# The Impact of Air Pollution on Attention Deficit Hyperactivity Disorder

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# Overview

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# Objective

Exploring the potential cause of air pollution in the development of ADHD

# Attention Deficit Hyperactivity Disorder (ADHD)

Attention deficit hyperactivity disorder (ADHD) affects school-aged children about 3 – 12% and adults approximately 3 – 5%

- Inattention
- Hyperactivity
- Impulsiveness

# National Health Insurance Research Database (NHIRD)

- H_NHI_OPDTE : Id, Sex, Age, Disease
- H_NHI_OPDTO : Drug
- H_NHI_ ENROLENROL : Id, Birth, City

# Air Pollution

- Ministry of Environment
- 78 sites
- CO, NO2, PM10, PM2.5, etc.
- Health impact
- Enviroment effect

# Data

2009 - 2018 year

We using the variables as described below

- **COUNT** is the number of doctor visits
- **CITY** is place of residence
- **SEX** is gender
- **AGE** is age, age less than or equal to 24
- **CO, NO2, PM10, PM2.5** are air pollutants
- **DD, DLD, BDD, Adjust, Anxiety, ASD** are comorbidity

# Zero-inflated Poisson Model (ZIP)

$$Y_i \sim \begin{cases} 0 \quad \textit{with} \quad \textit{probability} \quad \alpha_i \\ \textit{Poisson}(\lambda_i) \quad \textit{with} \quad \textit{probability} \quad (1-\alpha_i) \end{cases}$$

# Zero-inflated Poisson Model (ZIP)

- $\alpha_i$ is the probability of excessive zeros
- $Y_i$ is the number of occurrences
- $\lambda_i$ is the average frequency of occurrences

**The probability mass function of zero-inflated Poisson model**

$$P_r(Y_i = y_i) = \begin{cases} \alpha_i + (1-\alpha_i)\exp^{-\lambda_i} & \text{if } y_i = 0 \\ (1-\alpha_i)\frac{\lambda_i^{y_i}\exp^{-\lambda_i}}{y_i!} & \text{if } y_i \neq 0 \end{cases}$$

# Zero-inflated Poisson Model (ZIP)

The link functions are

$$
\begin{aligned}
\textit{logit}(\alpha_i) = \log\left(\frac{\alpha_i}{1-\alpha_i}\right) &= x_i\beta_1 \\
&\Rightarrow \frac{\alpha_i}{1-\alpha_i} = \exp(x_i\beta_1) \\
&\Rightarrow \alpha = \exp(x_i\beta_1)(1-\alpha_i) \\
&\Rightarrow \alpha_i + \alpha_i \exp(x_i\beta_1) = \exp(x_i\beta_1) \\
&\Rightarrow \alpha_i = \exp(x_i\beta_1)/1 + \exp(x_i\beta_1)
\end{aligned}
$$

$$
\log(\lambda_i) = x_i\beta_2 \Rightarrow \lambda_i = \exp(x_i\beta_2)
$$

# Zero-inflated Poisson Model (ZIP)

$$f(Y_i = y_i) = \prod_{i=1}^{n} f_{Y_i}(y_i) = \prod_{i=1}^{n} \left[ \alpha_i + (1-\alpha_i) \exp^{-\lambda_i} I\{y_i = 0\} + (1-\alpha_i) \frac{\lambda_i^{y_i} \exp^{-\lambda_i}}{y_i!} I\{y_i \neq 0\} \right]$$

$$\begin{aligned} \log f(Y_i = y_i) &= \log \left[ \prod_{i=1}^{n} \left[ \alpha_i + (1-\alpha_i) \exp^{-\lambda_i} I\{y_i = 0\} + (1-\alpha_i) \frac{\lambda_i^{y_i} \exp^{-\lambda_i}}{y_i!} I\{y_i \neq 0\} \right] \right] \\ &= \sum_{y_i=0} \left[ \log \left[ \alpha_i + (1-\alpha_i) \exp^{-\lambda_i} \right] \right] + \sum_{y_i \neq 0} \left[ \log(1-\alpha_i) + y_i \log \lambda_i - \lambda_i - \log y_i! \right] \end{aligned}$$

# Distribution of Patients

| Variables | N (%)[1] | |
|---|---|---|
| | ADHD (N = 82,587) | Non-ADHD (N = 7,019,304) |
| Sex | | |
| Male | 65,512 (79.325%) | 3,545,035 (50.504%) |
| Female | 17,075 (20.675%) | 3,474,269 (49.496%) |
| Area | | |
| Northern | 50,698 (61.387%) | 3,250,348 (46.306%) |
| Central | 12,772 (15.465%) | 1,754,087 (24.989%) |
| Southern | 17,123 (20.733%) | 1,834,337 (26.133%) |
| Easthern | 1,797(2.176%) | 147,837 (2.106%) |
| Outlying Islands | 197 (0.239%) | 32,695 (0.466%) |
| Medication | | |
| No | 19,821 (24.000%) | 7,007,845 (99.837%) |
| Yes | 62,766 (76.000%) | 11,459 (0.163%) |
| Age (Mean $\pm$ SD) | $13.414 \pm 3.680$ | $15.709 \pm 6.525$ |

# Zero-inflated Poisson (ZIP)

| | | Count Model | | Zero-inflation Model | |
|---|---|---|---|---|---|
| Area | Variable | Estimate (Std. Error) | $\exp\beta$ | Estimate (Std. Error) | $\exp\beta$ |
| Northern | Age | -0.015 (0.000)*** | 0.986 | 0.045 (0.000)*** | 1.047 |
| | Female | 0.110 (0.001)*** | 1.116 | 1.280 (0.008)*** | 3.597 |
| | CO | -0.119 (0.004)*** | 0.888 | -0.591 (0.021)*** | 0.554 |
| | PM10 | 0.010 (0.002)*** | 1.011 | -0.023 (0.011)* | 0.978 |
| | DD | 1.134 (0.002)*** | 3.108 | -1.595 (0.021)*** | 0.203 |
| Central | Age | -0.029 (0.000)*** | 0.971 | 0.052 (0.001)*** | 1.053 |
| | Female | 0.106 (0.003)*** | 1.112 | 1.517 (0.018)*** | 4.559 |
| | CO | 0.170 (0.004)*** | 1.185 | -0.383 (0.022)*** | 0.682 |
| | PM10 | 0.221 (0.003)*** | 1.247 | -0.191 (0.018)*** | 0.826 |
| | DD | 0.530 (0.005)*** | 1.699 | -1.385 (0.046)*** | 0.250 |
| Southern | Age | 0.015 (0.000)*** | 1.015 | 0.071 (0.001)*** | 1.074 |
| | Female | 0.043 (0.003)*** | 1.044 | 1.501 (0.015)*** | 4.486 |
| | CO | 0.105 (0.003)*** | 1.111 | -0.289 (0.015)*** | 0.749 |
| | PM10 | 0.173 (0.005)*** | 1.189 | -0.219 (0.024)*** | 0.803 |
| | DD | 1.020 (0.004)*** | 2.773 | -1.550 (0.043)*** | 0.212 |
| Eastern | Age | 0.030 (0.001)*** | 1.030 | 0.066 (0.003)*** | 1.068 |
| | Female | 0.075 (0.010)*** | 1.078 | 1.349 (0.047)*** | 3.854 |
| | CO | 0.216 (0.051)*** | 1.241 | -2.885 (0.262)*** | 0.056 |
| | PM10 | -0.056 (0.011)*** | 0.946 | -0.438 (0.052)*** | 0.645 |
| | DD | 0.925 (0.017)*** | 2.522 | -0.706 (0.156)*** | 0.494 |

Table: Zero-inflated Poisson (ZIP)

# Conclusion

- The probability of health increases in female compared to male (Huss et al. (2008); C.L.-C.Huang et al. (2016))
- With increasing age, the probability of health increases
- PM10 and CO have impact on zero part (Riediker et al. (2004); Yorifuji et al. (2016))
- With ADHD, the overall probability of health decreases because of these comorbid conditions

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*D*evelopmental disabilities research reviews

# Northern

| | Count Model | | Zero-inflation Model | |
|---|---|---|---|---|
| Variable | Estimate (Std. Error) | $\exp \beta$ | Estimate (Std. Error) | $\exp \beta$ |
| (Intercept) | 3.170 $(0.002)^{***}$ | 23.806 | 3.877 $(0.008)^{***}$ | 48.269 |
| Age | -0.015 $(0.000)^{***}$ | 0.986 | 0.045 $(0.000)^{***}$ | 1.047 |
| Female | 0.110 $(0.001)^{***}$ | 1.116 | 1.280 $(0.008)^{***}$ | 3.597 |
| PM2.5 | 0.066 $(0.002)^{***}$ | 1.068 | 0.022 $(0.010)^{*}$ | 1.022 |
| CO | -0.119 $(0.004)^{***}$ | 0.888 | -0.591 $(0.021)^{***}$ | 0.554 |
| NO2 | 0.084 $(0.004)^{***}$ | 1.087 | 0.491 $(0.019)^{***}$ | 1.633 |
| PM10 | 0.010 $(0.002)^{***}$ | 1.011 | -0.023 $(0.011)^{*}$ | 0.978 |
| DD | 1.134 $(0.002)^{***}$ | 3.108 | -1.595 $(0.021)^{***}$ | 0.203 |
| DLD | 0.621 $(0.002)^{***}$ | 1.860 | -0.643 $(0.025)^{***}$ | 0.526 |
| Adjustment Disorder | 0.047 $(0.005)^{***}$ | 1.048 | -1.148 $(0.031)^{***}$ | 0.317 |
| Anxiety | -0.144 $(0.002)^{***}$ | 0.866 | -3.198 $(0.011)^{***}$ | 0.041 |
| BDD | -0.172 $(0.008)^{***}$ | 0.842 | -3.021 $(0.047)^{***}$ | 0.049 |
| ASD | 0.291 $(0.002)^{***}$ | 1.338 | -3.383 $(0.014)^{***}$ | 0.034 |

Table: Northern

# Central

| | Count Model | | Zero-inflation Model | |
|---|---|---|---|---|
| Variable | Estimate (Std. Error) | $\exp \beta$ | Estimate (Std. Error) | $\exp \beta$ |
| (Intercept) | 3.290 $(0.005)^{***}$ | 26.843 | 4.359 $(0.016)^{***}$ | 78.179 |
| Age | -0.029 $(0.000)^{***}$ | 0.971 | 0.052 $(0.001)^{***}$ | 1.053 |
| Female | 0.106 $(0.003)^{***}$ | 1.112 | 1.517 $(0.018)^{***}$ | 4.559 |
| PM2.5 | -0.158 $(0.005)^{***}$ | 0.854 | 0.091 $(0.026)^{***}$ | 1.095 |
| CO | 0.170 $(0.004)^{***}$ | 1.185 | -0.383 $(0.022)^{***}$ | 0.682 |
| NO2 | -0.317 $(0.004)^{***}$ | 0.728 | 0.447 $(0.022)^{***}$ | 1.564 |
| PM10 | 0.221 $(0.003)^{***}$ | 1.247 | -0.191 $(0.018)^{***}$ | 0.826 |
| DD | 0.530 $(0.005)^{***}$ | 1.699 | -1.385 $(0.046)^{***}$ | 0.250 |
| DLD | 1.088 $(0.005)^{***}$ | 2.968 | -0.956 $(0.051)^{***}$ | 0.384 |
| Adjustment Disorder | 0.211 $(0.010)^{***}$ | 1.235 | -1.833 $(0.056)^{***}$ | 0.160 |
| Anxiety | 0.089 $(0.006)^{***}$ | 1.093 | -2.247 $(0.034)^{***}$ | 0.106 |
| BDD | -0.310 $(0.037)^{***}$ | 0.733 | -1.242 $(0.175)^{***}$ | 0.289 |
| ASD | 0.303 $(0.004)^{***}$ | 1.354 | -3.356 $(0.033)^{***}$ | 0.035 |

Table: Central

# Southern

| | Count Model | | Zero-inflation Model | |
|---|---|---|---|---|
| Variable | Estimate (Std. Error) | $\exp \beta$ | Estimate (Std. Error) | $\exp \beta$ |
| (Intercept) | 2.822 $(0.005)^{***}$ | 16.810 | 4.080 $(0.035)^{***}$ | 59.145 |
| Age | 0.015 $(0.000)^{***}$ | 1.015 | 0.071 $(0.001)^{***}$ | 1.074 |
| Female | 0.043 $(0.003)^{***}$ | 1.044 | 1.501 $(0.015)^{***}$ | 4.486 |
| PM2.5 | -0.205 $(0.005)^{***}$ | 0.815 | 0.263 $(0.026)^{***}$ | 1.301 |
| CO | 0.105 $(0.003)^{***}$ | 1.111 | -0.289 $(0.015)^{***}$ | 0.749 |
| NO2 | -0.129 $(0.003)^{***}$ | 0.879 | 0.106 $(0.013)^{***}$ | 1.112 |
| PM10 | 0.173 $(0.005)^{***}$ | 1.189 | -0.219 $(0.024)^{***}$ | 0.803 |
| DD | 1.020 $(0.004)^{***}$ | 2.773 | -1.550 $(0.043)^{***}$ | 0.212 |
| DLD | 0.483 $(0.005)^{***}$ | 1.621 | -0.207 $(0.052)^{***}$ | 0.813 |
| Adjustment Disorder | -0.099 $(0.007)^{***}$ | 0.905 | -1.536 $(0.043)^{***}$ | 0.215 |
| Anxiety | 0.037 $(0.003)^{***}$ | 1.038 | -4.033 $(0.017)^{***}$ | 0.018 |
| BDD | -0.290 $(0.046)^{***}$ | 0.748 | 0.457 $(0.215)^{*}$ | 1.579 |
| ASD | 0.385 $(0.003)^{***}$ | 1.470 | -3.470 $(0.030)^{***}$ | 0.031 |

Table: Southern

# Eastern

| | Count Model | | Zero-inflation Model | |
|---|---|---|---|---|
| Variable | Estimate (Std. Error) | $\exp \beta$ | Estimate (Std. Error) | $\exp \beta$ |
| (Intercept) | 2.501 $(0.018)^{***}$ | 12.195 | 3.796 $(0.045)^{***}$ | 44.523 |
| Age | 0.030 $(0.001)^{***}$ | 1.030 | 0.066 $(0.003)^{***}$ | 1.068 |
| Female | 0.075 $(0.010)^{***}$ | 1.078 | 1.349 $(0.047)^{***}$ | 3.854 |
| PM2.5 | 0.108 $(0.016)^{***}$ | 1.114 | 0.604 $(0.076)^{***}$ | 1.829 |
| CO | 0.216 $(0.051)^{***}$ | 1.241 | -2.885 $(0.262)^{***}$ | 0.056 |
| NO2 | -0.323 $(0.050)^{***}$ | 0.724 | 2.362 $(0.252)^{***}$ | 10.612 |
| PM10 | -0.056 $(0.011)^{***}$ | 0.946 | -0.438 $(0.052)^{***}$ | 0.645 |
| DD | 0.925 $(0.017)^{***}$ | 2.522 | -0.706 $(0.156)^{***}$ | 0.494 |
| DLD | 0.194 $(0.025)^{***}$ | 1.214 | -0.723 $(0.197)^{***}$ | 0.485 |
| Adjustment Disorder | -0.001 $(0.028)$ | 0.999 | -1.017 $(0.168)^{***}$ | 0.362 |
| Anxiety | -0.157 $(0.011)^{***}$ | 0.855 | -3.781 $(0.057)^{***}$ | 0.023 |
| BDD | -0.451 $(0.094)^{***}$ | 0.637 | -2.037 $(0.467)^{***}$ | 0.130 |
| ASD | 0.387 $(0.011)^{***}$ | 1.473 | -4.090 $(0.085)^{***}$ | 0.017 |

Table: Eastern

*Thanks for your listening*