

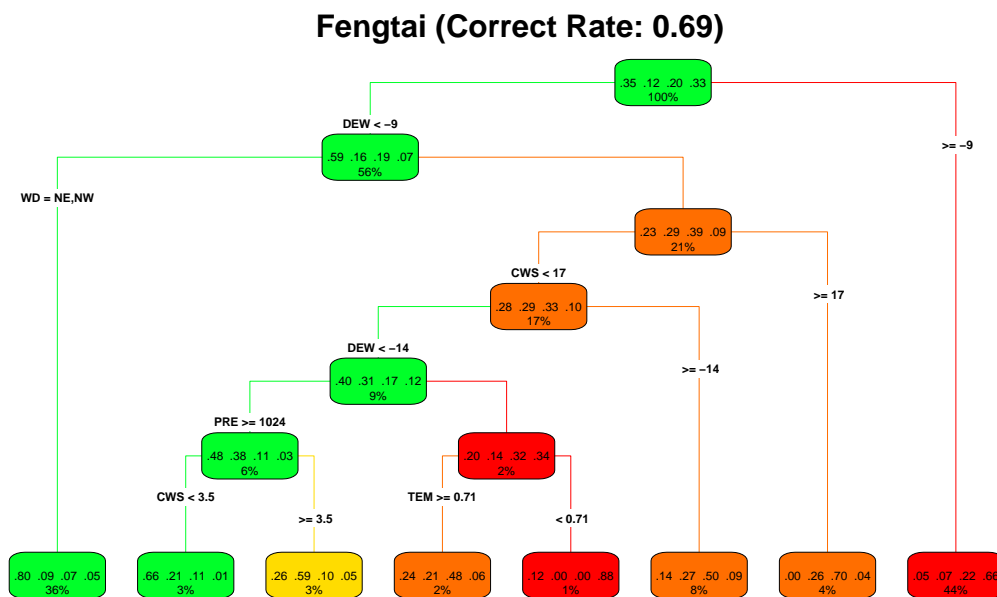
Supplementary Material for Cautionary tales on air-quality improvement in Beijing

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The Supplementary Material comprises Figures S1-S5 and Tables S1-S3 as follows.

- Fig. S1. PM_{2.5} classification trees with respect to five meteorological variables in two air quality monitoring sites of Fengtai and Shunyi in the winter of 2016.
- Fig. S2. Simple monthly averages by the calendar and seasonal years in Central region.
- Fig. S3. Seasonal adjusted average PM_{2.5} from 2013 to 2015 in Beijing.
- Fig. S4. Comparison of seasonally adjusted average PM_{2.5} and the simple averages for the Central region and the Guokong sites.
- Fig. S5. Coal consumption and output of high energy consuming industrial products.
- Table S1. Locations of pollutant monitoring sites and the corresponding matched weather stations.
- Table S2. Seasonal and annual adjusted means for the areas in the three regions and 11 Guokong stations in Beijing.
- Table S3. Differences of seasonal and annual adjusted means for the areas in the three regions and 11 Guokong stations in Beijing.

(a)



(b)

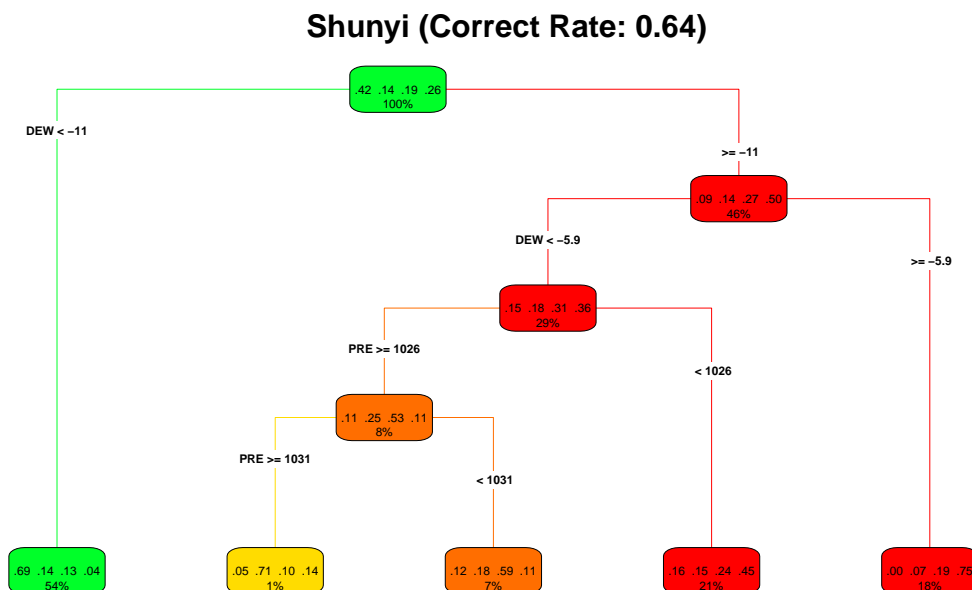


Fig. S1 $PM_{2.5}$ classification trees with respect to five meteorological variables (without cumulative precipitation (CP)) in two air quality monitoring sites, Fengtai (a) and Shunyi (b), in the winter of 2016. The response $PM_{2.5}$ is classified into four categories: $PM_{2.5} \leq 35\mu g/m^3$ (green), $35\mu g/m^3 < PM_{2.5} \leq 75\mu g/m^3$ (yellow), $75\mu g/m^3 < PM_{2.5} \leq 150\mu g/m^3$ (orange) and $PM_{2.5} > 150\mu g/m^3$ (red). The four numbers inside each colored node indicates the proportions of the four $PM_{2.5}$ categories at each layer of the branch, and the percentage represents the marginal proportion of the sample at the node.

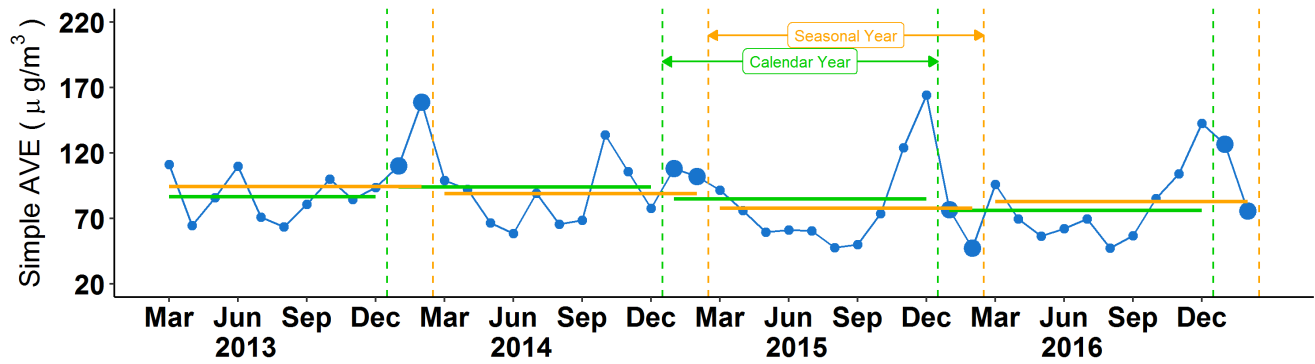
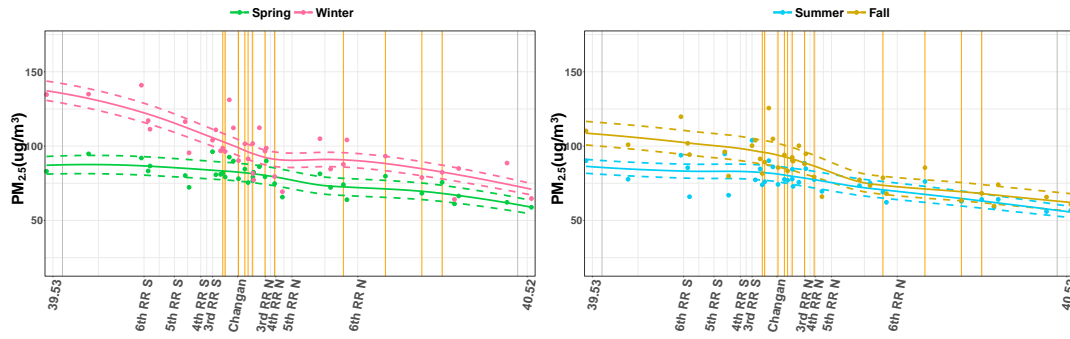
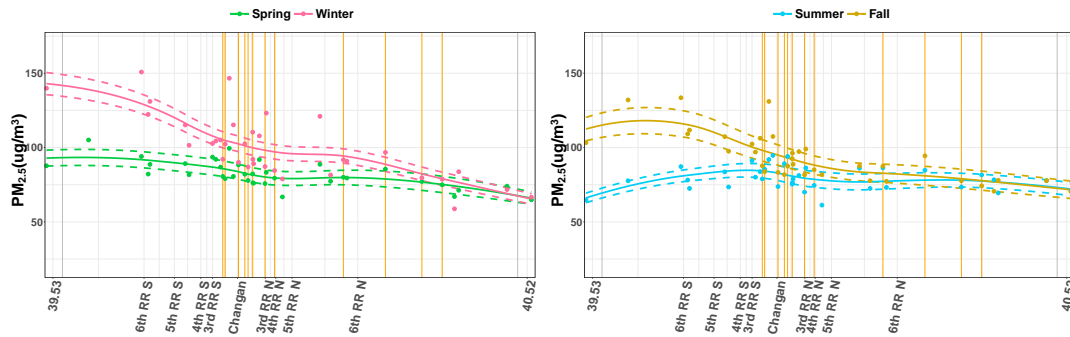


Fig. S2 Simple monthly averages by the calender (green line segments) and seasonal (yellow line segments) years in the Central region. The bigger blue dots mark January and February averages. The unusually low January and February levels in 2016 are very visible.

(a)



(b)



(c)

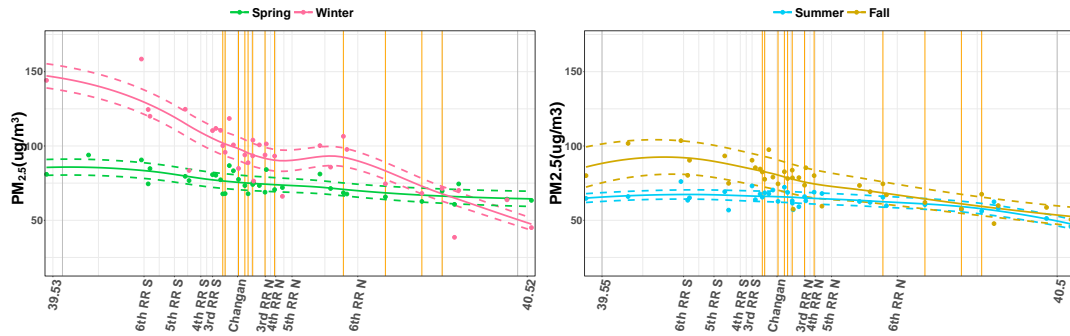


Fig. S3 Seasonal adjusted average $PM_{2.5}$ from 2013 to 2015 in Beijing. Adjusted average $PM_{2.5}$ curves (solid line) in the South-North direction (latitude) and the 95% confidence intervals (dashed lines) for four seasons (spring in blue, summer in green, autumn in yellow and winter in purple) in 2013 (a), 2014 (b) and 2015 (c). Yellow lines mark the latitudes of the Guokong sites. Dots indicate the site specific adjusted averages.

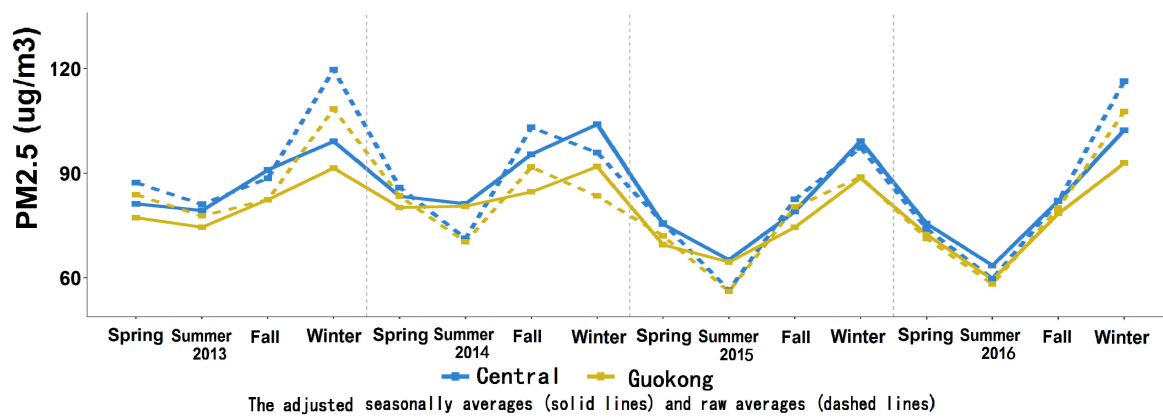
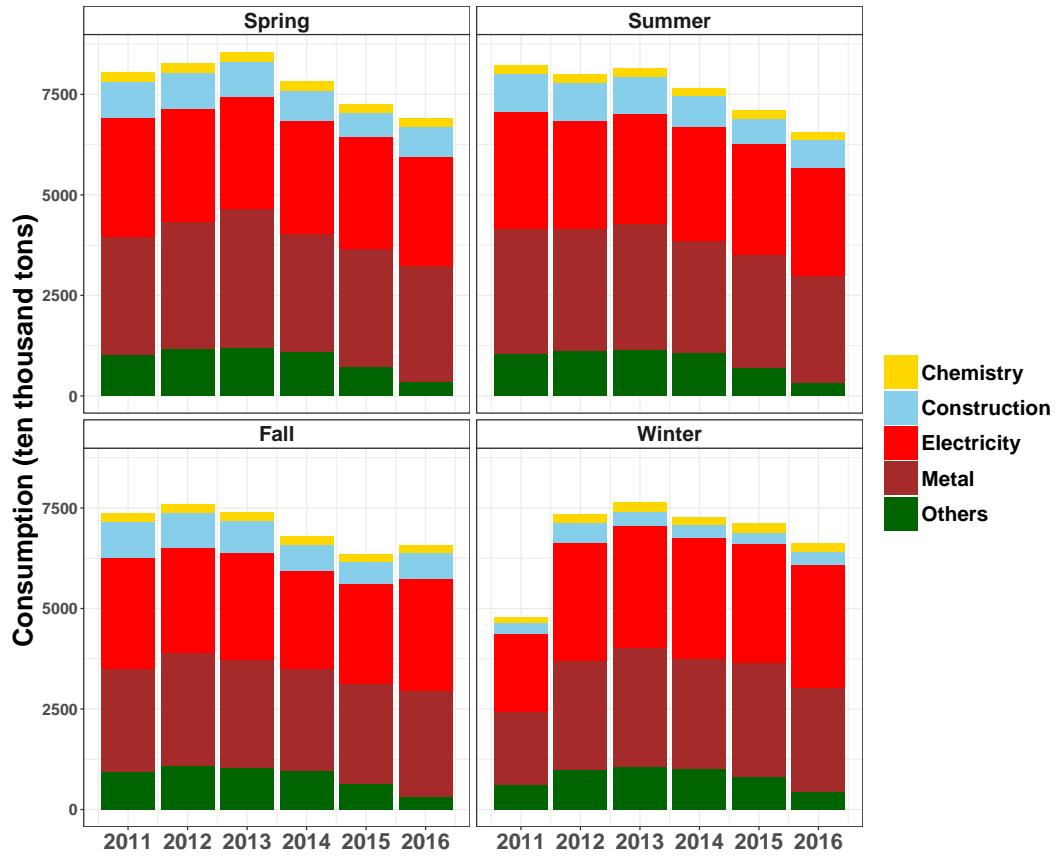


Fig. S4 Comparison of seasonally adjusted average PM_{2.5} (solid lines) and the simple averages (dashed lines) for the Central region (blue) and the Guokong sites (yellow).

(a)



(b)

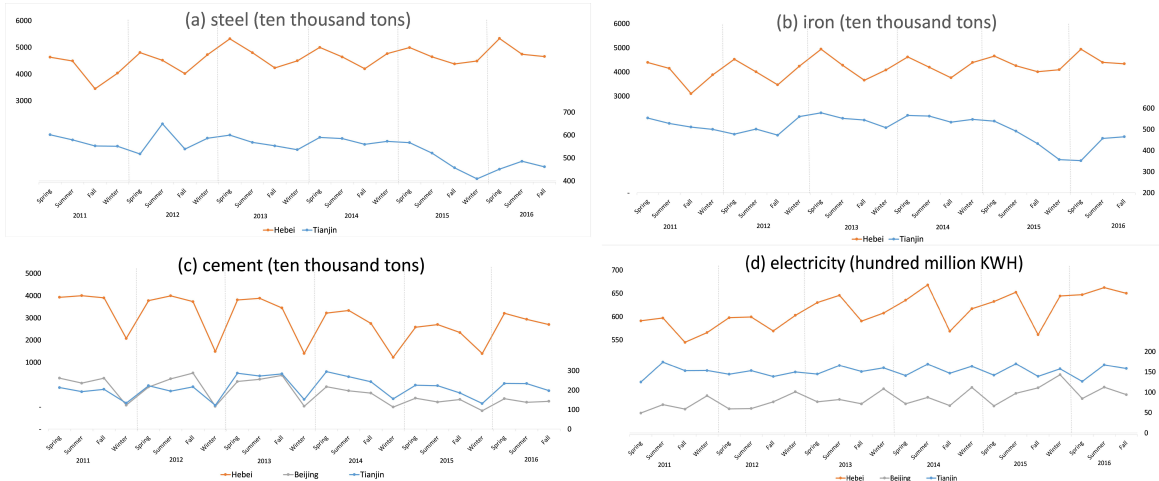


Fig. S5 Coal consumption and output of high energy consuming industrial products. (a). Seasonal coal consumption of Hebei. It consists of coal consumption in electric power, metallurgical, chemical and construction material industries and all other industries. **(b).** Steel, iron, cement output and the amount of electricity generation in Huabei District. Steel, iron and cement are the high energy consuming products of metallurgical industry and construction material industry in Hebei province.

Table S1 Locations of pollutant monitoring sites and the corresponding matched weather stations. In the table, weather station 1 is the weather station before Feb 2015 while weather station 2 is after. For the station type, GK refers to Guokong sites and SK is used to represent Shikong for abbreviation. For better understanding, we highlight all Guokong sites with red.

| Region | Subregion | Pollutant Monitoring Site | Station Type | Weather Station 1 | Weather Station 2 |
|---------|-------------|---------------------------|--------------|-------------------|-------------------|
| Central | Northwest | Aotizhongxin | GK | 54399 | 54511 |
| | | Beibuxinqu | SK | 54499 | 54499 |
| | | Changping | GK | 54499 | 54499 |
| | | Guanyuan | GK | 54399 | 54511 |
| | | Gucheng | GK | 54513 | 54505 |
| | | Mentougou | SK | 54505 | 54505 |
| | | Wanliu | GK | 54399 | 54511 |
| | | Xizhimenbei | SK | 54399 | 54511 |
| | Zhiwuyuan | SK | 54399 | 54499 | |
| | Northeast | Dongsi | GK | 54433 | 54511 |
| | | Dongsihuan | SK | 54433 | 54511 |
| | | Nongzhanguan | GK | 54433 | 54511 |
| | | Shunyi | GK | 54398 | 54398 |
| | | U.S. Post | SK | 54433 | 54511 |
| | Southwest | Daxing | SK | 54594 | 54594 |
| | | Fangshan | SK | 54596 | 54596 |
| | | Fengtai | SK | 54514 | 54511 |
| | | Nansanhuan | SK | 54514 | 54511 |
| | | Wanshouxigong | GK | 54514 | 54511 |
| | | Yungang | SK | 54596 | 54596 |
| | Southeast | Qianmen | Sk | 54433 | 54511 |
| | | Tiantan | GK | 54433 | 54511 |
| | | Tongzhou | SK | 54431 | 54431 |
| | | Yizhuang | SK | 54594 | 54511 |
| | | Yongdingmen | SK | 54514 | 54511 |
| | South | Liulihe | SK | 54597 | 54596 |
| | | Yongledian | SK | 54431 | 54431 |
| | | Yufa | SK | 54594 | 54594 |
| North | Badaling | SK | 54406 | 54406 | |
| | Dingling | GK | 54499 | 54499 | |
| | Donggaocun | SK | 54424 | 54424 | |
| | Huairou | GK | 54419 | 54419 | |
| | Miyun | SK | 54416 | 54416 | |
| | Miyunshuiku | SK | 54416 | 54416 | |
| | Pinggu | SK | 54424 | 54424 | |
| | Yanqing | SK | 54406 | 54406 | |

Table S2 Seasonal and annual adjusted averages for the areas in the three regions and 11 Guokong stations in Beijing.
The numbers in the parentheses are the standard errors of the adjusted averages. The numbers inside the parentheses next to the areas are the number of sites used.

| Region | Season | 2013 | 2014 | 2015 | 2016 |
|--------------|---------|------------|------------|------------|------------|
| Central (25) | Spring | 81.3(2.7) | 83.5(2.1) | 75.5(2.1) | 75.6(2.5) |
| | Summer | 79.4(2.1) | 81.3(2.0) | 65.2(1.4) | 63.6(1.4) |
| | Autumn | 91.0(3.3) | 95.4(2.8) | 79.1(4.4) | 82.2(2.8) |
| | Winter | 99.1(2.1) | 104.0(2.2) | 99.2(3.3) | 102.3(2.9) |
| | Average | 87.7(1.3) | 91.1(1.2) | 79.8(1.5) | 80.9(1.2) |
| North (8) | Spring | 66.1(2.3) | 73.3(2.2) | 66.8(2.1) | 64.3(2.4) |
| | Summer | 62.5(2.0) | 74.6(1.7) | 56.6(1.4) | 53.4(1.2) |
| | Autumn | 66.7(2.3) | 75.4(2.6) | 59.8(2.8) | 62.3(2.0) |
| | Winter | 81.3(1.9) | 76.0(1.6) | 67.3(2.0) | 81.4(2.2) |
| | Average | 69.2(1.1) | 74.8(1.0) | 62.6(1.1) | 65.3(1.0) |
| South (3) | Spring | 90.0(3.0) | 95.6(2.5) | 88.5(2.4) | 83.6(2.9) |
| | Summer | 87.3(2.1) | 76.5(1.5) | 68.9(1.3) | 63.5(1.4) |
| | Autumn | 110.3(3.8) | 123.0(3.6) | 95.1(5.4) | 98.9(3.1) |
| | Winter | 136.6(3.0) | 157.8(3.1) | 161.2(3.5) | 153.4(3.8) |
| | Average | 106.0(1.4) | 113.2(1.4) | 103.4(1.8) | 99.9(1.5) |
| Guokong (11) | Spring | 78.1(2.4) | 80.5(1.9) | 70.2(1.9) | 73.1(2.4) |
| | Summer | 75.6(2.0) | 81.3(1.9) | 65.3(1.4) | 60.4(1.4) |
| | Autumn | 84.2(3.0) | 85.4(2.3) | 76.1(4.1) | 80.0(2.6) |
| | Winter | 92.7(1.9) | 93.0(1.9) | 90.6(3.0) | 95.2(2.9) |
| | Average | 82.7(1.2) | 85.1(1.1) | 75.5(1.4) | 77.2(1.2) |

Table S3 Differences of seasonal and annual adjusted averages for the areas in the three regions and 11 Guokong stations in Beijing. The numbers in the parentheses are the standard errors of the differences of adjusted averages. The numbers inside the parentheses next to the areas are the number of sites used.

| Region | Season | 2014-2013 | 2015-2014 | 2016-2015 |
|--------------|---------|---------------|---------------|---------------|
| Central (25) | Spring | 2.3(3.3) | -8.0(3.0)*** | 0.1(3.3) |
| | Summer | 1.9(2.7) | -16.0(2.4)*** | -1.6(2.1) |
| | Autumn | 4.4(4.4) | -16.3(5.3)*** | 3.1(5.0) |
| | Winter | 4.9(3.0) | -4.9(3.7) | 3.2(4.1) |
| | Average | 3.4(1.8)* | -11.3(1.9)*** | 1.2(1.9) |
| North (8) | Spring | 5.7(3.8)** | -7.1(3.5)** | -4.9(3.7) |
| | Summer | -10.8(2.4)*** | -7.6(2.0)*** | -5.5(1.9)* |
| | Autumn | 12.7(5.4)*** | -27.8(6.6)*** | 3.8(6.2) |
| | Winter | 21.3(4.1)* | 2.9(4.7)*** | -15.6(4.9)*** |
| | Average | 7.2(2.1)*** | -9.9(2.3)*** | -5.5(2.2) |
| South (3) | Spring | 7.2(3.2) | -6.5(3.2)** | -2.5(3.2) |
| | Summer | 12.1(2.7)*** | -18.0(2.4)*** | -3.2(1.8)*** |
| | Autumn | 8.7(3.6)*** | -15.6(3.8)*** | 2.4(3.4) |
| | Winter | -5.1(2.7)*** | -8.9(2.7) | 9.9(2.9)*** |
| | Average | 5.7(1.6)*** | -12.3(1.6)*** | 1.7(1.5)*** |
| Guokong (11) | Spring | 2.4(3.0) | -10.3(2.7)*** | 2.9(3.1) |
| | Summer | 5.6(2.7) | -16.0(2.4)*** | -4.9(2.1)*** |
| | Autumn | 1.2(3.9)** | -9.3(4.8)** | 3.9(4.7) |
| | Winter | 0.3(2.7) | -2.4(3.3) | 4.6(3.8) |
| | Average | 2.4(1.6) | -9.5(1.7)*** | 1.6(1.8) |

The number of * represents the level of significance for testing the increase or decrease of the annual change between two consecutive years (No * means the increase/decrease was not significant; *: $0.025 \leq p\text{-value} < 0.05$; **: $0.01 \leq p\text{-value} < 0.025$; ***: $p\text{-value} < 0.01$).