

# Smog in Our Brains

## Gender Difference in the Impact of Exposures to Air Pollution on Cognitive Performance

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# Acknowledgements



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# Motivation

- Large literature examines the effect of air quality on various health outcomes
  - life expectancy, illness and hospitalization rates, child health, and health behavior
- By comparison, the literature on the effect of air pollution on cognition is limited, but has picked up recently
  - exposure to air pollution in early life leaves a lasting negative effect on later school performance (Sanders 2012; Bharadwaj et al. 2014; Molina 2016; Marcotte 2016)
  - contemporaneous exposures to air pollution affect test scores (Ham et al. 2014; Lavy et al. 2014a, 2014b)
- Shed light on burgeoning literature of air pollution on happiness, mental well-being, worker productivity



# Motivation

- EPA's recent statement on reviewing PM standards –  
*"Additional research is necessary to assess the impact of ambient air pollutants on central nervous system function, such as cognitive processes, especially during critical windows of brain development. To this end, as the number of ... studies continue to increase and add to the weight of overall evidence, future National Ambient Air Quality Standards assessments will again assess and address the adequacy of existing standards."*



# Potential Contribution

- **Contribute to the knowledge about environmental stressors and gender differences in cognition**
- **several challenges plague the identification of these studies**
  - school/school-grade/sibling fixed effect -> individual fixed effect
  - contemporaneous exposures **vs.** cumulative exposure -> both
  - selected groups (military recruits, students) -> nationally representative sample (respondents older than age 10)
  - average air quality data over a certain period -> matching daily air quality at the time and place of interview with survey responses
  - developed **vs.** developing country settings



# Potential Mechanisms

- **physiological pathways**
  - affect structure and function of brains
  - affect brain chemistry directly (ozone, PM);
  - trigger an inflammatory response in the central nervous system (PM)
  - other physiological pathways: e.g. CO inhibits the body's ability to release oxygen
- **psychological pathways**
  - headache and head tightness (CO, NO<sub>2</sub>)
  - psychiatric distress (SO<sub>2</sub>), depression (CO, NO<sub>2</sub>, SO<sub>2</sub>, ozone, PM)
  - attention problems
  - Fatigue



# Results Preview

- In the long run: air pollution impedes both word and math scores
- In the short term: more evident negative effect on word tests
- *Heterogeneous effects by gender*: men perform worse than women in both tests when exposed to the same dose of air pollution;
- *Heterogeneous effects by age*: the gender difference in word tests is more salient among the old cohort, while it is more evident among the young in math tests.





- Cognitive tests

- China Family Panel Studies (CFPS)

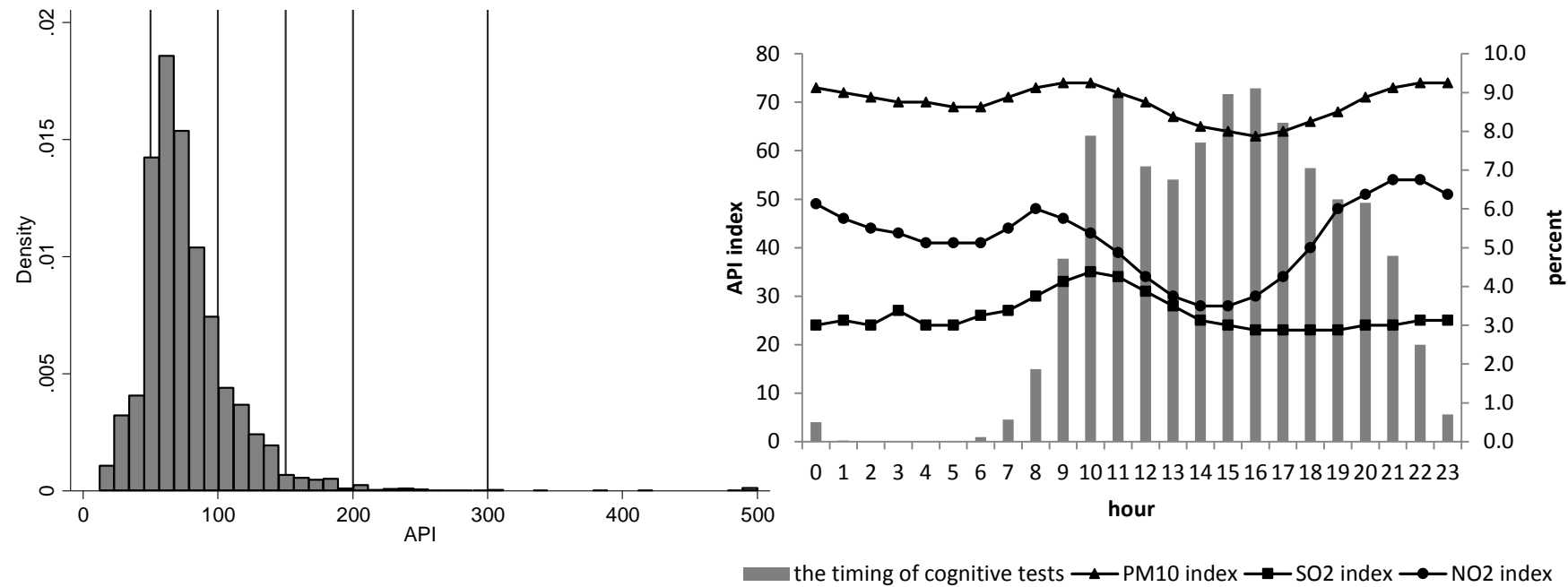
A nationally representative survey of Chinese communities, families, and individuals conducted in 2010, 2012 and 2014

- standardized mathematics and word recognition questions (2010 & 2014)
    - obtained from textbooks of different grade levels
    - sorted in ascending order of difficulty
    - the final test score is the rank of the hardest question the respondent is able to answer correctly

- Air Pollution Index (API)
  - air quality daily report published by the MEP (Ministry of Environmental Protection) of China
  - covered 369 major cities in 2014
  - ranging from 0 to 500, generated by a piece-wise linear transformation from the concentrations of three criteria air pollutants  $\text{SO}_2$ ,  $\text{NO}_2$  and  $\text{PM}_{10}$
  - a larger number indicating worse air quality



Figure: PM10 API, SO<sub>2</sub> API and NO<sub>2</sub> API during the day

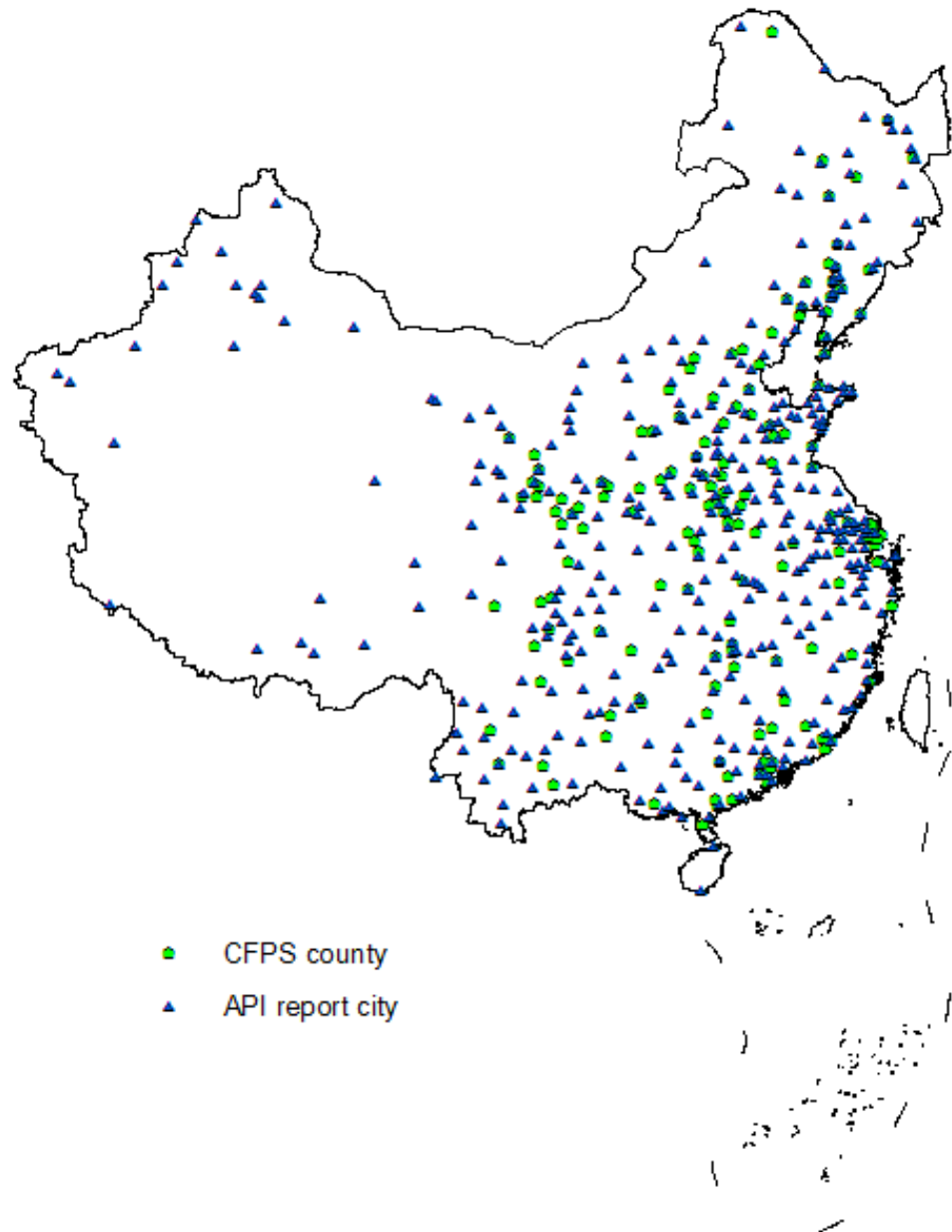
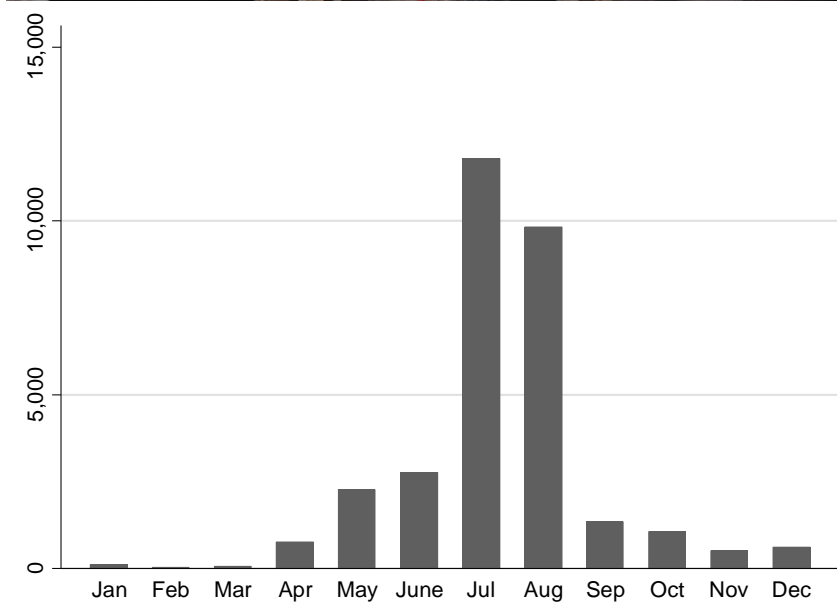


- Weather

- the National Climatic Data Center (NCDC) under the National Oceanic and Atmospheric Administration (NOAA) of the United States
- on consecutive days from 402 stations in China
- including rich weather conditions: mean temperature and its square term, total precipitation, mean wind speed, and a dummy for bad weather

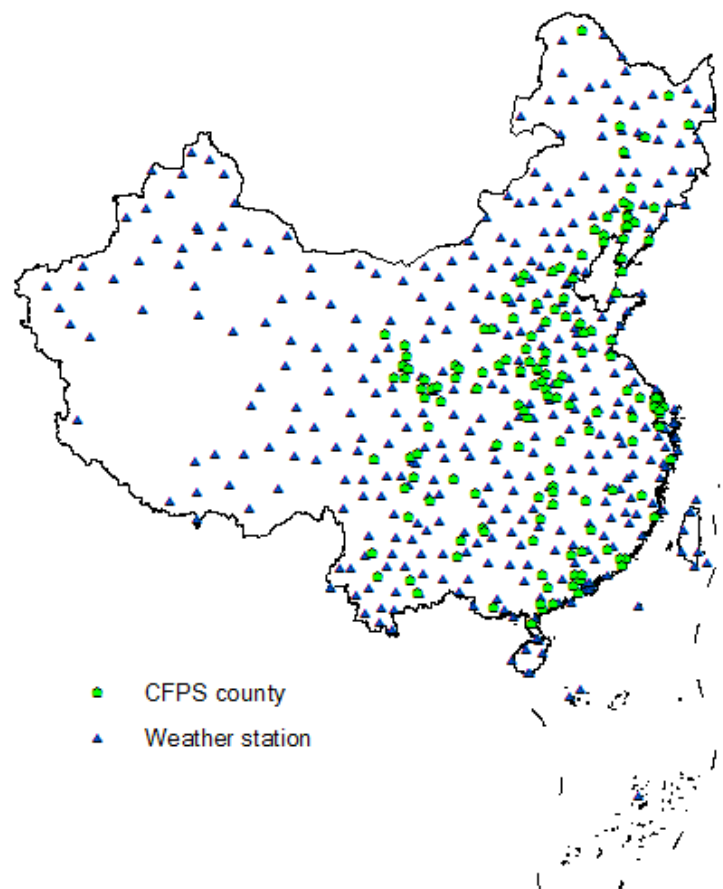
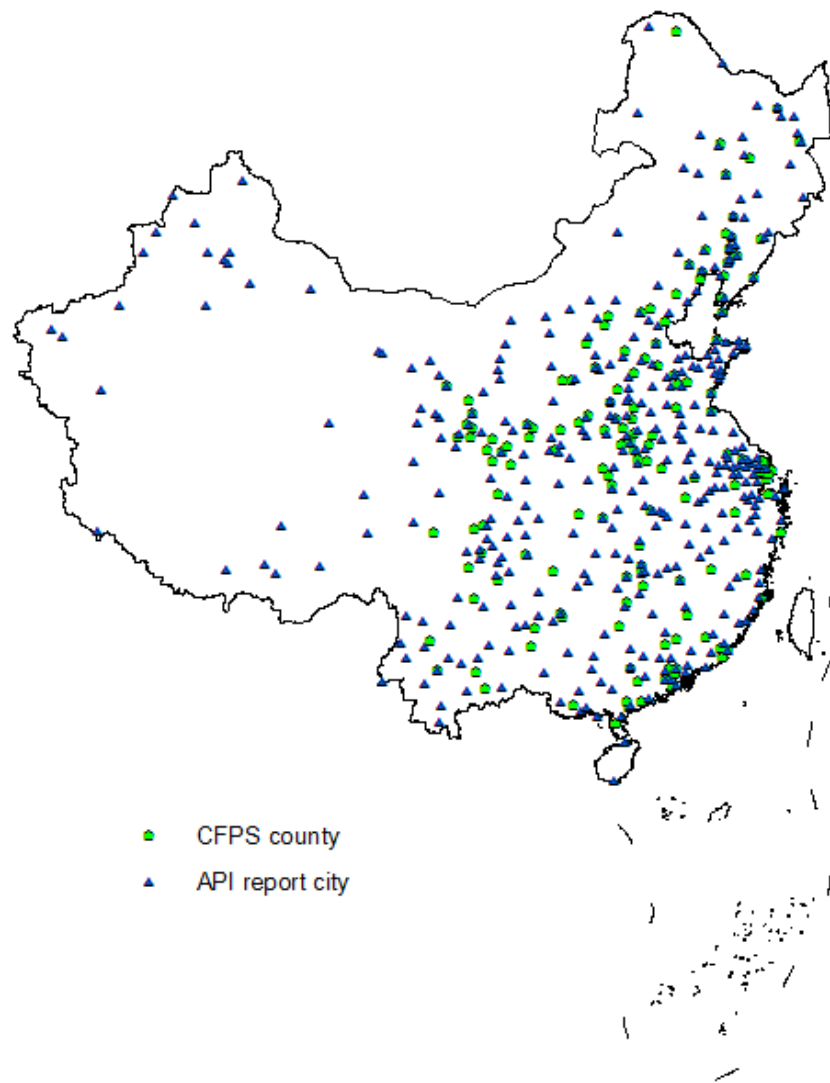


# Data - Timing of Interviews



# Data - Matching

API readings are obtained from the city where each CFPS county is located. If the city does not report API, we match the county to the nearest API report city within 100 kilometers.



We use weighted average weather data among all monitor stations within 60 km, where the weights are equal to the inverse distance between the stations and each CFPS county centroid. In the absence of stations within a radius of 60 km, the measure from the nearest station outside this radius but within 100 km is used.

# Empirical Strategy

$$Score_{ijt} = \alpha P_{jt} + X'_{ijt} \beta + W'_{jt} \phi + T'_{jt} \gamma + \lambda_i + \delta_j + \eta_t + f(t) + \varepsilon_{ijt}$$

$Score_{ijt}$ : test scores of respondent  $i$  in county  $j$  at date  $t$

$P_{ijt}$ : log form of API in county  $j$  at date  $t$

$X_{ijt}$ : demographic controls: household per capita income (log); gender; age and its square and cubic term; education years; health status; migration

$W_{jt}$ : weather conditions - temperature bins, total precipitation, mean wind speed, and a dummy for bad weather

$T_{jt}$ : county-level characteristics - GDP per capita, population density and industrial value share

$\lambda_i$ : individual fixed-effect

$\delta_j$ : county fixed-effect

$\eta_t$ : year, month, day-of-week and post meridiem hour fixed-effects

$f(t)$ : quadratic monthly time trend

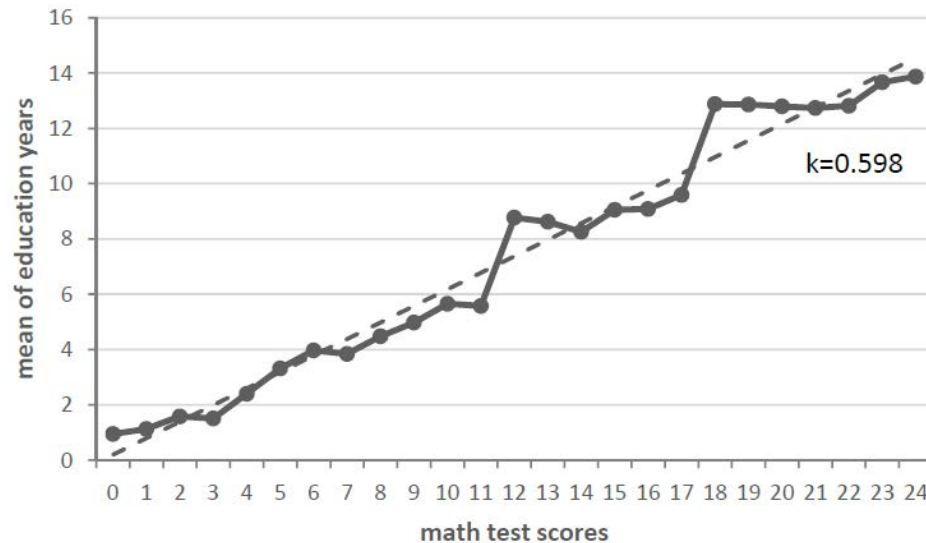
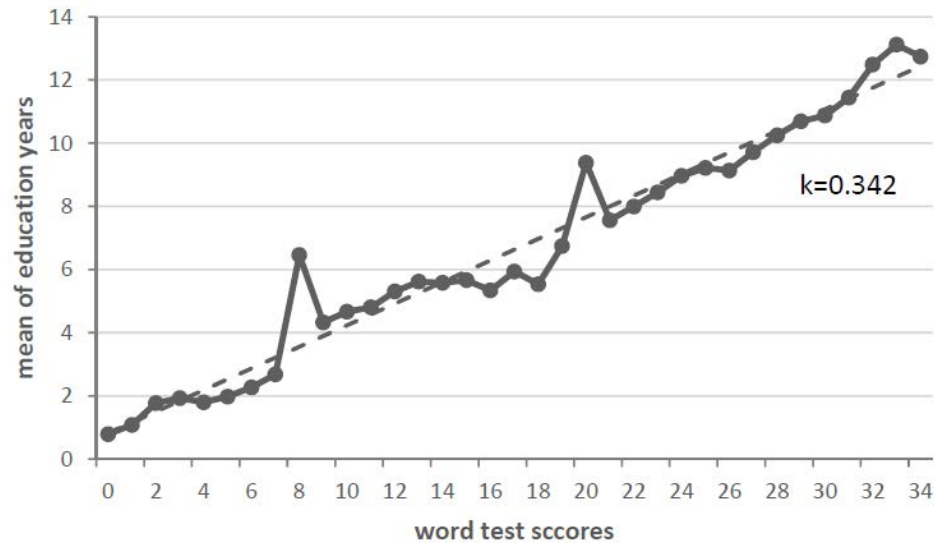


# Summary Statistics

| Variable                        | All    |        | Male   |        | Female |        |
|---------------------------------|--------|--------|--------|--------|--------|--------|
|                                 | Mean   | SD     | Mean   | SD     | Mean   | SD     |
| word scores                     | 18.018 | 10.574 | 19.656 | 9.512  | 16.515 | 11.256 |
| math scores                     | 10.381 | 6.433  | 11.440 | 5.956  | 9.409  | 6.697  |
| API                             | 77.568 | 36.743 | 77.226 | 36.082 | 77.883 | 37.337 |
| 7-day mean API                  | 76.909 | 24.939 | 76.704 | 24.793 | 77.097 | 25.072 |
| 30-day mean API                 | 76.988 | 20.505 | 76.816 | 20.472 | 77.146 | 20.535 |
| 90-day mean API                 | 79.420 | 19.206 | 79.263 | 19.170 | 79.565 | 19.239 |
| 180-day mean API                | 86.784 | 23.441 | 86.492 | 23.338 | 87.053 | 23.534 |
| 1-year mean API                 | 86.175 | 22.218 | 86.011 | 22.313 | 86.325 | 22.130 |
| 2-year mean API                 | 79.183 | 16.472 | 79.027 | 16.564 | 79.327 | 16.386 |
| 4-year mean API                 | 75.605 | 12.702 | 75.432 | 12.746 | 75.765 | 12.659 |
| per capita income (log)         | 8.878  | 1.160  | 8.895  | 1.158  | 8.862  | 1.161  |
| age                             | 44.638 | 17.954 | 44.779 | 18.237 | 44.508 | 17.689 |
| self-report health status (1-5) | 2.382  | 1.254  | 2.273  | 1.213  | 2.481  | 1.283  |
| years of education              | 7.015  | 4.783  | 7.752  | 4.450  | 6.339  | 4.975  |

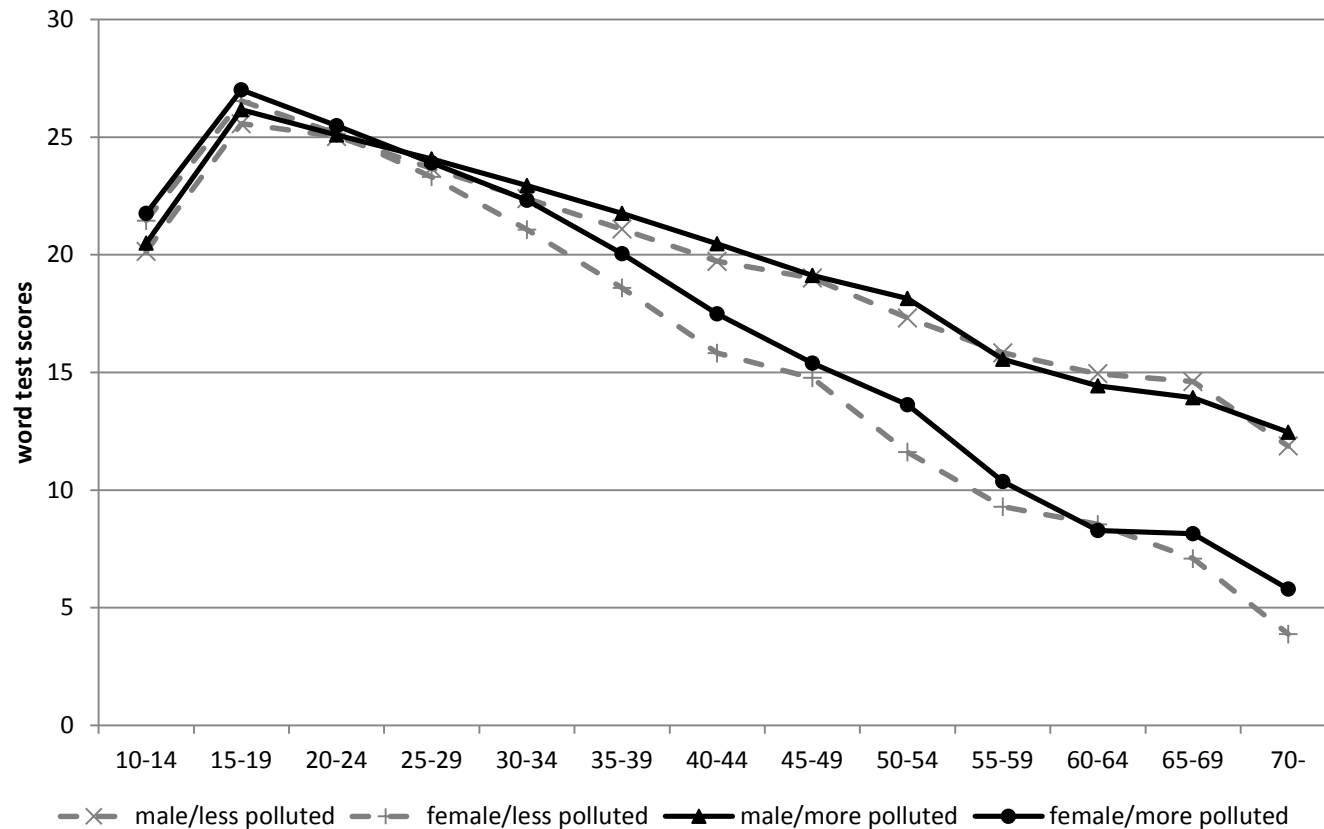


# Summary Statistics – Education and Cognition Scores



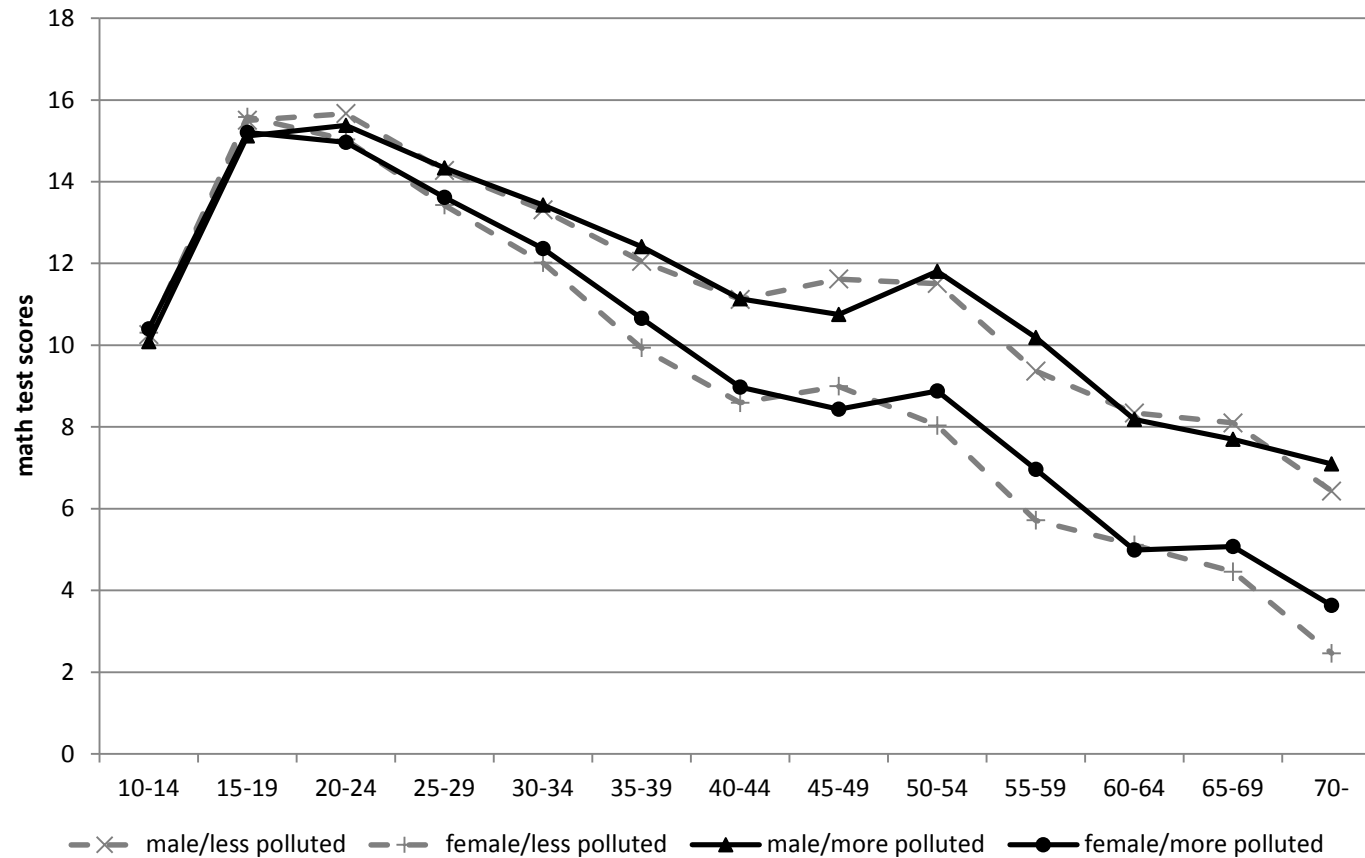
# Results – word test scores

Panel A: Mean word test scores by age and pollution level

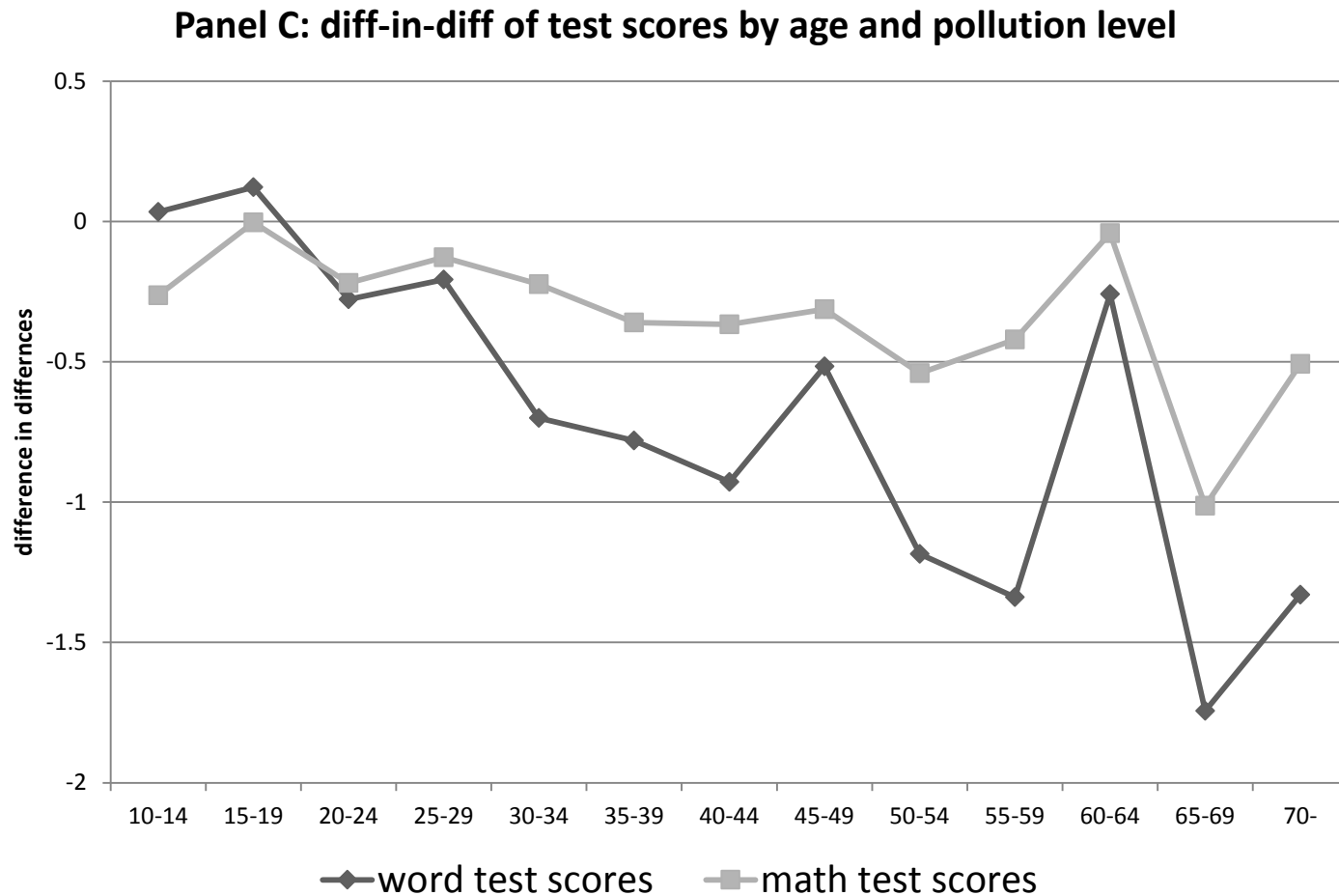


# Results – math test scores

Panel B: Mean math test scores by age and pollution level



# Results – difference in differences



The diff-in-diff calculates gender difference (male-female) in differences in test scores between polluted and less polluted areas.



# Baseline Results – CS versus FE, controls

| A. word test scores                      |           |          |          |            |           |           |             |           |           |
|--|-----------|----------|----------|------------|-----------|-----------|-------------|-----------|-----------|
|  | today     |          |          | 7-day mean |           |           | 1-year mean |           |           |
|  | (1)       | (2)      | (3)      | (4)        | (5)       | (6)       | (7)         | (8)       | (9)       |
| $\frac{1}{k} \sum_{i=0}^{k-1} API_{t-i}$ | -0.003*   | -0.005** | -0.005** | -0.011***  | -0.016*** | -0.016*** | -0.031***   | -0.039*** | -0.040*** |
|  | (0.002)   | (0.002)  | (0.002)  | (0.003)    | (0.005)   | (0.005)   | (0.012)     | (0.012)   | (0.012)   |
| income per capita                        | 0.411***  |          | 0.172*   | 0.411***   |           | 0.170*    | 0.414***    |           | 0.177**   |
|  | (0.045)   |          | (0.087)  | (0.044)    |           | (0.088)   | (0.044)     |           | (0.083)   |
| health status                            | -0.082*   |          | -0.074   | -0.081*    |           | -0.074    | -0.079      |           | -0.071    |
|  | (0.049)   |          | (0.071)  | (0.049)    |           | (0.071)   | (0.049)     |           | (0.069)   |
| education years                          | 1.273***  |          | 0.245*** | 1.274***   |           | 0.246***  | 1.273***    |           | 0.241***  |
|  | (0.034)   |          | (0.055)  | (0.034)    |           | (0.054)   | (0.034)     |           | (0.054)   |
| individual FE                            | No        | Yes      | Yes      | No         | Yes       | Yes       | No          | Yes       | Yes       |
| Observations                             | 31,216    | 31,216   | 31,216   | 31,216     | 31,216    | 31,216    | 31,216      | 31,216    | 31,216    |
| Adjusted (within) R <sup>2</sup>         | 0.623     | 0.041    | 0.056    | 0.623      | 0.043     | 0.058     | 0.623       | 0.045     | 0.061     |
| B. math test scores                      |           |          |          |            |           |           |             |           |           |
|  | today     |          |          | 7-day mean |           |           | 1-year mean |           |           |
|  | (1)       | (2)      | (3)      | (4)        | (5)       | (6)       | (7)         | (8)       | (9)       |
| $\frac{1}{k} \sum_{i=0}^{k-1} API_{t-i}$ | -0.000    | -0.001   | -0.001   | -0.003**   | -0.003**  | -0.003**  | -0.005      | -0.007*   | -0.007**  |
|  | (0.001)   | (0.001)  | (0.001)  | (0.001)    | (0.002)   | (0.001)   | (0.004)     | (0.004)   | (0.004)   |
| income per capita                        | 0.093***  |          | 0.022    | 0.093***   |           | 0.022     | 0.093***    |           | 0.023     |
|  | (0.021)   |          | (0.037)  | (0.021)    |           | (0.037)   | (0.021)     |           | (0.037)   |
| health status                            | -0.083*** |          | -0.074** | -0.083***  |           | -0.074**  | -0.082***   |           | -0.073**  |
|  | (0.020)   |          | (0.033)  | (0.020)    |           | (0.033)   | (0.020)     |           | (0.032)   |
| education years                          | 0.586***  |          | 0.258*** | 0.586***   |           | 0.258***  | 0.586***    |           | 0.257***  |
|  | (0.017)   |          | (0.022)  | (0.017)    |           | (0.022)   | (0.017)     |           | (0.022)   |
| individual FE                            | No        | Yes      | Yes      | No         | Yes       | Yes       | No          | Yes       | Yes       |
| Observations                             | 31,216    | 31,216   | 31,216   | 31,216     | 31,216    | 31,216    | 31,216      | 31,216    | 31,216    |
| Adjusted (within) R <sup>2</sup>         | 0.822     | 0.054    | 0.260    | 0.822      | 0.054     | 0.260     | 0.822       | 0.055     | 0.260     |



# Baseline Results – word & math test scores

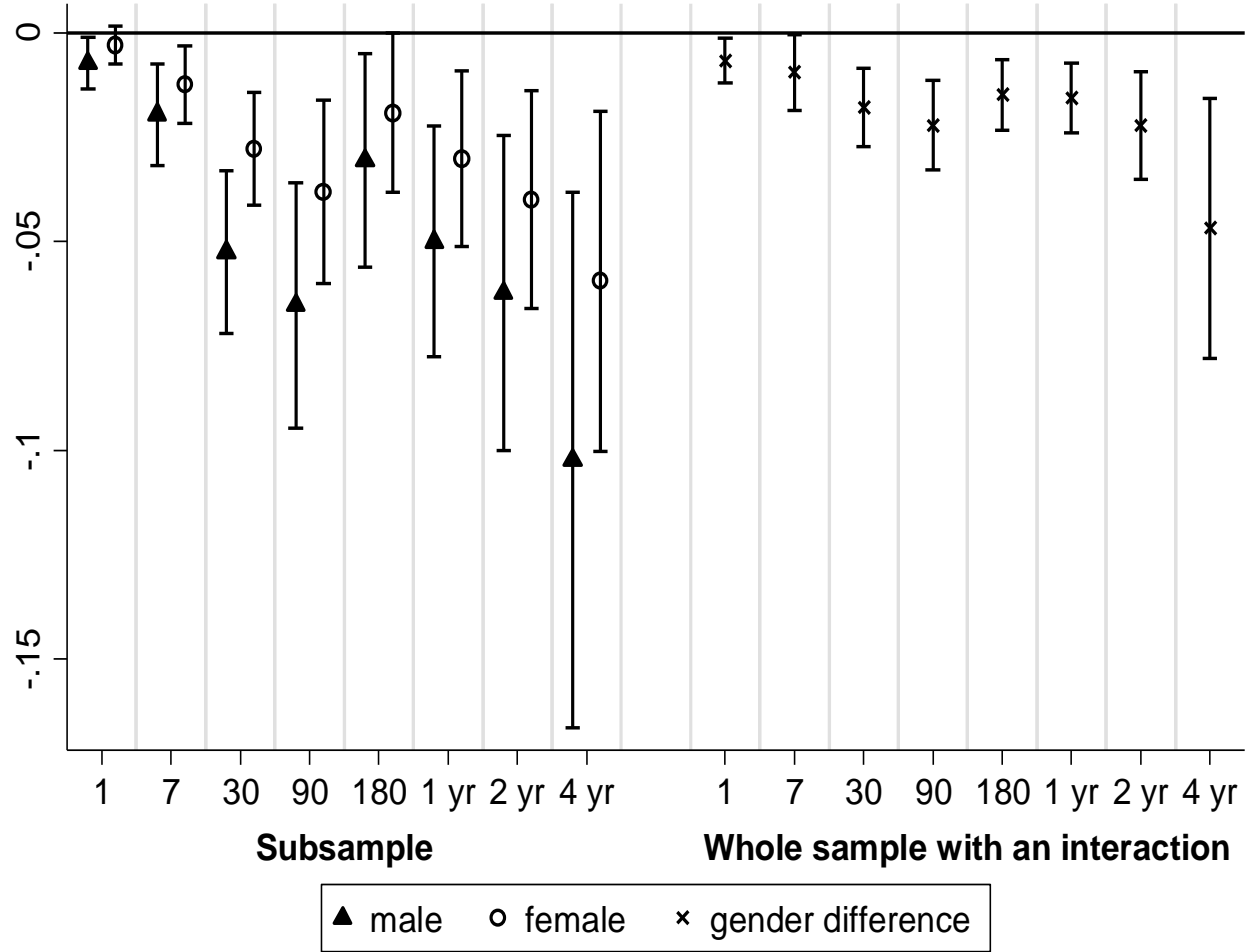
|   | contemporaneous  | cumulative       |                  |                  |                  |                  |                  |                  |
|---|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
|   | today            | 7-day            | 30-day           | 90-day           | 180-day          | 1-year           | 2-year           | 4-year           |
|   | (1)              | (2)              | (3)              | (4)              | (5)              | (6)              | (7)              | (8)              |
| A. word test scores   |                  |                  |                  |                  |                  |                  |                  |                  |
| $\frac{1}{k} \sum_{i=0}^{k-1} API_{t-i}$                                  | -0.005**         | -0.016***        | -0.040***        | -0.051***        | -0.024**         | -0.040***        | -0.051***        | -0.080***        |
|   | (0.002)          | (0.005)          | (0.008)          | (0.012)          | (0.011)          | (0.012)          | (0.015)          | (0.025)          |
| Observations  | 31,216           | 31,216           | 31,216           | 31,216           | 31,216           | 31,216           | 31,216           | 31,216           |
| Adjusted (within) R <sup>2</sup>  | 0.056            | 0.058            | 0.062            | 0.061            | 0.058            | 0.061            | 0.060            | 0.060            |
| Impact of one SD reduction in mean API on test scores (SD of test scores) | 0.164<br>(0.015) | 0.340<br>(0.032) | 0.682<br>(0.065) | 0.823<br>(0.078) | 0.519<br>(0.049) | 0.841<br>(0.080) | 0.840<br>(0.079) | 1.016<br>(0.096) |
| B. math test scores   |                  |                  |                  |                  |                  |                  |                  |                  |
| $\frac{1}{k} \sum_{i=0}^{k-1} API_{t-i}$                                  | -0.001           | -0.003**         | -0.006***        | -0.010***        | -0.006*          | -0.007**         | -0.011**         | -0.022***        |
|   | (0.001)          | (0.001)          | (0.002)          | (0.004)          | (0.003)          | (0.004)          | (0.005)          | (0.008)          |
| Observations  | 31,216           | 31,216           | 31,216           | 31,216           | 31,216           | 31,216           | 31,216           | 31,216           |
| Adjusted (within) R <sup>2</sup>  | 0.260            | 0.260            | 0.260            | 0.260            | 0.260            | 0.260            | 0.260            | 0.261            |
| Impact of one SD reduction in mean API on test scores (SD of test scores) | 0.033<br>(0.005) | 0.064<br>(0.010) | 0.102<br>(0.016) | 0.161<br>(0.025) | 0.130<br>(0.020) | 0.147<br>(0.023) | 0.181<br>(0.028) | 0.279<br>(0.043) |

Source: China Family Panel Studies 2010 and 2014.

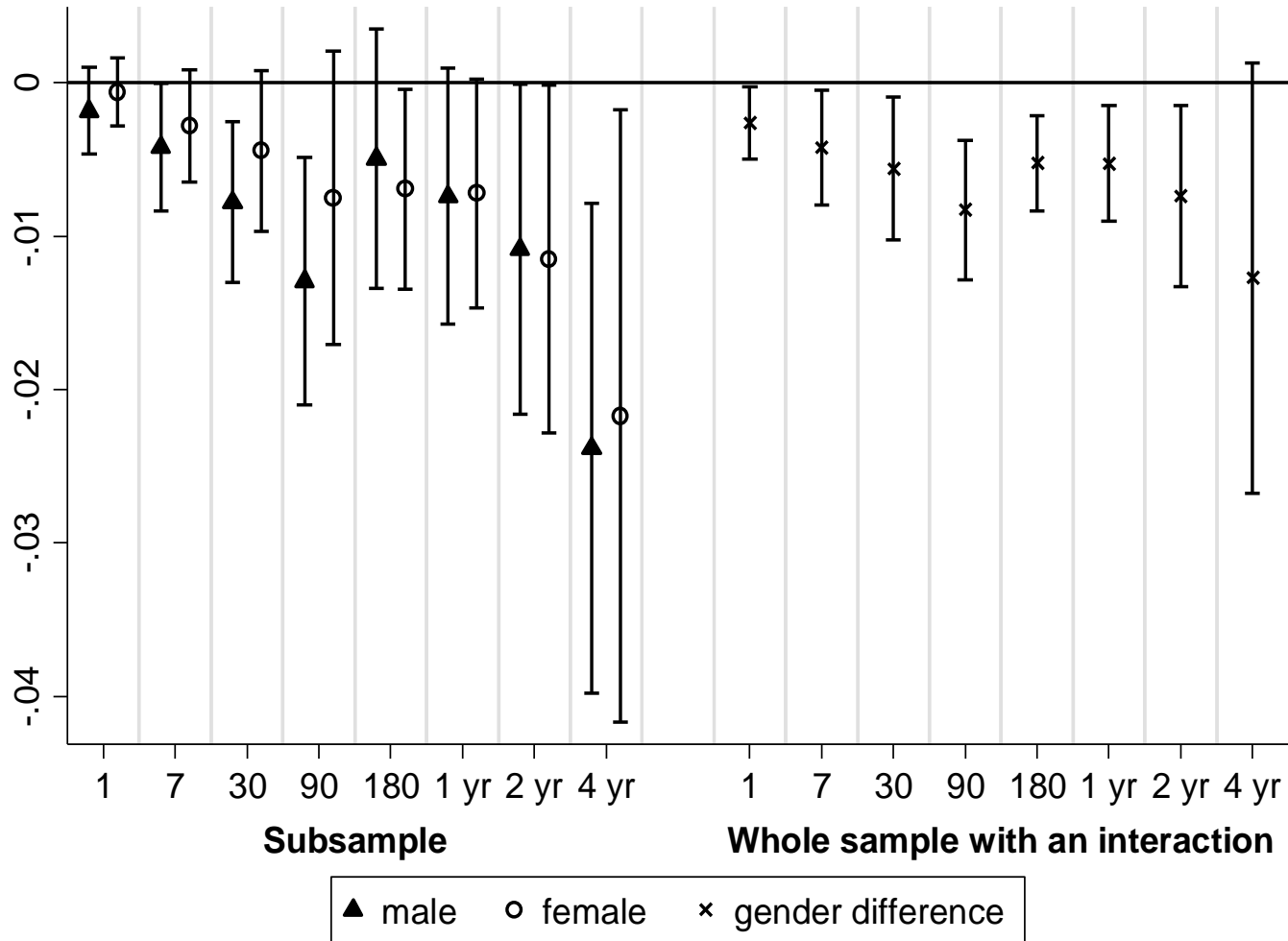
Note:  $\frac{1}{k} \sum_{i=0}^{k-1} API_{t-i}$  indicates the mean of API in the past k days, where k equals 1, 7, 30, 90, 180, 365, 730 and 1460, respectively. All the regressions include individual fixed effect, county fixed effect, year, month, day-of-week and post meridiem hour fixed effects, and a time trend in the quadratic form. Demographic controls include gender, age and its square and cubic terms, household per capita income, health status, education years and an indicator for migration. Weather controls include 20-degree F indicators for temperature bins (i.e., <25°F, 25-45°F, 45-65°F, 65-85°F and >85°F), total precipitation, mean wind speed, and a dummy for bad weather. County-level characteristics include GDP per capita, population density and industrial value share. Robust standard errors, clustered at the county level, are presented in parentheses. API = air pollution index. \*10% significance level. \*\*5% significance level. \*\*\*1% significance level. SD = standard deviation.



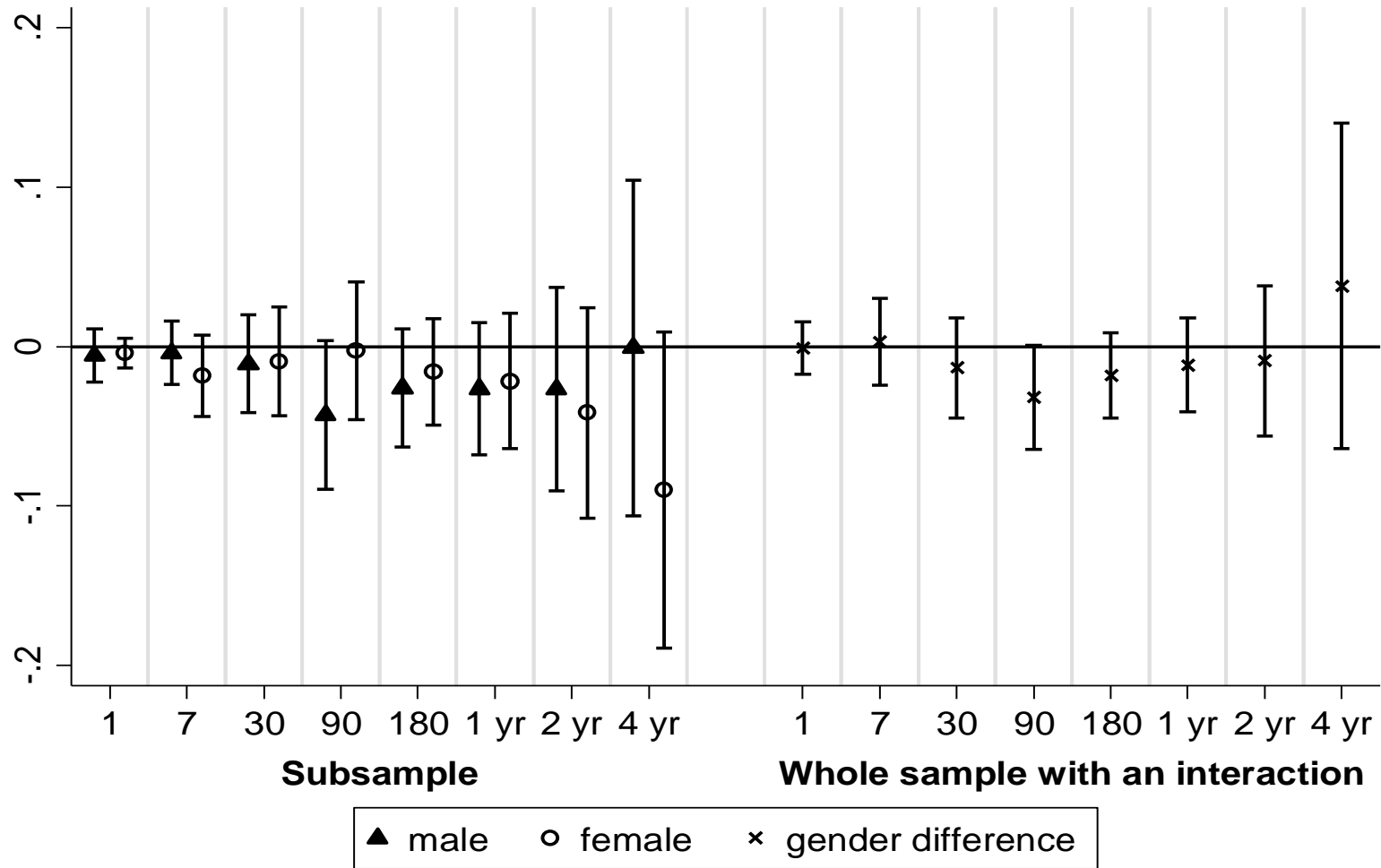
# Results - Gender difference in cognitive tests – word scores



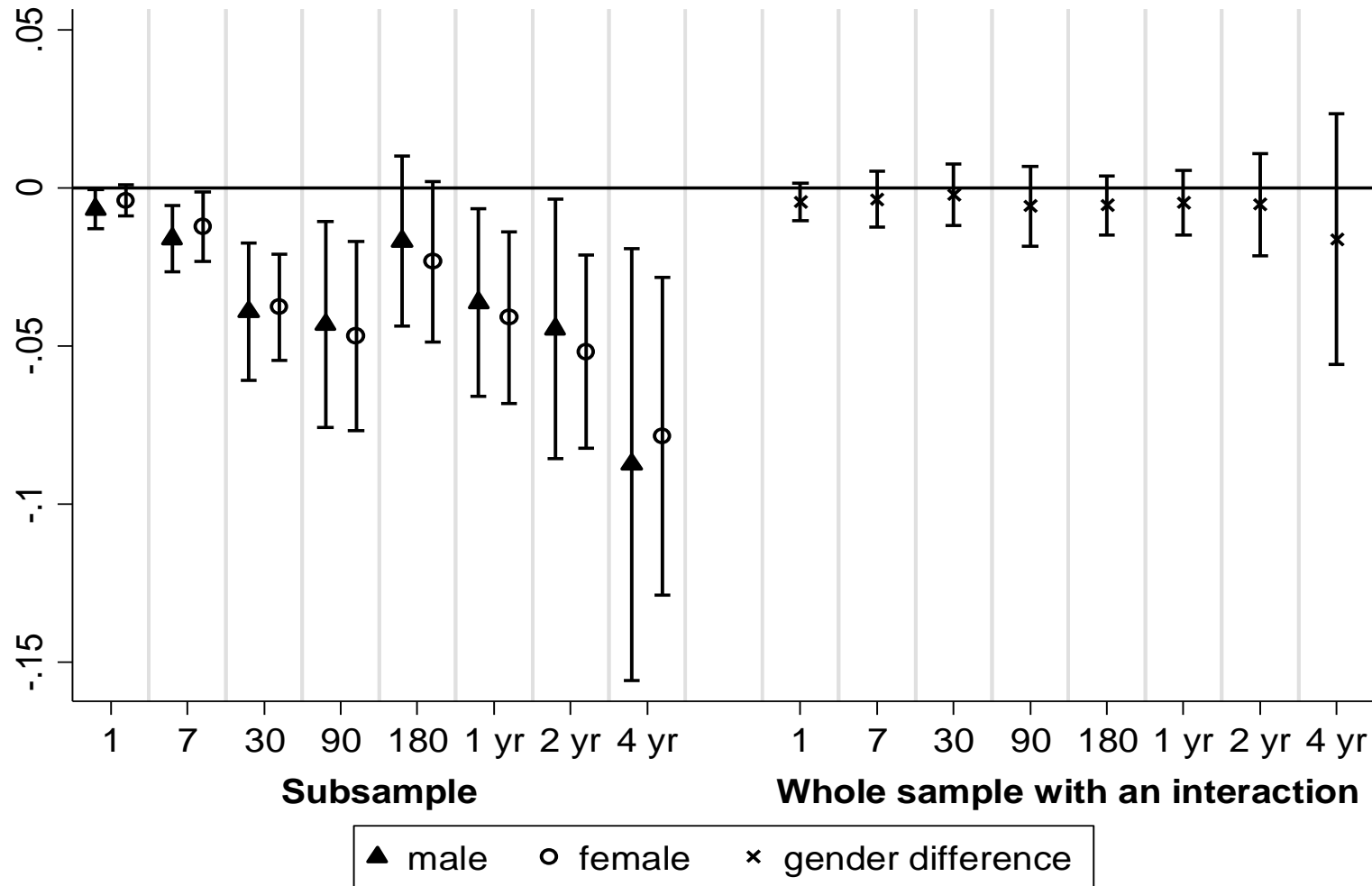
# Results - Gender difference in cognitive tests – math scores



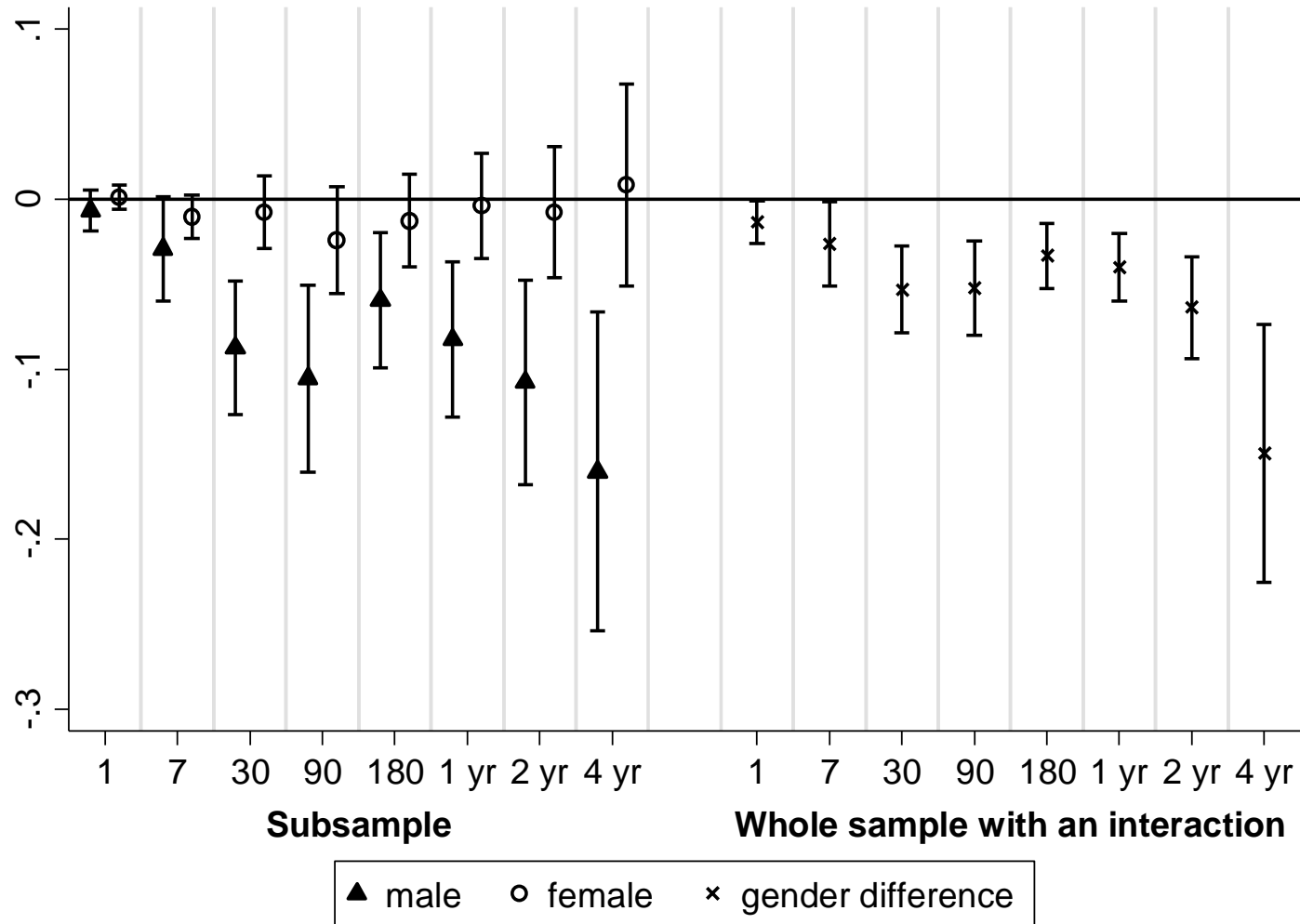
# Results - Gender difference in word tests, age 20 or below



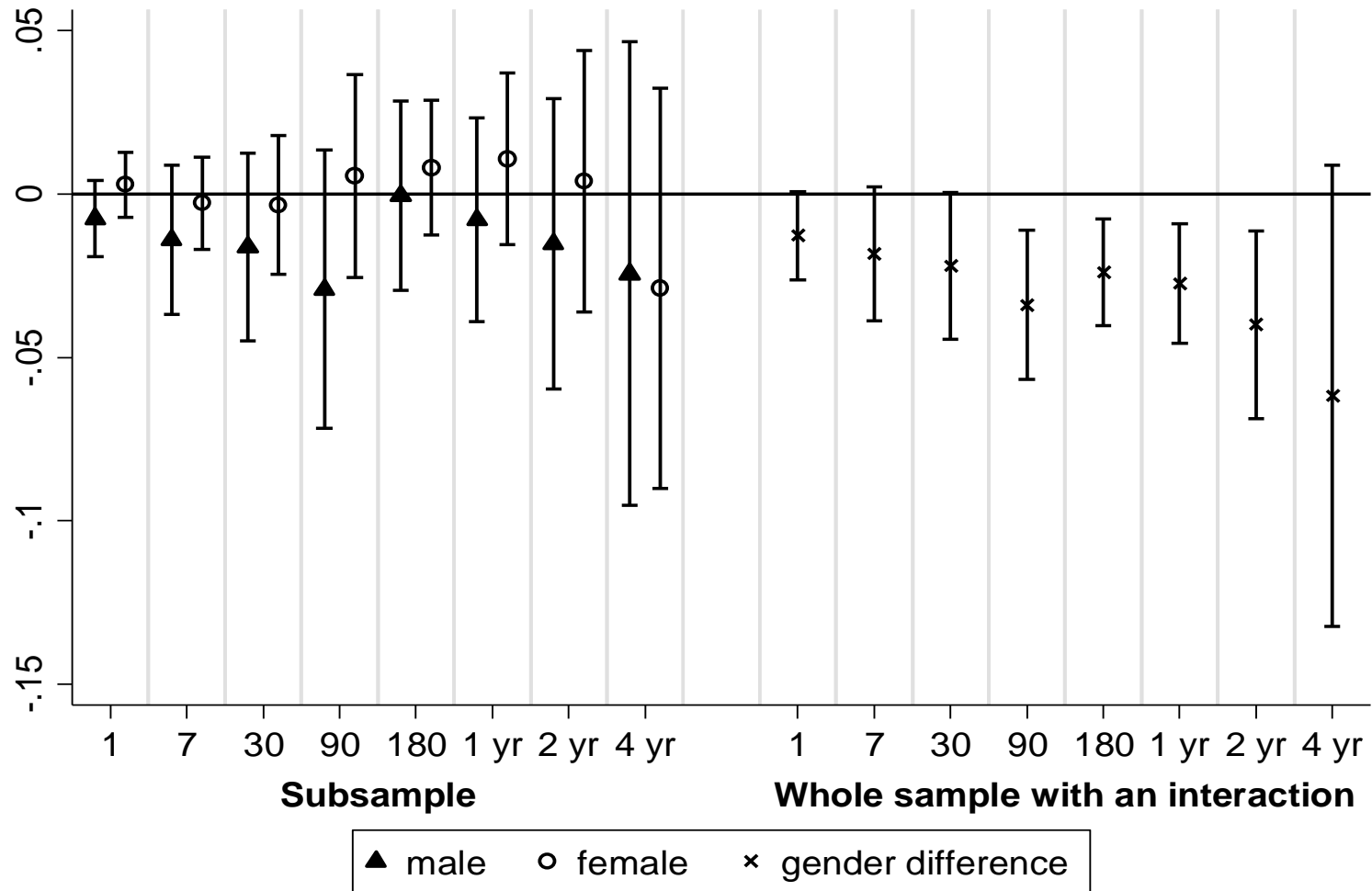
# Results - Gender difference in word tests, age 21-59



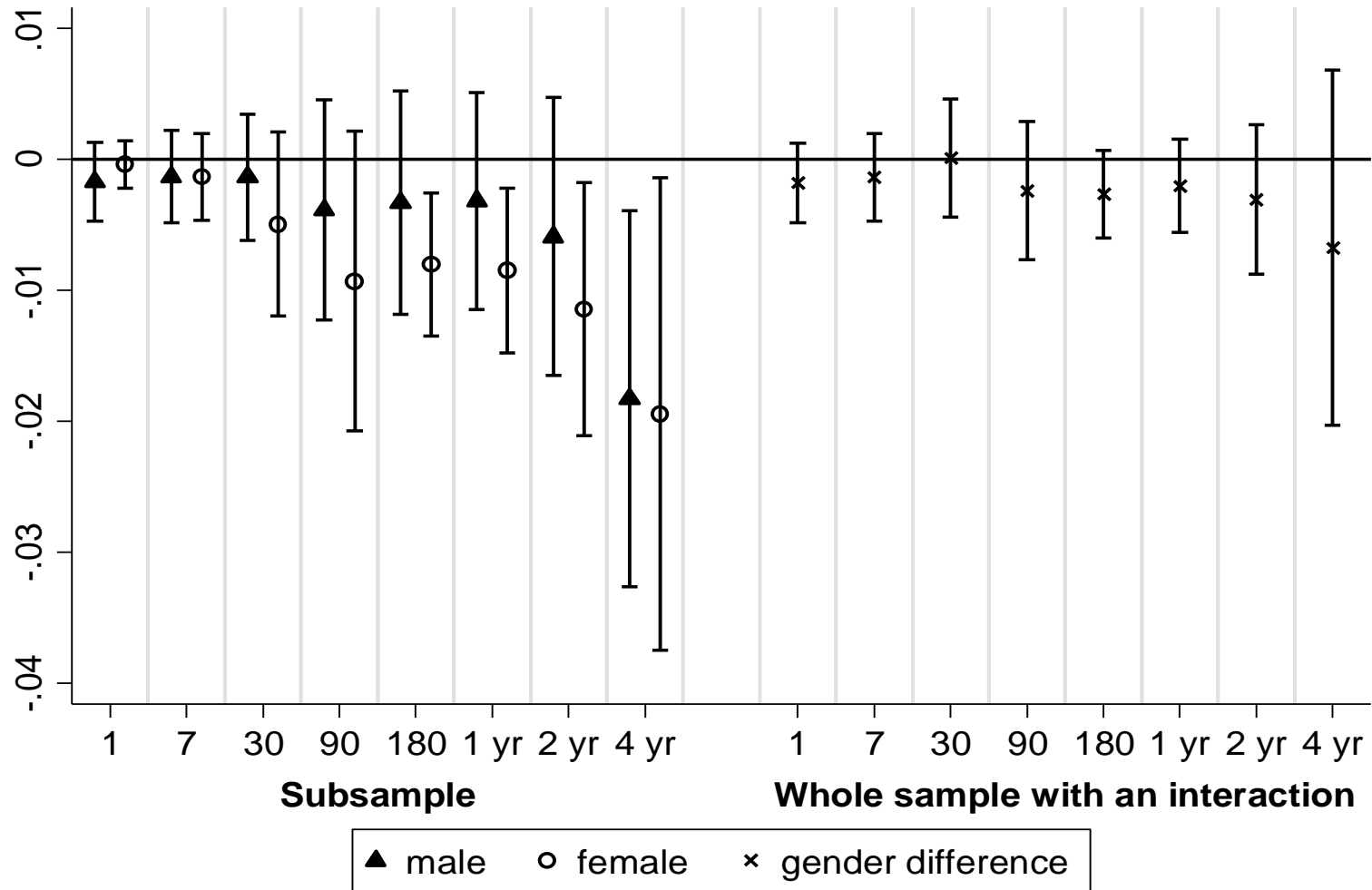
# Results - Gender difference in word tests, age 60 or above



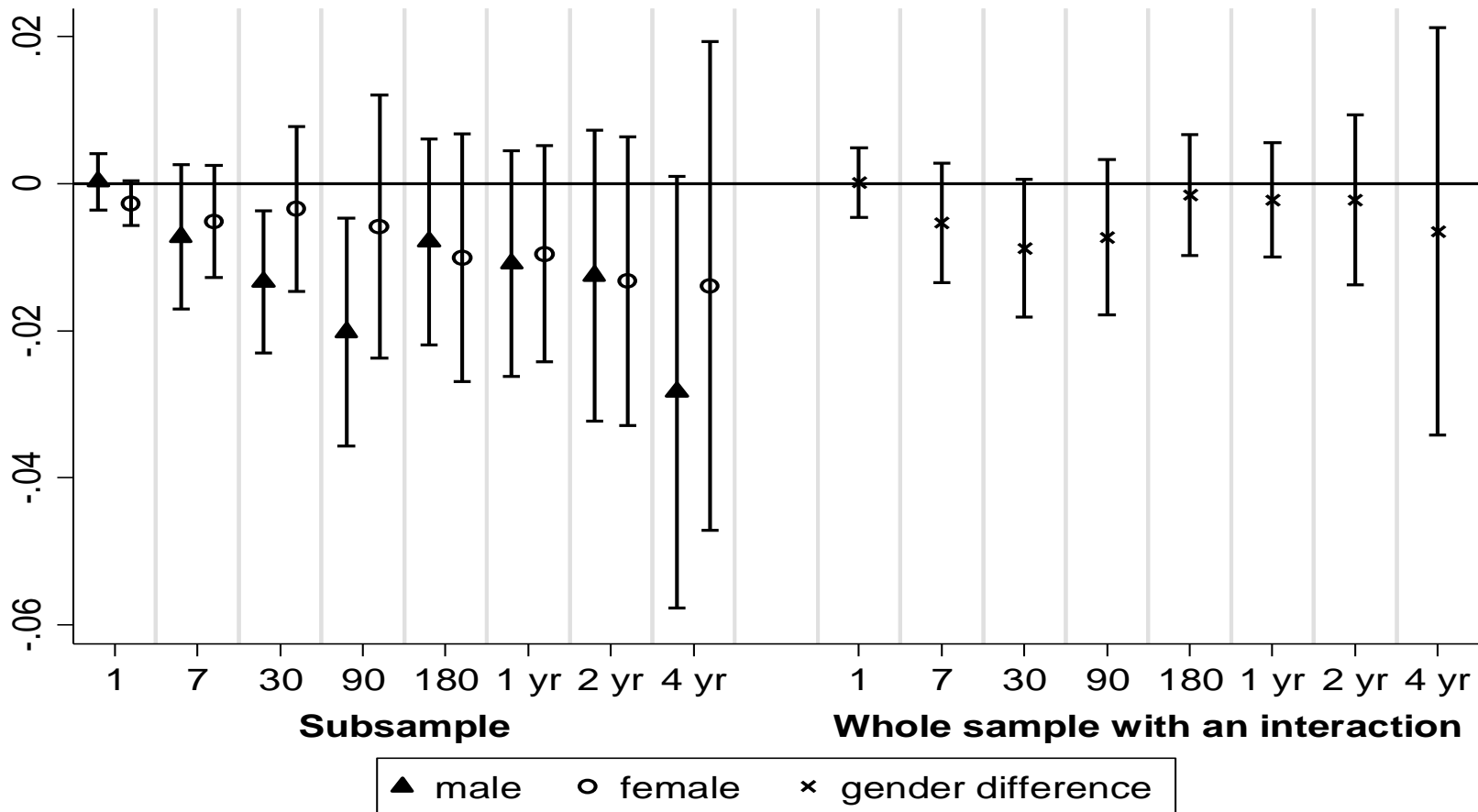
# Results - Gender difference in math tests, age 20 or below



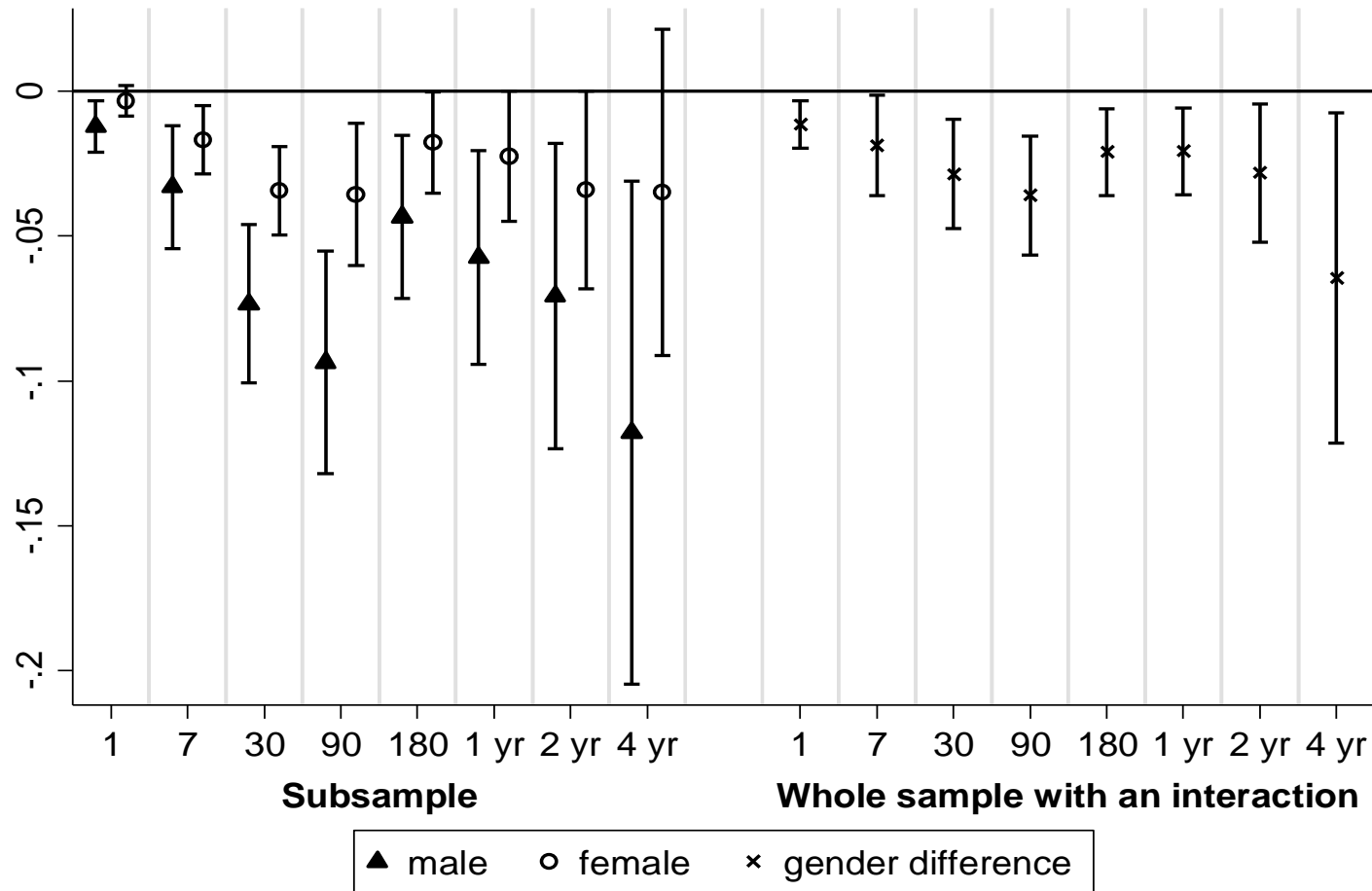
# Results - Gender difference in math tests, age 21-59



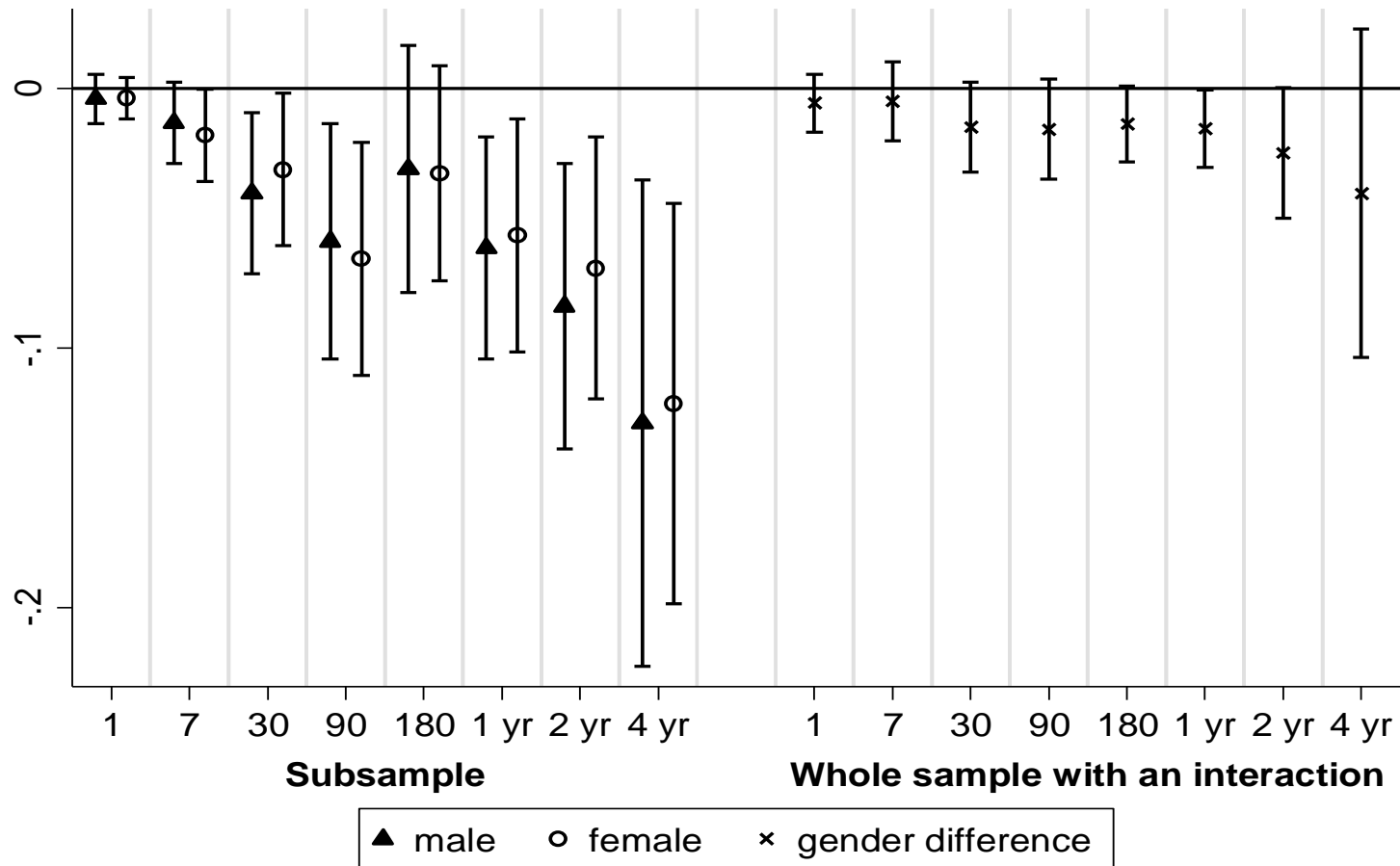
# Results - Gender difference in math tests, age 60 or above



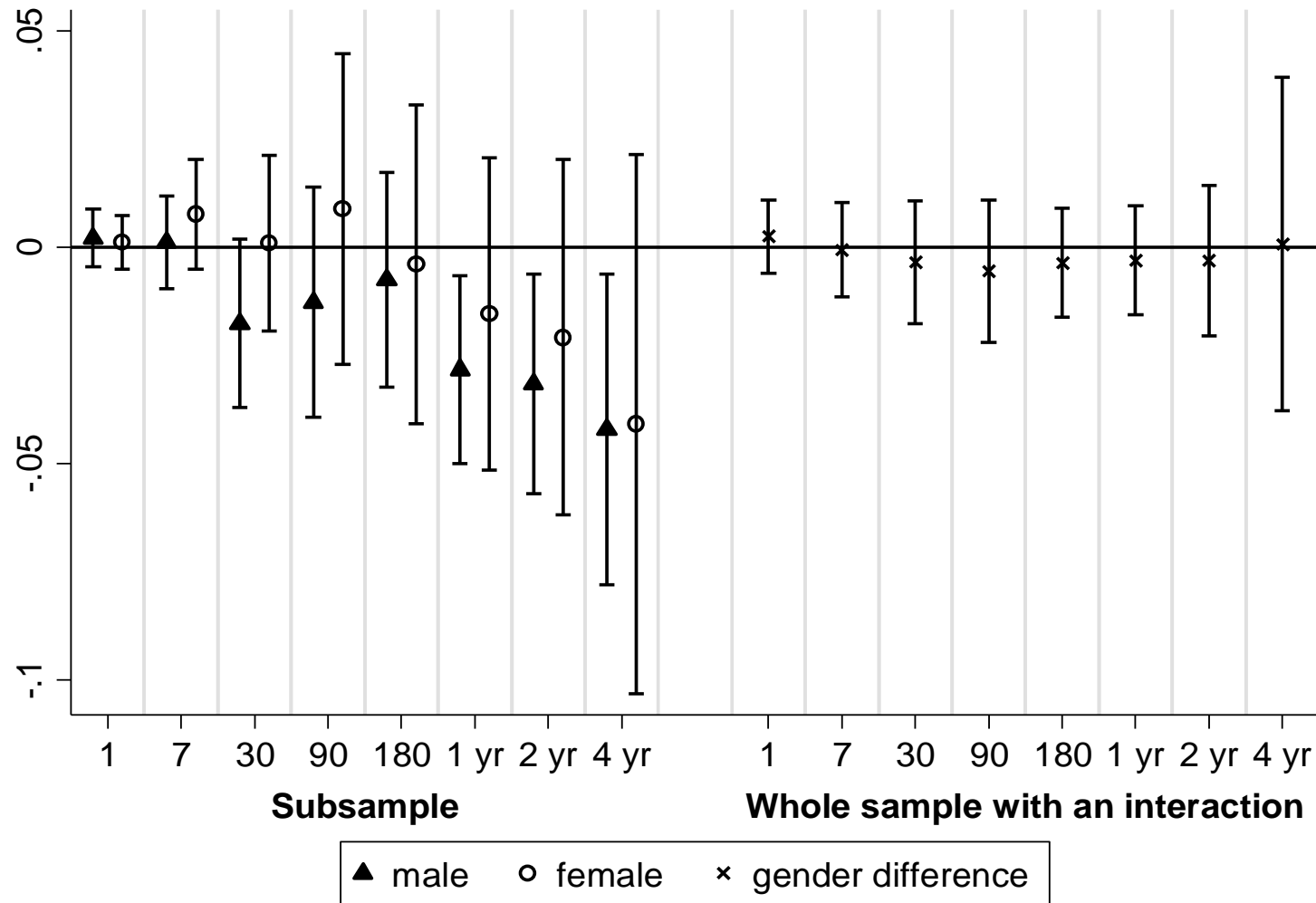
# Results - Gender difference in word tests, primary school or below



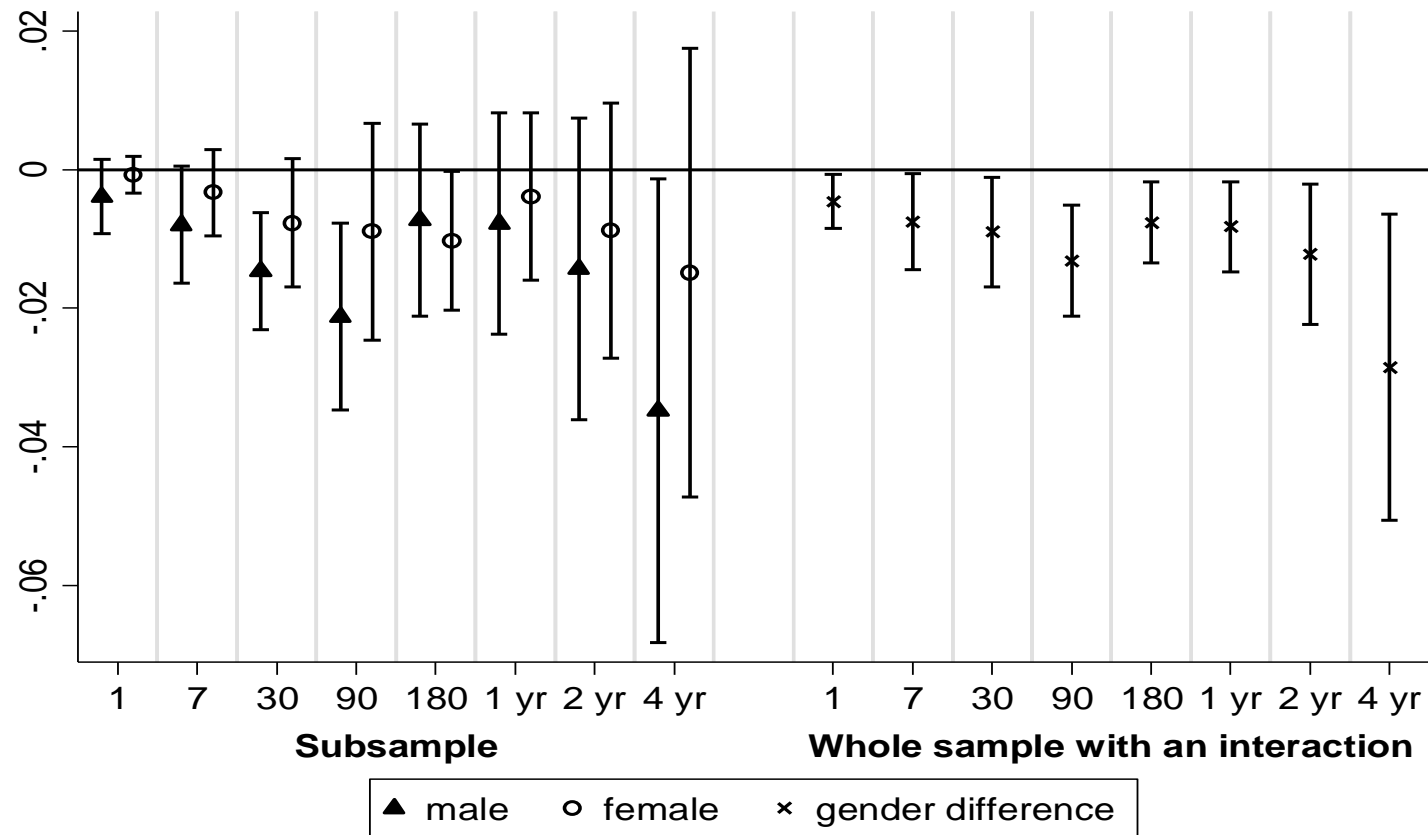
# Results - Gender difference in word tests, middle school



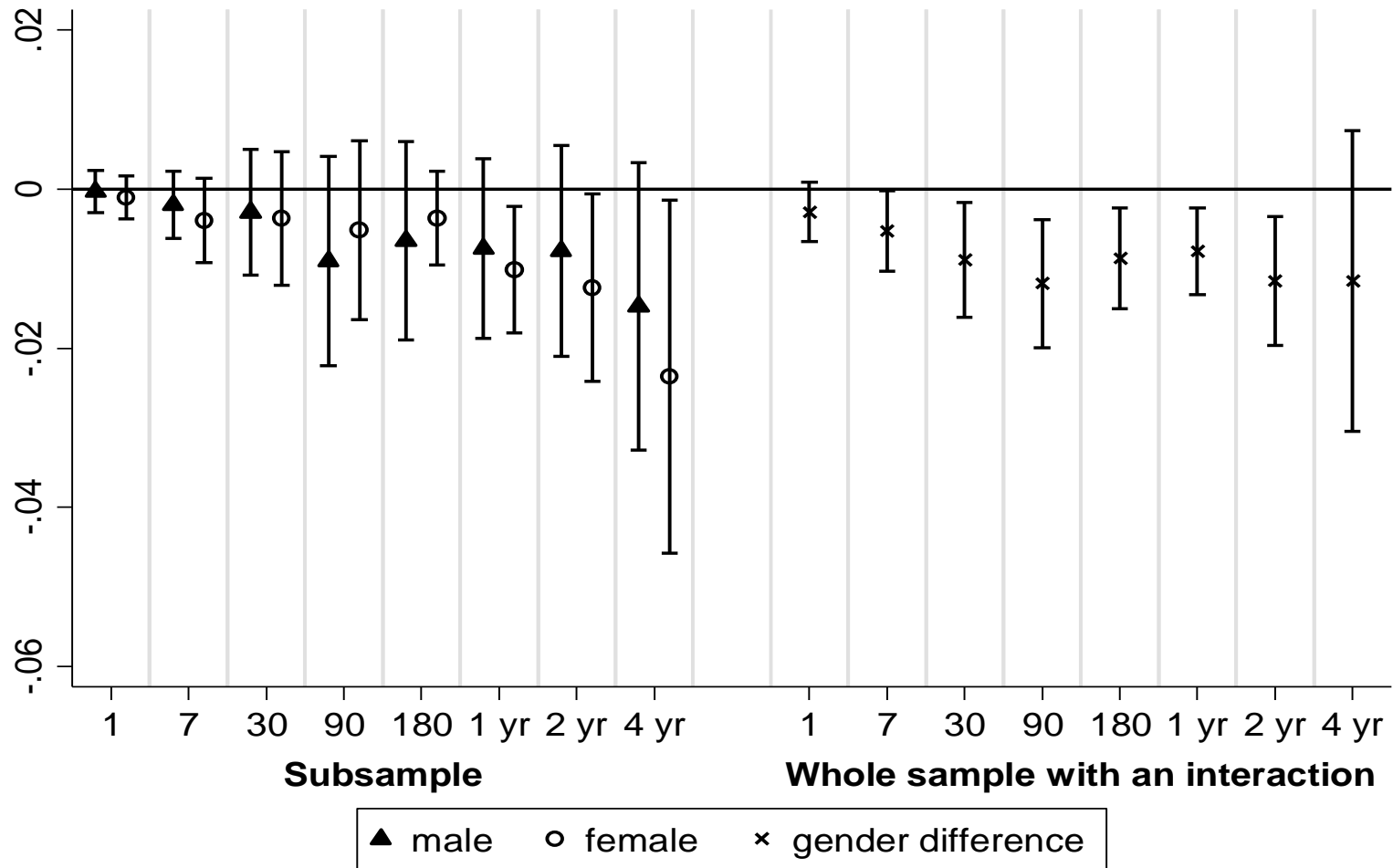
# Results - Gender difference in word tests, high school or above



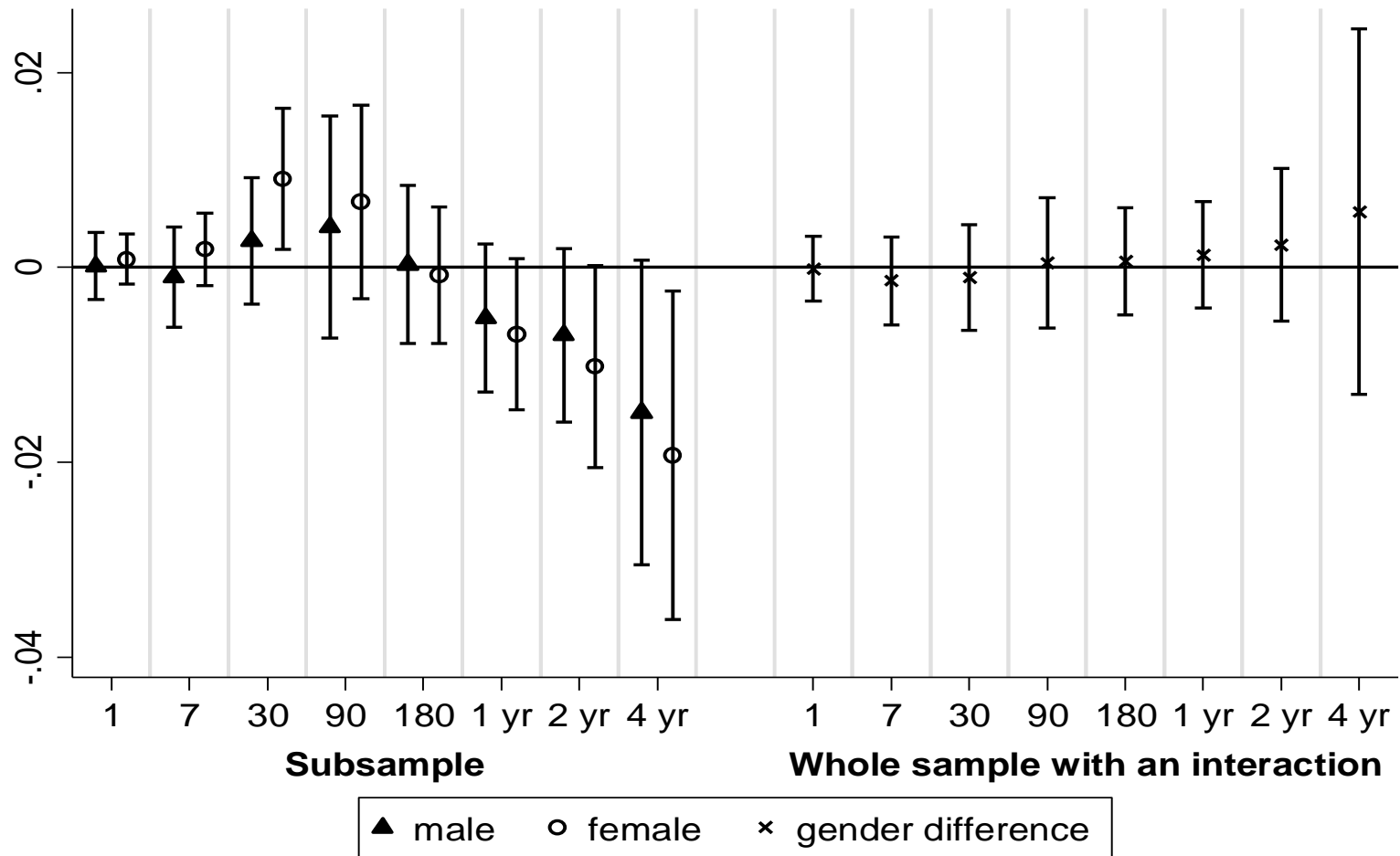
# Results - Gender difference in math tests, primary school or below



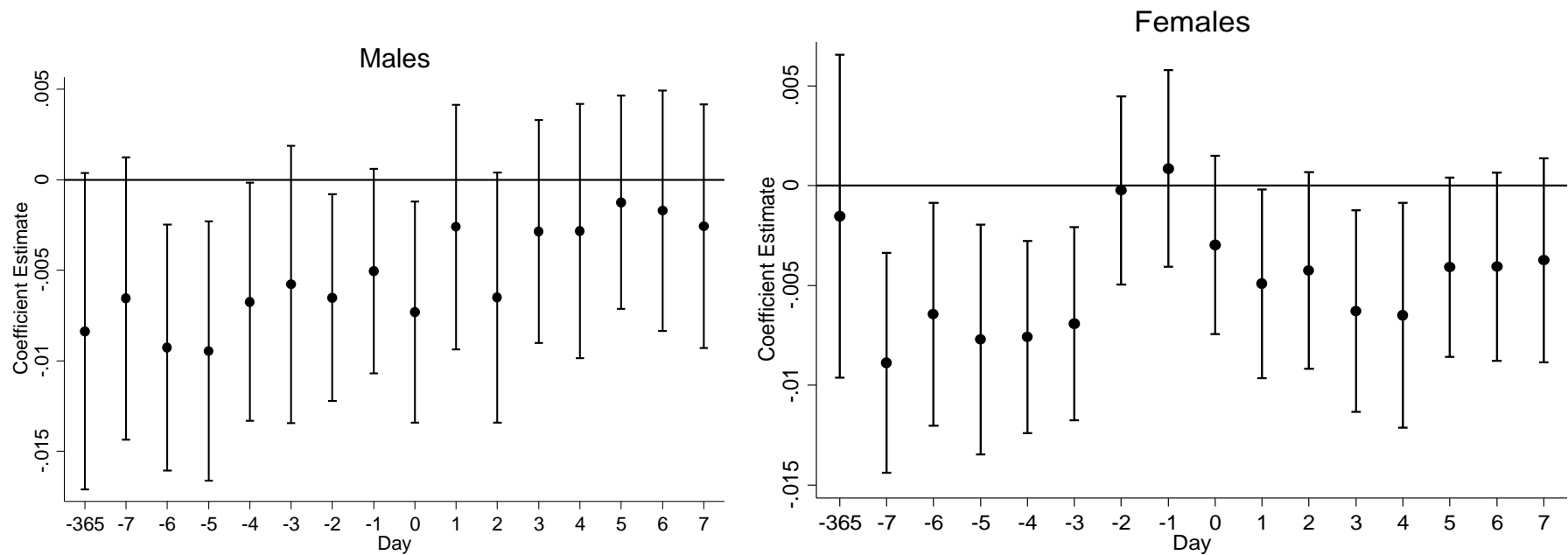
# Results - Gender difference in math tests, middle school



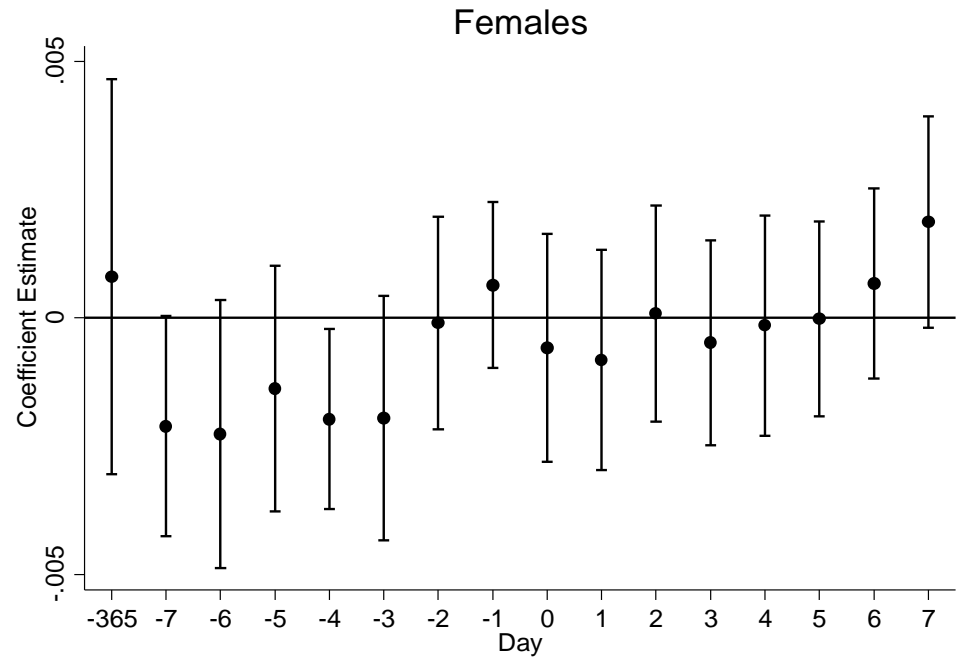
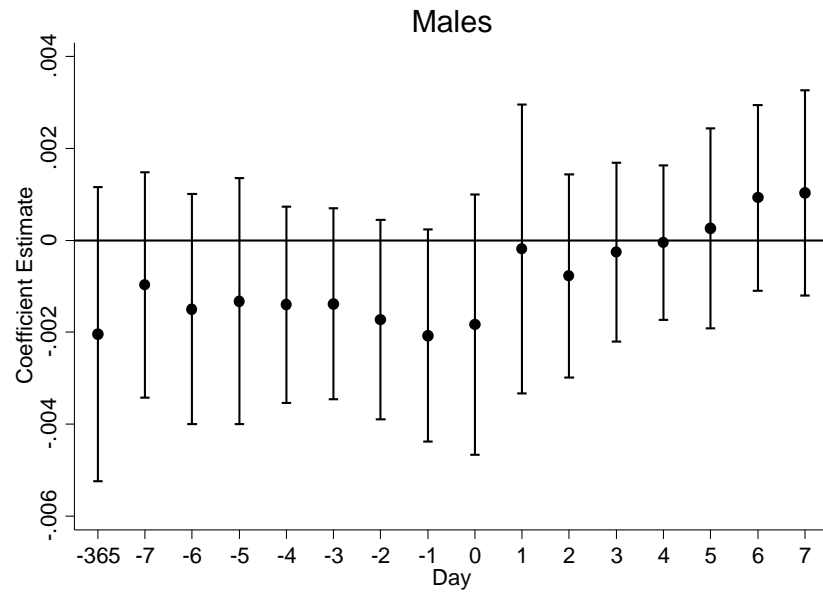
# Results - Gender difference in math tests, high school or above



# Results - Placebo test on word scores



# Results - Placebo test on math scores



# Results - Non-linear Specifications

**Table A3: Effects of air pollution on word test scores, by API cut-off**

| Dependent variable<br>word scores | A. today          |                      |                   | B. 7-day mean       |                      |                   | C. 30-day mean       |                      |                      |
|-----------------------------------|-------------------|----------------------|-------------------|---------------------|----------------------|-------------------|----------------------|----------------------|----------------------|
|                                   | all               | male                 | female            | all                 | male                 | female            | all                  | male                 | female               |
|                                   | (1)               | (2)                  | (3)               | (4)                 | (5)                  | (6)               | (7)                  | (8)                  | (9)                  |
| 51-100                            | 0.226<br>(0.232)  | 0.054<br>(0.289)     | 0.388<br>(0.245)  | -0.284<br>(0.296)   | -0.578<br>(0.417)    | -0.000<br>(0.290) | -0.242<br>(0.360)    | -0.664<br>(0.515)    | 0.169<br>(0.295)     |
| 101-150                           | 0.058<br>(0.302)  | -0.082<br>(0.371)    | 0.160<br>(0.359)  | -0.929**<br>(0.438) | -1.263**<br>(0.569)  | -0.627<br>(0.447) | -1.357**<br>(0.664)  | -1.733**<br>(0.851)  | -0.993*<br>(0.565)   |
| 151-200                           | 0.067<br>(0.510)  | 0.291<br>(0.771)     | -0.152<br>(0.673) | -1.368<br>(0.868)   | -1.792<br>(1.258)    | -0.890<br>(1.066) | -6.970***<br>(0.984) | -8.517***<br>(1.233) | -5.271***<br>(0.858) |
| 201-300                           | -1.021<br>(1.353) | -3.228**<br>(1.565)  | 0.633<br>(1.143)  | -3.233<br>(2.001)   | -4.159<br>(3.138)    | -2.236<br>(1.625) | --                   | --                   | --                   |
| 301-500                           | -1.203<br>(0.957) | -3.225***<br>(1.138) | 0.028<br>(1.110)  | --                  | --                   | --                | --                   | --                   | --                   |
| Observations                      | 31,216            | 14,942               | 16,274            | 31,216              | 14,942               | 16,274            | 31,216               | 14,942               | 16,274               |
| Adj. (within) R-squared           | 0.056             | 0.060                | 0.059             | 0.057               | 0.061                | 0.060             | 0.058                | 0.062                | 0.062                |
| Dependent variable<br>word scores | D. 90-day mean    |                      |                   | E. 180-day mean     |                      |                   | F. 1-year mean       |                      |                      |
|                                   | all               | male                 | female            | all                 | male                 | female            | all                  | male                 | female               |
|                                   | (1)               | (2)                  | (3)               | (4)                 | (5)                  | (6)               | (7)                  | (8)                  | (9)                  |
| 51-100                            | -0.790<br>(0.536) | -1.259*<br>(0.664)   | -0.332<br>(0.510) | -1.167<br>(0.732)   | -2.022**<br>(0.954)  | -0.336<br>(0.577) | -1.600<br>(1.034)    | -2.592**<br>(1.290)  | -0.677<br>(0.784)    |
| 101-300                           | -1.147<br>(0.732) | -1.870**<br>(0.885)  | -0.478<br>(0.690) | -1.735**<br>(0.850) | -2.839***<br>(1.073) | -0.688<br>(0.730) | -2.351**<br>(1.125)  | -3.589**<br>(1.395)  | -1.212<br>(0.883)    |
| Observations                      | 31,216            | 14,942               | 16,274            | 31,216              | 14,942               | 16,274            | 31,216               | 14,942               | 16,274               |
| Adj. (within) R-squared           | 0.056             | 0.060                | 0.059             | 0.057               | 0.063                | 0.059             | 0.059                | 0.064                | 0.060                |

**Back-of-the-envelope calculations: males' word test scores on a day with hazardous air (API $\geq$ 301) are on average 0.34 SD lower than scores on a day with good air (API $\leq$ 50).**



# Results – Contemporaneous versus Cumulative Exposure

| A. word test scores                      |                 |           |           |           |            |           |           |           |
|--|-----------------|-----------|-----------|-----------|------------|-----------|-----------|-----------|
| Dependent variable                       | contemporaneous |           |           |           | cumulative |           |           |           |
| word scores                              | today           | 7-day     | 30-day    | 90-day    | 180-day    | 1-year    | 2-year    | 4-year    |
|  | (1)             | (2)       | (3)       | (4)       | (5)        | (6)       | (7)       | (8)       |
| $API_t$                                  | -0.005**        | -0.000    | -0.000    | -0.002    | -0.003*    | -0.003    | -0.003    | -0.004*   |
|  | (0.002)         | (0.002)   | (0.002)   | (0.002)   | (0.002)    | (0.002)   | (0.002)   | (0.002)   |
| $\frac{1}{k} \sum_{i=0}^{k-1} API_{t-i}$ |                 | -0.016*** | -0.040*** | -0.049*** | -0.023**   | -0.038*** | -0.049*** | -0.078*** |
|  |                 | (0.005)   | (0.008)   | (0.012)   | (0.010)    | (0.011)   | (0.015)   | (0.025)   |
| Observations                             | 31,216          | 31,216    | 31,216    | 31,216    | 31,216     | 31,216    | 31,216    | 31,216    |
| Adjusted (within) R <sup>2</sup>         | 0.056           | 0.058     | 0.062     | 0.061     | 0.058      | 0.061     | 0.061     | 0.060     |
| B. math test scores                      |                 |           |           |           |            |           |           |           |
| Dependent variable                       | contemporaneous |           |           |           | cumulative |           |           |           |
| word scores                              | today           | 7-day     | 30-day    | 90-day    | 180-day    | 1-year    | 2-year    | 4-year    |
|  | (1)             | (2)       | (3)       | (4)       | (5)        | (6)       | (7)       | (8)       |
| $API_t$                                  | -0.001          | -0.000    | -0.000    | -0.001    | -0.001     | -0.001    | -0.001    | -0.001    |
|  | (0.001)         | (0.001)   | (0.001)   | (0.001)   | (0.001)    | (0.001)   | (0.001)   | (0.001)   |
| $\frac{1}{k} \sum_{i=0}^{k-1} API_{t-i}$ |                 | -0.003*   | -0.006*** | -0.010*** | -0.006*    | -0.007**  | -0.011**  | -0.022*** |
|  |                 | (0.002)   | (0.002)   | (0.003)   | (0.003)    | (0.003)   | (0.005)   | (0.008)   |
| Observations                             | 31,216          | 31,216    | 31,216    | 31,216    | 31,216     | 31,216    | 31,216    | 31,216    |
| Adjusted (within) R <sup>2</sup>         | 0.260           | 0.260     | 0.260     | 0.260     | 0.260      | 0.260     | 0.260     | 0.261     |



# Results - Heterogeneous effects

**Table A2: Heterogeneous effects of air pollution on word test scores, by income and workplace**

| Dependent variable<br>word scores        | contemporaneous | cumulative |           |           |           |           |           |           |
|--|-----------------|------------|-----------|-----------|-----------|-----------|-----------|-----------|
|  | today           | 7-day      | 30-day    | 90-day    | 180-day   | 1-year    | 2-year    | 4-year    |
|  | (1)             | (2)        | (3)       | (4)       | (5)       | (6)       |           |           |
| <b>A. income level: 0-50%</b>            |                 |            |           |           |           |           |           |           |
| $\frac{1}{k} \sum_{i=0}^{k-1} API_{t-i}$ | -0.008***       | -0.018***  | -0.043*** | -0.055*** | -0.033*** | -0.055*** | -0.084*** | -0.106*** |
|  | (0.003)         | (0.005)    | (0.011)   | (0.012)   | (0.011)   | (0.014)   | (0.019)   | (0.036)   |
| Observations                             | 12,726          | 12,726     | 12,726    | 12,726    | 12,726    | 12,726    | 12,726    | 12,726    |
| Adjusted (within) R <sup>2</sup>         | 0.065           | 0.065      | 0.069     | 0.068     | 0.067     | 0.071     | 0.073     | 0.069     |
| <b>B. income level: 50-100%</b>          |                 |            |           |           |           |           |           |           |
| $\frac{1}{k} \sum_{i=0}^{k-1} API_{t-i}$ | -0.002          | -0.014**   | -0.038*** | -0.048*** | -0.017    | -0.030**  | -0.032**  | -0.064**  |
|  | (0.002)         | (0.006)    | (0.009)   | (0.015)   | (0.012)   | (0.012)   | (0.016)   | (0.028)   |
| Observations                             | 17,765          | 17,765     | 17,765    | 17,765    | 17,765    | 17,765    | 17,765    | 17,765    |
| Adjusted (within) R <sup>2</sup>         | 0.055           | 0.058      | 0.062     | 0.060     | 0.056     | 0.058     | 0.057     | 0.058     |
| <b>C. workplace: outdoors</b>            |                 |            |           |           |           |           |           |           |
| $\frac{1}{k} \sum_{i=0}^{k-1} API_{t-i}$ | -0.007**        | -0.014**   | -0.045*** | -0.054*** | -0.024*   | -0.052*** | -0.078*** | -0.115*** |
|  | (0.003)         | (0.006)    | (0.012)   | (0.016)   | (0.013)   | (0.016)   | (0.020)   | (0.032)   |
| Observations                             | 12,812          | 12,812     | 12,812    | 12,812    | 12,812    | 12,812    | 12,812    | 12,812    |
| Adjusted (within) R <sup>2</sup>         | 0.050           | 0.050      | 0.055     | 0.054     | 0.050     | 0.056     | 0.057     | 0.056     |
| <b>D. workplace: indoors</b>             |                 |            |           |           |           |           |           |           |
| $\frac{1}{k} \sum_{i=0}^{k-1} API_{t-i}$ | -0.003          | -0.017***  | -0.036*** | -0.046*** | -0.021**  | -0.029*** | -0.031**  | -0.051*   |
|  | (0.002)         | (0.005)    | (0.007)   | (0.013)   | (0.010)   | (0.010)   | (0.014)   | (0.027)   |
| Observations                             | 18,404          | 18,404     | 18,404    | 18,404    | 18,404    | 18,404    | 18,404    | 18,404    |
| Adjusted (within) R <sup>2</sup>         | 0.067           | 0.070      | 0.073     | 0.072     | 0.069     | 0.070     | 0.069     | 0.069     |



# Implications

- Gains from improving air quality may be underestimated by a narrow focus on health;
- Policy? contemporaneous versus cumulative exposure;
- Air pollution impairs cognitive functioning critical to everyday activities, human capital formation and productivity, and well-being in general;
- Leads to allocative inefficiency of workers across occupations;
- Enlarges social inequality;
- Implication for other environmental stressors



# Smog in Our Brains

## Gender Difference in the Impact of Exposures to Air Pollution on Cognitive Performance

# Thank you!

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