Temperature (warm) | 0.30 (-0.44, 1.06) | 0.26 (-0.81, 1.34)               | 2.83 (2.31, 3.36)                |
| Temperature (cold) | 3.66 (3.06, 4.26) | 3.97 (2.79, 5.16)                | 2.83 (2.31, 3.36)                |
| **Schizophrenia** | PM$_{2.5}$ | 0.77 (0.11, 1.44)                | 0.77 (0.10, 1.44)                | 0.80 (0.14, 1.47)                |
|                  | NO$_2$   | 0.64 (0.20, 1.08)                | 0.67 (0.23, 1.11)                | 0.61 (0.17, 1.06)                |
| Temperature (warm) | -0.72 (-1.93, 0.51) | -0.03 (-1.78, 1.76)              | -0.45 (-1.52, 0.63)              |
| Temperature (cold) | 3.03 (2.04, 4.02) | 4.39 (2.36, 6.46)                | 2.47 (1.60, 3.34)                |
| **Bipolar Disorder** | PM$_{2.5}$ | 1.19 (0.49, 1.90)                | 1.17 (0.50, 1.85)                | 1.23 (0.57, 1.91)                |
| Temperature (warm) | -0.43 (-1.66, 0.81) | -0.62 (-2.36, 1.15)              | -0.23 (-1.30, 0.85)              |
| Temperature (cold) | 3.52 (2.38, 4.68) | 2.65 (0.71, 4.62)                | 2.12 (1.25, 3.00)                |

$^a$, Percent Increase per 5 units increase in pollutants and ambient temperature, adjusted for concurrent exposures of air pollutants (PM$_{2.5}$, NO$_2$, Warm/Cold Season Temperature and Precipitation for moving average of lags of choice – see Methods);

$^b$, Percent Increase per 5 units increase in pollutants and ambient temperature, adjusted for concurrent exposures of air pollutants (PM$_{2.5}$, NO$_2$, for moving average of lags of choice, and moving average of lag0 – lag6 day warm/cold season temperature and specific humidity);

$^c$, Percent Increase per 5 units increase in pollutants and ambient temperature, adjusted for concurrent exposures of air pollutants (PM$_{2.5}$, NO$_2$, Warm/Cold Season Temperature and Precipitation for moving average of lags of choice, in particular in this case, moving average of lag0 to lag3 day temperature was adjusted instead of lag0 – lag6).
eTable 7. Percent Increase (95% Confidence Interval, CI) in Admission Rate for Targeted Psychiatric Disorders per 5 Units Increase in Warm/Cold Season Temperature (°C) Based on Temperature-Only Model Adjusted for Precipitation

| Outcome          | Exposure      | RR*, % (95% CI) |
|------------------|---------------|-----------------|
| Depression       | Temperature   |                 |
|                  | (warm)        | 0.50 (-0.24, 1.24) |
|                  | (cold)        | 3.71 (3.11, 4.31) |
| Schizophrenia    | Temperature   |                 |
|                  | (warm)        | -0.58 (-1.80, 0.65) |
|                  | (cold)        | 3.14 (2.16, 4.13) |
| Bipolar Disorder | Temperature   |                 |
|                  | (warm)        | -0.24 (-1.47, 1.00) |
|                  | (cold)        | 3.00 (2.01, 4.01) |

*Percent Increase per 5 units increase in warm and cold season ambient temperature (based on model with moving average of lag0 – lag6 day warm/cold season temperature and precipitation).
eTable 8. Pollutants Levels in Warm vs. Cold Season and Cold/Warm Ratio.

| Exposures | Cold season Mean (SD) | Warm season Mean (SD) | Cold/warm mean ratio |
|-----------|-----------------------|-----------------------|----------------------|
| PM$_{2.5}$ | 10.6 (6.9)            | 11.5 (7.0)            | 0.92                 |
| NO$_2$    | 23.7 (14.0)           | 19.4 (13.5)           | 1.22                 |
| Ozone     | 32.0 (10.2)           | 45.0 (13.2)           | 0.71                 |

* Standard deviation (SD).
**eFigure 1. Distributed Lag of Model Coefficients and 95% Confidence Interval (CI) of PM$_{2.5}$, Ozone and NO$_2$ on Psychiatric Disorder Admission Risk (Single Pollutant Constrained Distributed Lag Model Results).**

Beta represented model coefficient generated for each pollutant; L0-L6 indicated lag0 day to lag6 day; cum represented cumulative lag0-6.
Figure 2. Distributed Lag of Model Coefficients and 95% Confidence Interval (CI) of PM$_{2.5}$ and NO$_2$ on Psychiatric Disorder Admission Risk (Mutually Adjusted Constrained Distributed Lag Model Results).

beta represented model coefficient generated for each pollutant; L0-L6 indicated lag0 day to lag6 day; cum represented cumulative lag0-6.
eFigure 3. Distributed Lag of Model Coefficients and 95% Confidence Interval (CI) of Warm/Cold Season Temperature on Psychiatric Disorder Admission Risk Based (Single Temperature Constrained Distributed Lag Model Results).

beta represented model coefficient generated for temperature; L0-L6 indicated lag0 day to lag6 day; cum represented cumulative lag0-6.
The correlation plot showed the spearman correlation coefficients for each pair of same day ambient exposures including fine particulate matter (PM$_{2.5}$), ozone (O$_3$), nitrogen dioxide (NO$_2$) and temperature (Temp). Blue circles/numbers represent positive correlation coefficients while red ones indicate negative correlation coefficients. The darker the color is, the higher the corresponding correlation coefficient is.