Estimated effects of air quality control measures on mortality reduction and economic benefits during the 2014 Nanjing Youth Olympic Games

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Abstract. During the 2014 Youth Olympic Games in Nanjing, the local government implemented a series of emission control measures. Fixed-effect model and generalized additive model were conducted to evaluate the association between control measures and health benefits. Daily non-accidental mortality decreased from 71 deaths per day before taking control measures to 61 during the under-control period. Interim measures reduced SO2, NO2, PM2.5, PM10 by 6.63%, 12.96%, 8.72% and 10.30%, while comprehensive measures further reduced pollutants by 12.19%, 8.89%, 25.05% and 30.86%. A 10μg/m3 decrease in SO2, NO2, PM2.5, PM10 was associated with decreases in all-cause mortality of 2.91%(95%CI:1.57%,4.24%), 1.36%(95%CI:0.62%,2.11%), 0.55%(95%CI:0.23%,0.87%) and 0.39%(95%CI: 0.15%,0.62%). According to the calculation, the game specifically reduced about 1000 acute deaths from all cause and produced about 500 million USD of benefits, demonstrating a statistically significant association between air quality controls and health benefits. The result also shows that relevant controls to deal with NO2 and PM should be taken more stringently in heavily polluted cities.

1. Introduction

The 2nd Summer Youth Olympic Games (YOG) was held from 17 to 28 August 2014 in Nanjing, where suffers from severe air pollution. In order to realize the promise of “Green YOG”, the local government took a series of measures to reduce emissions of air pollutants. A large number of studies have shown that air pollution can cause significant human health risks [1]. Most researches on air control measures for major events focus on the evaluation of air quality. Huang et al.[2] found that the concentration of NO2 columns in Beijing and surrounding areas decreased significantly during the 2014 Beijing APEC compared with the previous three years. Integrated emission reduction measures reduced 66.8%, 51.3%, 21.5% and 17.1% of the SO2, NO2, PM10 and PM2.5 concentration during the Guangzhou Asian Games[3]. The three pollution control measures implemented at the 2015 2nd World Internet Conference (WIC) in Jiaxing cut PM2.5, inhalable particles, NO2 concentration by 62.1%, 47.1%, 31.2% respectively[4].

In this study, an integrated air quality and health benefit model was applied to evaluate the health-based benefits for YOG. The first step was to investigate the specific effects of control measures on the concentration changes of air pollutants. The second epidemiological question was to estimate the short-term health effects of changes in pollutants caused by control measures. Finally, we measured air pollution-associated health outcome in terms of mortality and monetization, which is
used to provide a basis for the formulation of control plans of environmental protection administrative departments.

2. Material and methods

2.1 Integrated air quality and health benefit framework

The study integrates three models, including Fixed Effect model to evaluate air quality, GAM[5] model to evaluate health impact and VOSL (Value of Statistic Life) model[6] of health economic cost of air pollution, to identify the health and economic benefits of air pollution due to emission control measures during YOG. The air quality model outputs the quantitative influence of control measures on the current period of pollutants based on the grid meteorological data and air pollutant data. The health effects of air quality changes including the mortality of all-cause, cardiovascular, respiratory, stroke, ischemic heart disease(IHD), chronic obstructive pulmonary disease(COPD) are calculated in the health impact model using the exposure-response functions which is drawn from an annual time-series analysis. Finally, Value Of Statistics Life(VOSL) Approach is used to monetize health benefits.

2.2 data collection and scenarios setting

The data consist of ground observations of air pollutants, meteorological parameters and basic population data from 1 January 2014 to 31 December 2014. Air quality data including PM$_{2.5}$, PM$_{10}$, NO$_2$ and SO$_2$ was collected from Qingyue Open Environmental Data Center (https://data.epmap.org), which has been providing air quality information of state controlling air monitoring sites in Nanjing. Weather data was drawn from the European Centre For Medium Range Weather Forecasts(ECMWF) Project[7] and China ground international exchange station(V3.0) (http://data.cma.cn/data/cdcdetail/dataCode/SURF_CLI_CHN_MUL_DAY_CES_V3.0.html). The population data was selected as the exposed population, according to the Nanjing statistics yearbook (2014) (Statistics Bureau of Nanjing City, 2011). Daily mortality data was obtained from Jiangsu Provincial Center for Disease Control and Prevention, providing total and specific-cause mortality. Causes of deaths were coded by the Tenth Revision of the International Classification of Diseases[8][9], which included total natural causes (A00 – R99), cardiovascular diseases (I00 – I99), respiratory diseases (J00 – J98), stroke (I60 – I69), ischemic heart disease(IHD: I20-I25) and chronic obstructive pulmonary disease (COPD: J41 – J44).

According to “the 2014 Nanjing Youth Olympic Games environmental quality interim control plan”, we divide the implementation stage of control measures into four periods. The air quality control measures in different situations are shown in table 1.

| Period          | Stage of implementation | Specific control measures                                                                 |
|-----------------|-------------------------|--------------------------------------------------------------------------------------------|
| January 1st to June 30th | Without control          |                                                                                             |
| July 1st to July 31st    | Interim control          | Coal-fired power plants control: Coal enterprises used high-quality low-sulfur coal with sulphur content less than 0.7 percent. Industrial point sources control: A total of 298 enterprises in Nanjing were suspended production and restricted production. The construction site control: 2,952 construction sites in Nanjing were closed. Road moving sources control: 30% of business vehicles were suspended; yellow label cars were banned all day; highly polluting vehicles were strictly restricted to enter into the main city; A total of 6277 heavy or medium vehicle transport vehicles were suspended. Regional joint prevention and control: Temporary controls on coal burning and other industries were imposed in 23 key cities around Nanjing. |
| August 1st to August 31st | Comprehensive implementation |                                                                                             |
| September 1st to December 31st | Without control          |                                                                                             |
2.3 Statistical analysis

We estimated the effect of air quality control measures of YOG on air pollutant concentrations using a fixed-effect model with instrumental variables. We introduced the lag period of 2 days to pollutants for regression by student’s t test and R square.

\[ Q_t = \alpha_0 + \alpha_1 \times Q_{t-1} + \alpha_2 \times Q_{t-2} + \alpha_3 \times pressure_t + \alpha_4 \times temperature_t \]

\[ + \alpha_5 \times DOW + \alpha_6 \times CON1 + \alpha_7 \times CON2 + \varepsilon_t \]

where \( Q \) represents the concentration of pollutant, pressure, temperature and DOW represent the surface pressure, 24-hour daily average temperature and indicator for day of week (regarding weekends as 1). CON is an indicator of control variable, as the enforce in August, we set CON1 as 1 in July and August, CON2 as 1 in August to differentiate the impact. \( t \) indicates the time, \( \alpha \) is the coefficient of the model. \( \varepsilon_t \) is unobservable disturbances.

Poisson additive models with over-dispersion were used to estimate the associations between mortality and air pollutants.

\[ \log[E(Y_t)] = \alpha_0 + p(t, k = 6) + p(h, k = 5) + p(p, k = 4) + l(t, 1) + \alpha_1 \times Q_t + \alpha_2 \times DOW \]

Where \( E(Y_t) \) is the expected mortality count, humidity is relative humidity, rain is daily precipitation and we lag the period for 1 day. Following the previous study, we determine the degrees of freedom \( k \) by AIC and Anova criterion, this resulted 6df for temperature, 5df for humidity and 4df for pressure. Also, we estimate the moving average for previous 3 day’s concentration of the air pollutant.

The mortality reduction can be estimated using the following formula (3). Our economic benefit assessment was based on the VOSL method (5) [10][11].

\[ N = -population \times (baseline \ incidence \times \exp(-\alpha_1 \times \Delta C) - 1) \]

\[ \Delta C = Q_t \times CON4 + Q_t \times CON5 \]

\[ VOSL = VOSLCQ \times (I_{NJ}/I_{CQ})^e \]

\[ EC_{al} = N \times VOSL \]

Where \( N \) is the cases of health effects, \( \alpha_1 \) is the coefficient, \( \Delta C \) is the change in air pollutant concentration. Where VOSL and VOSLCQ were the values of a statistical life of Nanjing residents and Chongqing residents in 2014, respectively. \( I_{NJ} \) and \( I_{CQ} \) were the incomes of Nanjing and Chongqing in 2014, respectively. VOSL represents an individual’s willingness to pay(WTP) for a marginal reduction in risk of death. \( e \) is the elastic coefficient of WTP and is assumed to be 1.0. \( EC_{al} \) is the economic benefit of human impacts linked to air pollution during YOG in Nanjing.

3. Results

Descriptive statistics of the data used in the statistical analysis are presented in Table 2. A total of 24728 total deaths were recorded. Daily non-accidental mortality decreased from 71 deaths per day before taking control measures to 61 during the under-control period, a 13.27% overall decrease. Daily total death toll rose to 66 when control measures were lifted after the game. Daily cardiovascular, respiratory, stroke, IHD and COPD disease mortality decreased by 18.32%, 23.99%, 11.36% and 31.81% and rose by 5(18.57%), 0.31(1.64%), 2.13(24.26%), 0.46(11.32%) and 0.38(14.66%). Compared to the WHO air quality guidelines of 25 \( \mu g/m^3 \), 50 \( \mu g/m^3 \), 25 \( \mu g/m^3 \) for PM2.5, PM10, SO2[12], the corresponding average concentration during under-control period were still not all up to standard, especially PM10 and PM2.5 were 1.5 to 2 times higher than the WHO guideline. However, the recovery of fine particle concentration after the cessation of the measures was weaker than that of other pollutants.

Table 2. Overall summary statistics for daily air pollution, mortality and weather variables in Nanjing, 2014.
Table 3. The associations between control measures and air pollutants.

| Pollutants   | Lag 1 | Lag 2 | CON(1)SD | 95%CI   | CON(2)SD | 95%CI   | R²  |
|--------------|-------|-------|-----------|---------|-----------|---------|-----|
| log_SO₂      | 0.5537| 0.0134| -0.0663   | (0.0187)| -0.1029   | (0.0297)| -0.1219| (0.0226)| -0.1663| (0.0776)| 0.5027|
| log_NO₂      | 0.4468| 0.0575| -0.1296   | (0.0137)| -0.1564   | (0.1029)| -0.0889| (0.0165)| -0.1213| (0.0565)| 0.4468|
| log_PM₂.₅   | 0.6468| -0.1736| -0.0872   | (0.0181)| -0.1226   | (0.0517)| -0.2505| (0.0226)| -0.2947| (0.2063)| 0.4005|
| log_PM₁₀     | 0.6234| -0.1419| -0.1030   | (0.0169)| -0.1361   | (0.0698)| -0.3086| (0.0212)| -0.3502| (0.2670)| 0.4573|

*p<0.10, **p<0.05, ***p<0.01

Table 3 shows interim control measures reduced concentrations of SO₂, NO₂, PM₂.₅, PM₁₀ by 6.63%, 12.96%, 8.72% and 10.30%, respectively. In August, further control measures reduced air pollutant concentrations by 12.19%, 8.89%, 25.05% and 30.86%. It can be seen that the greater the intensity of air quality control measures, the more air pollutant concentrations will be cut. At the same time, panel data provided sufficient data to determine the difference in air pollutant concentration caused by the policy, which supported us to accurately estimate the environmental benefits of regulatory measures.

We observed decrements of 2.91%(95% CI: 1.57%,4.24%), 1.36%(95% CI: 0.62%,2.11%), 0.55%(95% CI: 0.23%,0.87%) and 0.39%(95% CI: 0.15%,0.62%) in all-cause mortality for a 10 μg/m³ changes in SO₂, NO₂, PM₂.₅, PM₁₀ concentrations (Table 4). The results indicated that the influence of pollutants on mortality is delayed. PM₂.₅ showed significant influence on mortality and especially useful in Stroke, SO₂ was also a good indicator of air condition. In multi-pollutant models (Table 5) the relationship was no longer statistically significant (Table 6), so we used the single-pollutant model to estimate health and economic effects.

Table 4. Estimated percent decrease in mortality for a 10 μg/m³ change of pollutants in single-pollutant model.

| Pollutant | Lag | All cause | Cardiovascular | RPT | Stroke | IHD | COPD |
|-----------|-----|-----------|----------------|-----|--------|-----|------|
|           |     | Increase(95% CI) | Increase(95% CI) | Increase(95% CI) | Increase(95% CI) | Increase(95% CI) | Increase(95% CI) |

*The period from January 1st to June 30th
b The period from July 1st to August 31st
The period from September 1st to December 31st
Table 5. Estimated percent decrease in mortality for a 10 μg/m³ change of pollutants in multi-pollutant model.

| Mortality        | SO₂   | NO₂   | PM₂.5 | PM₁₀  | R²   |
|------------------|-------|-------|-------|-------|------|
|                   | Increase(95% CI) | Increase(95% CI) | Increase(95% CI) | Increase(95% CI) |      |
| All-cause        | 2.04** (0.124,3.96) | 0.64(-0.31,1.58) | 0.12(-0.71,0.94) | -0.03(-0.63,0.58) | 0.331 |
| Cardiovascular   | 2.61(-6.27,5.48) | 1.07(-3.42,2.49) | -0.65(-1.88,0.58) | 0.55(-0.35,1.44) | 0.348 |
| RPT              | 6.04**(-0.38,11.71) | -1.16(-3.96,1.64) | 1.20(-1.21,3.61) | 0.28(-2.04,1.49) | 0.199 |
| Stroke           | 3.88(-0.99,8.76) | 0.16(-2.25,2.57) | -0.53(-2.65,0.16) | 0.16(-1.37,1.68) | 0.169 |
| IHD              | 0.62(-7.84,6.60) | 2.10(-1.38,5.58) | 0.06(-2.98,3.09) | 0.98(-1.23,3.20) | 0.066 |
| COPD             | 5.67(-2.77,14.11)| -1.47(-5.55,0.03) | 4.63**(-0.92,8.33) | -2.57(-5.36,0.22) | 0.198 |

Table 6. Spearman correlations between air pollutants.

| Pollutant | SO₂ | NO₂ | PM₂.5 | PM₁₀ |
|-----------|-----|-----|-------|------|
| SO₂       | -   | -   | -     | -    |
| NO₂       | 0.666*** | -   | -     | -    |
| PM₂.5     | 0.611*** | 0.519*** | -     | -    |
| PM₁₀      | 0.713*** | 0.642*** | 0.885*** | -    |

We estimated the case of health effects and present the significant result in Table 7. The reduction of air pollutants concentration will decrease 977-1697 deaths. We obtained the per capita disposable income of Nanjing in 2014 as 6069 USD. According to the VOSL of Chongqing as 34458 USD[13], we calculated the VOSL of Nanjing as 426787 USD in 2014. Table 7 represents the economic Benefit of control measure as 553.12 million USD on average of all air pollutant, 452.77 million USD on average of SO₂ and PM₂.5. Although NO₂ was cut down less than other pollutants, it was actually going to have a larger population health effect. From the point of view of maximizing health benefits, the control measures should concentrate on reducing SO₂, but when taking air quality in Nanjing, reducing NO₂, PM₂.5 and PM₁₀ is more emergency.

Table 7. The cases and economic benefits of health effects between air pollutants and mortalities.

| Air Pollutant | All cause | Cardiovascular | RPT | Stroke | IHD | COPD | Economic Benefit(USD, Million) |
|---------------|-----------|----------------|-----|--------|-----|------|-------------------------------|
| SO₂           | 977.3     | 528.2          | 255.3 | -      | 122.1 | 113.1 | 417.11                        |
| NO₂           | 1697.0    | 1055.7         | -    | -      | 309.6 | -    | 724.27                        |
| PM₂.5         | 1144.4    | 581.7          | 206.0 | 99.5   | 227.9 | 107.7 | 488.43                        |
| PM₁₀          | 1365.2    | 839.4          | 227.0 | -      | 302.9 | 88.6 | 582.68                        |

4. Discussion
The study has presented a new comprehensive evaluation method of the economic assessment of the health effects related to the air quality control measures during YOG. The key aims of this study were to (1) estimate quantitative impact of control measures on air quality at different stages. (2) use the exposure-response relationship to calculate and monetize the health effects of control measures by affecting air quality.

Meanwhile, Limited by the length of the data, we failed to consider the seasonal trend of pollutant concentration in the model, which may lead to errors in the estimation results due to changes in climatic conditions. We should supplement data for more years especially exposed population demographic data in further research. In addition, our hypothesis about the relationship between the concentration of air pollutants and mortality (Eq.(1)) was validated by the model only from a statistical point of view, and the pathological correlation was not further explored. Evidence about the relative toxicity of different particles is ambiguous, and the synergistic effects of different particles do exist from a pathological point of view. Similar to most papers, we can only abandon this relationship and infer from the results of the single pollutant model because the results of this study cannot show significant differences.

5. Conclusion
An integrated air quality, health and economic model was established to evaluate the mortality reduction from non-accidental causes and from cardiovascular, respiratory, IHD, COPD and stroke diseases. In summary this event specifically reduced about 1000 acute deaths from all cause and produced about 500 million USD for any of the four pollutants. According to the model, we found that air quality control measures during YOG made a great contribution to population health effects and economic benefits. The results are of great reference value to similar studies in developing countries with rapid economic development, and the model can be applied to other major international events where air control measures are implemented.

6. References
[1] Mannucci P M, Harari S, Martinelli I, et al. Effects on health of air pollution: a narrative review[J]. Internal & Emergency Medicine, 2015, 10(6):657-662.
[2] Huang K, Zhang X, Lin Y. The “APEC Blue” phenomenon: Regional emission control effects observed from space[J]. Atmospheric Research, 2015, 164-165:65-75.
[3] Liu H, Wang X, Zhang J, et al. Emission controls and changes in air quality in Guangzhou during the Asian Games[J]. Atmospheric Environment, 2013, 76(5):81-93.
[4] Shen L, Wang H, Sheng L, et al. Influence of pollution control on air pollutants and the mixing state of aerosol particles during the 2nd World Internet Conference in Jiaxing, China[J]. Journal of Cleaner Production, 2017.
[5] Dominici F, Medermott A, Zeger S L, et al. On the use of generalized additive models in time-series studies of air pollution and health.[J]. American Journal of Epidemiology, 2002, 156(3):193-203.
[6] Zhang M, Song Y, Cai X, et al. Economic assessment of the health effects related to particulate matter pollution in 111 Chinese cities by using economic burden of disease analysis.[J]. Journal of Environmental Management, 2008, 88(4):947-954.
[7] Palmer T N, Barkmeijer J, Buizza R, et al. The ECMWF Ensemble Prediction System[J]. Meteorological Applications, 2010, 4(4):301-304.
[8] Shaughnessy W J, Venigaila M M, Trump D. Health effects of ambient levels of respirable particulate matter (PM) on healthy, young-adult population[J]. Atmospheric Environment, 2015, 123:102-111.
[9] Organization W H. Tenth revision of the International Classification of Diseases chapter V (F: mental, behavioural and developmental disorders, clinical descriptions and diagnostic guidelines][J]. World Health Organization, 1988.
[10] Du Y, Li T. Assessment of health-based economic costs linked to fine particulate (PM 2.5) pollution: a case study of haze during January 2013 in Beijing, China[J]. Air Quality, Atmosphere & Health, 2016, 9(4):439-445.

[11] Zhang M, Song Y, Cai X, et al. Economic assessment of the health effects related to particulate matter pollution in 111 Chinese cities by using economic burden of disease analysis.[J]. Journal of Environmental Management, 2008, 88(4):947-954.

[12] Organization W H. Air quality guidelines: Global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide.[J]. Indian Journal of Medical Research, 2007, 4(4):492-493.

[13] Wang H, Mullahy J. Willingness to pay for reducing fatal risk by improving air quality: A contingent valuation study in Chongqing, China[J]. Science of the Total Environment, 2006, 367(1):50-57.

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