THE EFFECTS OF THE 2008 BEIJING OLYMPIC GAMES ON AIR QUALITY AND PUBLIC HEALTH

By

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ABSTRACT OF THE THESIS

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The elevated air pollution level has frequently put China under the world's spotlight. To better prepare for the 2008 Olympic Games, China had taken a series of radical control actions to improve air quality, including plant closure and relocation, temporary production halt or reduction, furnace replacement, and stringent traffic control along with additional Olympic transportation options. Such actions were carried out in a large geographic area including Beijing and five adjacent provinces, namely, Hebei, Inner Mongolia, Shandong, Shanxi and Tianjin, with a significant cost totaling up to over US$10 billion, which partly made the Beijing Games the most expensive Olympic Games in the history. The objective of this thesis is to investigate the Olympic effect on air quality and public health.

In this study, both air quality data and hospital inpatient records (HIR) before and after the Olympic Games are collected for the Olympic city (Beijing) and non-Olympic city (Shijiazhuang, the capital city of Hebei province). The official daily air pollution index (API) published by the Ministry of Environmental Protection of China (MEP) is used to measure air quality. The HIR are collected from both surgical and respiratory departments in one main hospital of each city. Both data cover the time span from June 5th, 2001 to December 31, 2009 for both cities.

Based on the quasi-experimental technique, Difference-in-Difference (DID) analyses, I find that not only the Olympic Games had positive effects in air quality, but the air quality improvement also lasted even after the game, though in a smaller magnitude. On the other hand, the effects of Olympic Games on public health are limited.

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CHAPTER 1: INTRODUCTION

On July 13th, 2001, Beijing won the bid to host the Games of the XXIX Olympiad in summer 2008 and had seven years to prepare for it. During those seven years, the Beijing municipal government and the Beijing Organizing Committee for the Olympic Games (BOCOG) faced a lot of pressure on almost all aspects. The most challenging target is to improve the air quality so that it will meet the air quality guidelines set by the World Health Organization (WHO) and to further fulfill the "Green Olympics" commitment proposed in Beijing's Olympic bid on providing a satisfying and enjoyable environment to athletes and spectators from all over the world.

Beijing is one of the most polluted mega cities in the world (Gurjar, et al., 2008). According to WHO's the guidelines, the limitation on the annual mean concentration of particulate matter with diameters of 10 micrometers or less (PM_{10}) and nitrogen dioxide (NO_2) are $20\mu g/m^3$ and $40\mu g/m^3$ ((WHO), 2006), respectively. The concentrations of these two pollutants in Beijing far exceeded the guideline level in 2007, which are $148\mu g/m^3$ and $66\mu g/m^3$ (increased by 640% and 65%, respectively) ((BMBS), 2010). The main air pollutants in Beijing are particulate matter (PM), Sulfur dioxide (SO_2), nitrogen oxides (NO_x) and carbon monoxide (CO), most of which are produced in the combustion process of various fuels used in vehicles and industries (Brajer and Mead, 2003, Wang and Xie, 2009, Wang, et al., 2009). These air pollutants can be a trigger of various serious health problems such as asthma, cardiopathy, premature birth and some pulmonary diseases (Brajer and Mead, 2003, Friedman, et al., 2001).

To better improve the air quality for the Olympic Games, Beijing municipal government took effective steps and conducted comprehensive measures involving environment rehabilitation and pollutant reduction. The most dramatic actions that Beijing had taken were (1) expanding air quality monitoring and enforcement beyond Beijing by calling for a cooperative and synchronized air pollution control effort of six neighboring provinces (Hebei, Inner Mongolia, Shandong, Shanxi and Tianjin); and (2) imposing stricter emission standards for vehicles and adopting a set of road traffic restrictions during the game time.

The objective of this thesis is to examine whether the 2008 Beijing summer Olympic Games had improved air quality and public health. To fulfill the research objective, a difference-in-difference (DID) approach is applied to analyze the change in air quality measured by the daily Air Pollution Index (API) and the change in respiratory inpatients in two cities (Beijing and Shijiazhuang) before and after the game. Shijiazhuang is the capital city of Hebei Province, a neighboring province of Beijing.

The results suggest that the air quality in Beijing during the Games period was significantly improved compared to the periods before the Games. Also, the post-game effects of the air quality in Beijing are discussed. The improvement of air quality can be considered to be related to the measures implemented since the measures are well targeted to the main pollutants and polluting sources (Chin, 1996). And after the Games, some of the restrictions were retained and some were partially kept in Beijing. Therefore, it is reasonable that we observe a reduction of emission and a better air quality during and after the Olympic Games. The analysis of the inpatient record data also show that the improvement of respiratory disease in Beijing compared to that in Shijiazhuang can be related to the implementation of air quality control policies during the Olympic Games.

The organization of this thesis is as follows: Chapter 2 provides brief background information regarding the Beijing Olympic Games and the measures taken during the Games to control air quality in Beijing. Chapter 3 provides a literature review on air quality and public health with a focus on previous studies on events such as Olympic Games. Chapter 4 provides the detailed descriptions of the data used in this work. Chapter 5 introduces the methodology that is applied for this study. Chapter 6 discusses the estimated effects of Olympic Games on both air quality and public health. Finally, Chapter 7 summarizes conclusions and policy implications as well as research limitations.

CHAPTER 2: BACKGROUND: BEIJING 2008 OLYMPIC GAMES AND POLLUTION CONTROL MEASURES

On July 13th, 2001, Beijing was elected as the host city of the 2008 Olympic Games According to the time line of Beijing 2008 Olympic Games, four consecutive periods are defined in this study. The pre-preparation period is defined as the period before the establishment of the Beijing Organizing Committee for the Olympic Games (BOCOG) on December 13th, 2001. The preparation period for the Olympic Games is between the establishment of BOCOG and the day for the opening ceremony of Beijing Olympic Games. The forty Game days from August 8th, 2008 to September 17th, 2008 are defined as the "Game period". And the time after the closing ceremony of Beijing Olympic Games is defined as the "post-Game period".

In order to ensure a satisfactory environment and air quality for the Olympic Games, Beijing had taken various steps involving not only Beijing but also surrounding areas. Based on the US EPA's Models-3/CMAQ model simulation over the Beijing region, Streets et al. (2007) examined the contribution of fine particulate matter (PM) and ozone (O_3), which are among the most important air pollutants. The results of this study suggested that there was a regional impact on Beijing's air quality, and that emission sources outside Beijing contributed a lot to the air pollutants in Beijing. Therefore, a regional air quality control measure rather than a measure only implemented in Beijing should be introduced to ensure an acceptable ambient air quality during the Olympic Games.

Beijing announced an “Air Quality Guarantee Plan for the 29th Olympic and Paralympics Games in Beijing” during the preparation period. The plan expanded air quality monitoring and encouraged environment improving in the surrounding area of Beijing as the six provinces promised to cooperate cohesively and took synchronized actions to ensure satisfactory air quality during the Games. According to the plan, six parts of emission restrictions were included. Much stricter emission restrictions were posed against almost all possible sources of pollution, such as traffic, construction, soot-generating factories, coal-consuming industries (such as power plant) and organic waste gas emitting sectors (BMPG, 2007). Emission in polluting factories was required to be reduced within the specified timeframe, polluting factories fails to meet the emission standard would be shut down, and some heavy polluting factories and power plants were required to reduce extra 30% emission so that the Chinese emission standard is met. In addition, all the ongoing constructions were suspended to control construction dust, and no new construction project would be approved during Game time (BMPG, 2007). At the same time, emissions of motor vehicles were also strictly controlled. Since the vehicle registration in Beijing was increasing significantly every year (The vehicle registration in Beijing increased from 3 million in May 2007 to 4 million in December 2009, and reached 4.56 million on September 28th, 2010), vehicle emission became one of the most important pollution sources (Wang, et al., 2010). To alleviate the impact of vehicle pollutant emission, stricter emission standards were implemented. On the other hand, a set of road traffic restriction measures were adopted during the game time. On June 19th, 2008, the Beijing municipal government announced “Temporary Traffic Control Measures for Beijing-Registered Motor Vehicles during the 2008 Beijing Olympic and Paralympic Games” and “Temporary Traffic Control Measures for the Beijing-Bound Non-Beijing-Registered Motor Vehicles During the 2008 Beijing Olympic and Paralympic Games”. According to these two announcements, only vehicles that meet the Chinese National Emission Control Standard II or higher level were allowed on road in Beijing. Furthermore, “vehicle with license plate number ending in odd digits shall be allowed on the road on odd dates and those with plate number ending in even digits shall be allowed on the road on even dates.((BTMB), 2008, (BTMB), 2008) Wang, et al. (2009) suggested in their article that heavy truck is the main source of black carbon which is a type of particulate pollutant. And Cai and Xie (2007) mentioned in their study that van notably contribute to the pollutant SO_2 and NO_x. Accordingly, a specific restriction was posed on these vehicles. For example, cargo trucks were banned off road within the 6th ring road from 6 am to midnight” ((BTMB), 2008, (BTMB), 2008). During the period that these temporary traffic restrictions are in effect, traffic flow was reduced by 32.3% in Beijing (Wang and Xie, 2009). At the same time, public transportation system of Beijing was expanded with the operation of three new subway lines and an Olympic Bus Lines system.

CHAPTER 3: LITERATURE REVIEW

3.1 Air quality and health consequence

Human health is closely related to the environment. It is believed that air quality is one of the most important factors that affect public health. In the literature, many studies provide supporting evidence of the relationships between air quality and various elements of human health, such as diseases, birth and age groups, life expectancy, and life styles and health care behaviors, etc.

In general, as many studies suggested, the effects of air pollutants on diseases can be categorized as acute effects and chronic effects (Chen, et al., 2004, Portney and Mullahy, 1986, Portney and Mullahy, 1990, Zhang, et al., 2010). Specifically, it is found in many studies that air pollution is positively associated with the incidence of cardiopathy, acute and chronic pulmonary diseases, premature birth, and increased risk of cancer (Chen, et al., 2011, Dockery, et al., 1993, Liu and Zhang, 2009, Miller, et al., 2007, Millman, et al., 2008, Nyberg, et al., 2000). Moreover, different air pollutants can have effects on different diseases. Alberini and Krupnick (1998) found, using the survey data collected from November 1991 to January 1992, that particulate matter with diameters of 10 micrometers or less (PM_{10}) can trigger a new episode of acute respiratory illness as poor air quality measured by PM_{10} compromises the immune system. Matthew (2004) also found that carbon monoxide can have significant effects on children aged from one to 18 with asthma.

Moreover, air-borne pollutions are found to have more significant adverse impact on vulnerable groups such as infants and children (Buka, et al., 2006). And children with lower socioeconomic status are more vulnerable to the air pollution (Matthew J, 2004). Adverse health impacts in terms of the infant birth condition, child pulmonary disease, and neural development are found to be related to both indoor and outdoor air pollutions (Millman, et al., 2008). Another study using the Yale Mothers and Infants Health Study Data, conducted by Zhang et al. (2008), reveals that different air pollutants are related to different respiratory symptoms of mothers and infants. It is shown in the study that the particulate matters and high humidity increase the risk of having cough symptoms and particulate matter is positively associated with the runny nose symptom for mothers, while high sulfate level increases the risk of having a runny nose and cough symptoms for infants.

Another focus in the literature is the impact of air quality on the life expectancies. Chen et al. (2011) examine the difference of life expectancies among Chinese people who live in different areas of China. During the central planning period, northern China established a winter heating system while no central heating system was built in southern China. Since the combustion of coal or other fuels in the heating system is a major source of particulates, the difference between southern and northern China provides a natural experiment to analyze the difference of life expectancy due to air pollution. The authors found that an additional 100 $\mu g/m^3$ total suspended particulates (TSP) concentration reduces the life expectancy by two years and half. Another study by Hoek et al.(2002) also reported that traffic-related air pollution is related to cardiopulmonary mortality especially near major road, and that long term exposure to traffic-related air pollution has negative influence on life expectancy.

Moreover, there are also some other studies in the literature investigating the relationship between air quality and people’s choice of life styles and health care behaviors. An example of such studies, conducted by Di Novi (2010), is to model the influence of motor vehicle emissions on the health-improving life styles. It is found in the study that only if the traffic-related air pollution is below the level of AQI 100, will people have the incentives to invest in the health-improving activities. According to their findings, since the amount of health investments is related to the likelihood of good health, air quality is also able to affect human health indirectly by affecting the choices of people’s behavior.

Air quality and human health are closely related in many different aspects. Therefore, in order to evaluate the environmental impact and guide the environmental improvement efforts, it is important to study the intrinsic connections between air quality and public health.

3.2 Impact of air quality related events

In particular, in this study, we will focus on the relationship between the Olympic Games and the air quality as well as public health. In fact, in the literature, to study the effects of air pollution and anthropogenic air quality improvement, people usually take advantage of some air quality related events, such as Olympic Games or other major international events that require better air quality, new actions and regulations for air quality improvement, and implementation of air quality related standards, etc. These special events provide researchers great opportunity to study the air quality improvement efforts and its potential influences before and after the events. For example, Friedman et al. (2001) examined the relationship between the changes in air quality and traffic pattern in Atlanta during the 1996 summer Olympic Games and the asthma incidence of children aged one to 16 years old. In the study, decreases in the concentration of PM_{10}, carbon monoxide, and nitrogen dioxide are found during the Olympic period compared with the pre-event period. At the same time, a decrease in the number of asthma incidents (including emergency care and hospitalization) is also found, which is considered to be related to the improvement of air quality during the Games due to the introduction of traffic restrictions. Another example of using special events is a study on the impact of the high sulfur fuel ban by Hong Kong government in 1990 (Barron, et al., 1995). The implementation of the ban is used as an occasion to study the health impact of the air quality change due to this measure. The costs-and-benefit analysis is employed and it is found that the benefit is significantly greater than the cost after the termination of using high sulfur fuels, which provides supportive evidence for the implementation of ban. In addition, the event of new environmental standards can also be used for comparative studies. Auffhammer and Kellogg (2011) employed a difference-in-difference (DID) estimator and a regression discontinuity (RD) design to study the effects of gasoline content standards on the air quality in California. They find that the imposition of California reformulated gasoline (CARB) standards significantly reduced the ozone concentration, especially in the area suffering from heavy *ex ante* ozone pollution. However, another two regulations, i.e. federal Reid vapor pressure (RVP) and federal reformulated gasoline (RFG), have no significant effect on the reduction of ozone pollution at any area.

In this work, we are interested in the event of Beijing 2008 Olympic Games and aim to study the impact of the Games on the air quality as well as public health. In the recent publications, there are already some studies focusing on the Beijing 2008 Olympic Games. Okuda et al. (2011) compiled the concentration of PM_{10}, sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) by converting the official Air Pollution Index (API) data reported by Beijing Municipal Environmental Protection Bureau, the concentrations of $PM_{2.5}$ and black carbon (BC) obtained from Tsinghua University, and the samples of TSP and $PM_{2.5}$ collected from Chinese Academy of Science from 2005 to 2008. They find that the concentrations of PM_{10}, BC, SO_2, and NO_2 decreased during the Olympic Games period, while no significant reduction of $PM_{2.5}$ is found. Furthermore, based on the analysis of the composition of aerosols, the authors conclude that the reduction of $CaSO_4$, which was highly related to the shutting-down of construction sites, played a crucial role in reducing larger particles. In another study, Chen et al. (2011) compared air quality measured by air quality index (AQI) and visibility between Beijing and other 5 co-host cities as well as 28 non-Olympic cities using difference-in-difference (DID) approach. The study period covers more than nine years, starting from the first day when AQI data become available to public in China on June 5th, 2000, until 13 months after the Beijing Olympic Games. It is found that the air quality was improved during the Games, but the improvement was short-lived as approximately 60% of the improvement faded off within the first year after the Games.

In addition to the air quality impact of the Beijing 2008 Olympic Games, health effects are also discussed in the literature. Li et al. (2010) analyzed the hospital outpatient data from the Beijing Chaoyang Hospital from June 1st to September 20th, 2008. They find that the concentration of air pollutants was improved during the Olympics Games period and the improvement also leads to the reduced number of adult outpatients who were diagnosed with asthma symptoms.

During the Beijing Olympic Games, various social and environmental measures and policies were implemented in order to maintain satisfactory air quality. In the literature, the effectiveness of these policies is evaluated in some studies. Cheung and Mun (2010) conducted a cost-and-benefit analysis to examine the pollution control measures to prepare Beijing with better air quality for the Olympic Games. It was pointed out in their study that the cost/benefit ratio of the Beijing Green Olympics may be larger than one in the short-run, since some of the indirect benefits gained from the improved air quality, such as enhanced public awareness of environmental protection and improvement of life quality and public health, are hard to manifest itself in the short run, but such indirect benefit will decrease the cost/benefit ratio in the long run. Another study done by Mead and Brajer (2008) estimated the health benefits gained during the cleanup process from 1998 to 2008 while Beijing was preparing for the game. The cost of illness (COI) and the willingness to pay (WTP) methods are applied to calculate the equivalent monetary benefits gained from the public health improvements including reduced mortality and morbidity due to better air quality. It is found that the quantified monetary benefits of the cleanup efforts and public health improvement during the 10-year preparation period is nearly 50 billion Chinese Yuan (about US $7 billion). Although the benefit value in the 10-year period does not cover the pledged value of cleanup cost (about US $12 billion), the results still suggests that the efforts made to improve the environment in Beijing will still be increasingly beneficial during a long time after the Olympic Games, making it financially worthwhile in the long run.

The existing studies in the literature provide important foundation for our current study. In this work, we first focus on the relationship between the Beijing 2008 Olympic Games and air quality in Beijing, aiming to evaluate the improvement of air quality before, during, and after the Games. Moreover, we will further explore the impact of air quality improvement on different types of diseases during the Olympic Games. With this study, we would like to provide a closer scrutiny of the impact of Beijing 2008 Olympic Games on the environment and public health with newly available data and systematic model analysis.

CHAPTER 4: DATA

In this study, various data sets are used, which include air pollution index (API) obtained from the Ministry of Environmental Protection of China (MEPC), meteorological data compiled from http://www.tutiempo.com, hospital inpatient records in both respiratory and non-respiratory departments, and socioeconomic information for the Olympics host city Beijing (BJ), and Shijiazhuang (SJZ), the capital city of the neighboring province Hebei. All the data are at the city level except for the hospital data which are at the individual patient level.

4.1 Air Pollution Index (API)

Various types of air quality indices exist in different countries to measure daily air quality, such as Air Quality Health Index, Air Quality Index (AQI), Pollutant Standards Index, and Air Pollution Index (API). Although the terms of these indices are different, the basic idea to use a single index value to measure air quality and/or quantify the level of air pollution is similar. The Chinese government adopts API as a major measure of air quality. Since different countries may choose different indices to evaluate air quality and the acceptable ranges and threshold values for different indices, the World Health Organization (WHO) does not have consolidated standards for the potential impact of different indices values on the public health. Instead, the WHO has established guidelines of concentrations for different pollutants. Specifically, the WHO has different guidelines for one-minute average concentration, one-hour average concentration, eight-hour concentration, 24-hour concentration and annual-average concentration for different pollutants.

API is a composite index for air quality based on the concentration of major air pollutants.[1] The main air pollutants included are sulfur dioxide (SO_2), nitrogen oxides (NOx) and particulate matter with diameters of 10 micrometers or less (PM_{10}). Two additional air pollutants are also included to calculate API in China, namely, carbon monoxide (CO) and ozone (O_3), which are also harmful to public health. Sub-index of each pollutant is calculated either on a daily or an hourly basis in microgram per cubic meter ($\mu g/m^3$) based on its concentration.

According to the definition of Beijing Municipal Environmental Protection Bureau (BMEPB), the value of API is determined by the highest sub-index of major pollutants. For example, if the sub-index of SO_2 is 125, NO_x is 60 and PM_{10} is 85 for a certain day, then the API of that day is 125. A higher value of API indicates heavier air pollution and worse air quality, which may associate with an adverse impact to public health in a greater magnitude. According to the China National Standard of Ambient Air Quality, the classification of air quality and its health impacts by the API ranges are summarized in Table 1. A higher API is associated with increasingly negative health impacts. The

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[1] However, the function to calculate the index using pollutant concentration is not available to us.

impact on public health is negligible if the value of API is below 100. When the API value is over 200, air pollution has significant adverse impact on human activities and health.

The daily API data were obtained from the Ministry of Environmental Protection of China (MEPC) from the first day it reported API value on June 5th, 2000 until December 31st, 2009 which is one year after the Olympic Games.

4.2 Hospital inpatient records

To examine the Olympic effect on public health, hospital inpatient records from both the surgical and respiratory departments are collected from one hospital in each city. Since we focus on evaluating effects of air quality on the respiratory diseases, we need to have some control group that is not likely to be affected by air quality for comparison. Therefore, in addition to the respiratory department we are interested in, we also choose surgical department, for which we think the inpatient record should not be directly related with air quality conditions, to control some endogenous factors that may affect health conditions in general. We obtained the hospital inpatient record data for a wide range of time period. In total, we have 87,671 observations for hospital inpatients from December 25th, 1999 to October 9th, 2011, including 14,349 for Beijing and 73,322 for Shijiazhuang. Table 2 summarizes the hospital inpatients by disease type, hospital department, and city.

4.3 Meteorological data

The literature has documented a sophisticated relationship between meteorology and air pollutants (Elminir, 2005). Eleven weather variables on the daily basis are included as control variables in this study. They are daily average, maximum and minimum temperatures, mean humidity, precipitation, mean wind speed, indicator for rain or drizzle, indicator for rain or drizzle for the day before, indicator for snow or ice pellets, indicator for occurrence of thunder, and indicator for occurrence of fog. Since the air quality in Beijing can be dramatically changed after a period of rain (Streets, et al., 2007), The daily rain conditions and the conditions for the day before are also included in the model. The above meteorological variables are available at http://www.tutiempo.com.

4.4 Socio-Economic data

Economic development is found to affect pollutant concentration (Cai and Xie, 2007). To control for the effects of economic development on air quality, city-specific socioeconomic variables are also incorporated in the analysis. Specifically, the following variables are included: GDP and its growth rate; openness of trade measured by the ratio of total imports and exports to GDP; industry energy consumption; annual emission of SO_2, smoke and dust per gross value of industry (tons per 10,000 CNY); and ownership structure measured by the percentage of state owned enterprises (SOE), collectively owned enterprises (COE), private enterprises, and foreign funded enterprises. The above socioeconomic variables are compiled based on city, province, and national yearbooks of China in the study time periods.

As shown in Table 3, Beijing and Shijiazhuang have similar meteorological conditions, but significantly different economic conditions. For example, relative to Shijiazhuang, Beijing's GDP per capita and openness to trade is almost tripled. The proportions of different types of economic entities in the ownership structure and the pollutant emission per gross industry value are also significantly different between the two cities.

CHAPTER 5: CONCEPTUAL FREAMEWORK AND METHODOLOGY

5.1 Fixed effects and random effects models for panel data

A fixed effects model allows us to control for unobserved time-invariant factors. Thus, the fixed effects model is also named unobserved effects model. Usually, the fixed effects model is simply a linear model with an intercept that only differs for each group (e.g. city in our data set), i.e.

(1) $y_{it} = \alpha_i + x_{it}'\beta + \varepsilon_{it}, \quad \varepsilon_{it} \sim IID(0, \sigma_\varepsilon^2)$

where X_{it} represents independent variables and error term is identically and independently distributed by a standard normal distribution. The coefficients α_i contain the time-invariant effects that vary between groups but are not observed. Also, in the fixed effects model, it is assumed that α_i is correlated with the explanatory variables. The city fixed effects are estimated, which represents all the factors that affect air quality, but are not observed and do not change over time. α_i refers to the unobserved effects for each individual city. Therefore, by using the fixed effects model, we actually eliminate the unobserved city fixed effects and focus on the difference of API within each city.

The random effects model assumes that the unobserved α_i is uncorrelated with explanatory variables. Formally, the model can be formulated as follows.

(2) $y_{it} = \mu + x_{it}'\beta + \alpha_i + \varepsilon_{it}, \quad \varepsilon_{it} \sim IID(0, \sigma_\varepsilon^2); \alpha_i \sim IID(0, \sigma_\alpha^2)$

The random effects model gives the so-called "between estimator", which takes into account the effects between different groups, i.e. cities in our model.

Although the main difference between these two models is whether α_i is correlated with the explanatory variables or not, according to Verbeek (2000), we should not lay too much emphasis on the discussion about the nature of α_i when deciding which model is more appropriate. It is considered that if the individuals in the sample are countries, cities, companies or industries, which are not selected from a random sampling process, we may prefer to use the fixed effects model for the estimation. Also, as suggested by Baltagi (1995), since we focus on two specific cities, Beijing and Shijiazhuang, and the outcome of interest API is based on the policy interventions from these two cities, the fixed effects model is more favorable for the API data. We also conduct the Hausman test to confirm which model is appropriate. The details of the test procedure are described in section 6.2.

5.2 Specification of the fixed effects model for API

The specifications for the fixed effects model to analyze the API data are presented below.

$$\text{(3)} \quad \begin{aligned} API_{it} &= \alpha_i + \beta_1 \cdot t_{bj} + \beta_2 \cdot t_{sjz} + \sum_k \gamma \cdot BJ \otimes period_k + \sum_k \delta \cdot SJZ \otimes period_k + \lambda \cdot W_{it} \\ &+ \eta \cdot E_{it} + \varphi \cdot H_{it} + \psi \cdot Month + \varepsilon_{it} \end{aligned}$$

where the subscript i stands for city and subscript t stands for date. The parameter α represents city-fixed effects and t_{bj} and t_{sjz} stand for city-specific time trend.

$BJ \otimes period_k$ and $SJZ \otimes period_k$ stand for the interaction terms between city dummies and time period dummies for the pre-preparation, preparation, Game, and post-Game periods. W_{it} consists of the meteorological variables, and E_{it} include the socioeconomic variables. H_{it} is a binary variable indicating the heating season. Beijing and Shijiazhuang are located in north China. In this region of China, heating services are supplied by heating companies in winter (usually from November 15th every year to March 15th the next year) through a centralized heating system in urban area every winter. Traditionally, heating companies use coal as the main fuel, which is the major source of SO_2, PM_{10}, and NO_2 (Chin, 1996). We therefore include heating as a dummy variable to analyze the impact of heating on air quality. *Month* consists of month dummies. The literature shows that seasonal factors not only affect the regional air quality itself, but also have the trans-regional influence (Brajer and Mead, 2003, Chen, et al., 2007, Chin, 1996, Elminir, 2005, Wang, et al., 2010). Therefore, month dummies are also incorporated to reflect the seasonal fluctuations of air quality.

5.3 Logistic regression model for inpatient records

Logistic model is the most popular model for dealing with binary data (Agresti, 1996). It is a special case for General Linear Model (GLM), and it is also named as "logit model". In logistic model, the outcomes are either 1 or 0, which stand for "success" or "failure". It is usually formulated as

(5) $$logit[\pi(x)] = \log\left(\frac{\pi(x)}{1-\pi(x)}\right) = \alpha + \beta x$$

where *π(x)* is the probability of success at value *x* ranges between zero to one, and *logit [π(x)]* can be any real number. From the formula above, we can derive the following formula for the success probability, which is

(6) $$\pi(x) = \frac{\exp(\alpha+\beta x)}{1+\exp(\alpha+\beta x)}$$

And we can further derive the expression for marginal effect. For continuous dependent variable, the formula is

(7a) $$ME_{\mathrm{i}} = \frac{\partial \pi(x)}{\partial x_i} = \beta_i \cdot \pi(x) \cdot [1-\pi(x)]$$

and for binary dependent variable which takes values 0 and 1, the formula is

(7b) $$ME_i = \pi(x_1 = 1) - \pi(x_1 = 0)$$

The logistic regression model is employed for the inpatient records analysis in order to understand the relationship between air quality and public health. The disease type is chosen as the response variable in the analysis. There are two types of diagnoses, i.e., acute disease or chronic for both surgical and respiratory department indicated by S and R, respectively. The value of outcome variable is 1 if the disease type of certain patient is acute or chronic, and 0 otherwise. The model specification is the following.

(8a) $$\begin{aligned} Acute = {} & \alpha_0 + \sum_x \beta_x \cdot BJ \otimes period_x \otimes R + \sum_x \gamma_x \cdot BJ \otimes period_x \otimes S \\ & + \sum_x \delta_x \cdot SJZ \otimes period_x \otimes R + \sum_x \varphi_x \cdot SJZ \otimes period_x \otimes S \\ & + \eta \cdot API + \omega \cdot year + \lambda \cdot month \end{aligned}$$

$$\text{(8b)}\quad \begin{aligned} Chronic = \alpha_0 &+ \sum_x \beta_x \cdot BJ \otimes period_x \otimes R + \sum_x \gamma_x \cdot BJ \otimes period_x \otimes S \\ &+ \sum_x \delta_x \cdot SJZ \otimes period_x \otimes R + \sum_x \varphi_x \cdot SJZ \otimes period_x \otimes S \\ &+ \eta \cdot API + \omega \cdot year + \lambda \cdot month \end{aligned}$$

where Acute and Chronic are the two dummy variables representing disease types. The value of the corresponding variable is 1 if certain patient is diagnosed to have acute (chronic) disease in equation (8a) (equation (8b)), and zero otherwise. $BJ \otimes period_x \otimes R$, $BJ \otimes period_x \otimes S$, $SJZ \otimes period_x \otimes R$ and $SJZ \otimes period_x \otimes S$ are interaction terms for city, department, and periods. BJ and SJZ stand for the studied cities, Beijing and Shijiazhuang, respectively. The capital letter R and S represent either respiratory department (R) or surgical department (S). The variables year and month are the year and month dummies when certain patient was hospitalized.

5.4 Difference-in-difference approach

To study the different effects on air quality and public health from the two cities during the study periods, the difference-in-difference (DID) approach is employed. The DID approach is a quasi-experimental technique widely used in marketing, finance, economics and other social science areas to estimate the effects of a treatment, such as a policy intervention, in a given time period (Athey and W. Imbens, 2006). The DID approach measures not only the differences before and after the treatment is introduced, but also the differences between the two groups which are named as the treatment group (experiment group) and the control group. The treatment group is where the treatment is introduced and the control group is supposed not to be exposed to the treatment. Within each group, there should be some explanatory variables that stay the same for all the individuals, such as the treatment or the policy being studied, while the dependent variables may vary across group members (Donald and Lang, 2007). The DID approach employs the control group to control for other confounding factors beside the treatment, which may also influence the dependent variable. The pre-assumption and the criteria to select the control group is that the changes, except for the treatment itself, occurring along the time should be identical between the treatment group and the control group.

For the API model in our study, Beijing, the host city of the XXIX Olympic Games, is the treatment city, and its neighborhood city, Shijiazhuang, is selected as the control city. For the four study periods, the Game period is set as the base period. The API of the Game period is compared to each of the other periods to observe whether there is an improvement of air quality in the Game period. In addition, we also compare the API differences for each period relative to the Game period between the two cities to obtain the information regarding which city has a greater improvement of API, and whether the improvement could be significantly related to the Olympic Games. There are two layers of differences which constitutes the key idea of Difference-in-Difference (DID) method. The DID method used in this case can be described by the following intuitive formula.

(9) $$DID = (BJ_{Pi} - BJ_{Game}) - (SJZ_{Pi} - SJZ_{Game})$$

The first layer difference is between different periods and the Game period, while the second layer difference is between the two cities. A positive value of this DID value means the improvement of air quality in Beijing for the Game period compared with each of the other periods is greater than that for Shijiazhuang, and vice versa.

For the inpatient record data, we also did similar comparisons using DID approach. In the logistic model for inpatient record, the marginal effects representing the risks of diseases are grouped by different departments (respiratory or surgical) and different disease types (acute or chronic). In each of the four groups (acute respiratory, acute surgical, chronic respiratory, chronic surgical), we compare risk change for different periods relative to that in the Game period in each city. The DID approach is further applied in each group to investigate the difference in the risk change between the two cities under each disease group condition, and to evaluate if the difference between the two cities is significant. Finally, we can compare the DID analysis results among the four groups to demonstrate the different impacts of the Olympic Games on different disease groups. These procedure leads to the Triple Difference method, which can be described by the following equation with three layers of differences.

(10) $$\text{TriD} = \left[\left(R_{BJ_{Pi}} - R_{BJ_{Game}}\right) - \left(R_{SJZ_{Pi}} - R_{SJZ_{Game}}\right)\right] - \left[\left(S_{BJ_{Pi}} - S_{BJ_{Game}}\right) - \left(S_{SJZ_{Pi}} - S_{SJZ_{Game}}\right)\right]$$

As shown in the above formula, the first layer difference is again between each period and the Game period. The second layer of difference is between the two cities, Beijing (BJ) and Shijiazhuang (SJZ). And the third layer of difference is between the two departments, i.e. respiratory (R) and surgical (S) departments. A positive value of this Triple Difference indicates that relative to other periods, the improvement of the risk in the Game period in Beijing compared to that in Shijiazhuang in respiratory department is greater than the improvement in surgical department, and vice versa. This Triple Difference method is applied for both acute and chronic diseases. In this way, we are able to identify if there is an “Olympic effect” on the risk of certain disease type, department, in certain city.

CHAPTER 6: Empirical Analysis

6.1. Empirical Analysis of Air Quality

6.1.1 Summary Statistics of API by City and time period

The API data consist of 3497 daily observations from June 5th, 2000 to December 31st, 2009. The Ministry of Environmental Protection of China (MEPC) reported its first API value on June 5th, 2000. The observations are separated into four specified periods: the pre-preparation period, the preparation period, the Game period, and the post-Game period.

Table 4 shows a regional difference and time variant pattern of API. Generally speaking, the average API for the two cities are statistically similar except for the Game period when average API in Beijing is slightly lower than in Shijiazhuang and the pre-preparation period when the average API for Shijiazhuang was higher than that for Beijing by almost 30 percent. The average API was the lowest during the Game period in both cities. However, the average API increased during the post-Game period compared with that in the Game period, which is likely to be affected by the winter heating. That is, the elevated API in the post-Game periods, especially 2-3 month after and 4-6 months after the Game, does not necessarily imply that the Olympic effect on air quality is short-lived due to the confounding factor of winter heating.

According to the Independent Environmental Assessment by United Nations Environmental Program (UNEP, 2009), a API value less than 100 is defined as good air quality in all countries using API system. In China, a day with API less than 100 is described as “Blue Sky Day”. Table 4 also reports the percentage of days with API above 100 (bad air quality day). The proportion of bad air quality days decreased before the Game period and then rebounded afterwards. The proportion of bad air quality days was especially small during the Game period for both cities.

Figure 1 demonstrates the 30-day moving average of API for each city. The daily API was relatively lower during the Game period than that in other periods in both cities, which are consistent with Table 4. It also shows a significant seasonal variation of API – higher in winter but lower in summer. Winter heating is a potential significant contributor to lower air quality in winter for both cities. Thus, to estimate the Olympic effect I need to control for seasonality as well as the heating season. Moreover, from the 30-day moving average of API in Figure 1, we can also observe the change in volatility of the data. It is seen that during the Game period, the volatility of API appeared to be smaller, which may indicate that the improvement is relatively more stable.

Figure 2 shows the kernel density of the daily API for both cities over the study periods. For both cities, the mean of API in four different periods show that air quality is improved in the Game period compared with both the pre-preparation period and the preparation period, but the improvement faded or even disappeared in the post-Game period. On the other hand, there are some questionings that Chinese government may untruthfully report the API values since air quality is one of the evaluation criteria of the government officials' performance. For example, the API values slightly higher than 100 might be reported as values slightly lower than 100, resulting in more "Blue Sky Days" which is considered as better "achievement" for the government officials. To clarify if the falsely reported API exists, we may check the kernel density curves in Figure 2. If many API values slightly above 100 are reported as values slightly lower than 100, there will be some jump in density at the left of 100 and some drop at the right of 100, making the curve not smooth. In Figure 2, we can see that all the curves are smooth and no jump or drop is observed, which suggests that the API data are not falsely reported.

The above preliminary analysis finds that the API is generally improved in both cities during the Olympic Games. To better investigate the effects of the Olympic Games on the air quality, model-based data analysis is necessary.

6.1.2 Non-parametric analyses

Table 5 reports the results of mean tests of API by period, between city, and by city and period. First, columns (1) and (2) shows that, relative to that in the Game period, the average API values for other periods were significantly higher for each city, which indicates a possible improvement of air quality during the Olympic Games for both cities.

However, the API values rebounded after the Game period, but not to the level of the two pre-game periods yet. Second, column (3) shows the regional difference in API despite that the API value was not statistically different in the game period between two cities. The Difference-in-Difference (DID) results are shown in column (4). It is observed in column (4) that relative either to the preparation period or the post-Game period, the improvement of API in the game period was greater for Beijing than Shijiazhuang. However, Shijiazhuang had much higher API in the pre-preparation period compared with the game period. The significant improvement in Shijiazhuang in the Game period relative to that in the pre-preparation period may due to its initially much worse air quality condition for Shijiazhuang.

Similar mean tests are conducted for the proportion of “bad days” with an API value higher than 100 and the results are shown in Table 6. The results on the bad days in Table 6 are consistent with the results on API presented in Table 5. First, the mean test between periods shows the air quality condition is worse in all the other periods than the Game period since these periods have significantly higher percentage of “bad-day” compared with the Game period. Second, according to the mean test between the two cities for the pre-preparation period, we can detect that Beijing actually had a lower proportion of “bad-day”. In other words, Beijing has a better air quality condition in that period than Shijiazhuang, which is also statistically significant. However, in the preparation and post-Game periods, Beijing has a significantly worse air quality condition than

Shijiazhuang. These results are consistent with the findings in Table 5. The only difference in the mean test between the two cities for each period is the results for the Game period. Although the results for the Game period from Table 5 and 6 have opposite signs, they are not statistically significant. In the last column of Table 6, the DID results again demonstrate that the improvement of air quality in the Game period relative to the preparation period and post-Game period in Beijing is significantly greater than that in Shijiazhuang. Also, similar to the analysis of the last column in Table 5, although Shijiazhuang has a significantly greater air quality improvement in the Game period relative to the pre-preparation period than Beijing, such improvement is based on much worse air quality conditions during the pre-preparation period in Shijiazhuang.

6.1.3 Regression Analyses on API

The regression analysis is based on equation (3) specified in section 5.2. The following tests are conducted for model specification. First, the Hausman test is conducted to detect the systematically difference between the fixed effect model and the random effect model. Three model specifications with different sets of control variables are considered. The results of Hausman test suggest that the third specification including all the available variables favors random effects model, while the other two specifications with less control variables favor fixed effects model. However, since two of the three model specifications favor fixed effects model, for the convenience of comparison of the three model estimations, we only present the results of fixed effects model for all the three specifications.

Second, a joint F test is conducted with respect to the month dummies, the meteorological variables, and the socioeconomic variables, respectively. The test results show that each of these three groups of variables is jointly significantly non-zero, which provides supporting evidence for including these control variables in the model specifications.

Table 7 presents the estimations of the three specifications for the API model, and each column is corresponding to one specification. All of the three specifications include the interaction terms between city dummies and time period dummies, which are the main focus of the analysis. The city-specific time trend is also included. The first specification controls for the fixed effect of seasonal variation and heating season by including dummy variables for months and heating season. Eleven meteorology variables are added to the second specification to control for weather variation and effects on air quality. In the third specification, ten more socioeconomic variables are taken into account to control for the effects from the changes of social and economic factors on API.

As shown in Table 7, we can see that although the values are very close to zero and some of them are not significant at any of the statistical levels, the date fixed effect on API for both cities is negative, which reflects that the air quality becomes better in both cities when it is approaching the Game time. The coefficients for the interaction terms stand for the first-differencing between the other periods and the Game period for each city. The results show the API is significantly lower in the game period relative to other periods for Beijing with exceptions for the coefficients of the preparation period in the second specification and the post-Game period in the third specification for Shijiazhuang. However, for those exceptions, the coefficients still have an expected sign but not statistically significant. On the other hand, the coefficients of the interactive terms for dummy variables between Shijiazhuang and time periods are not statistically significant, which suggest that air quality in Shijiazhuang was less likely to be improved in the Game period. Thus, the results suggest the statistically significant Olympic effect on air quality in Beijing.

To obtain more detailed information, we look at the estimations for each period and city separately. We first focus on the coefficients for Beijing. In the preparation period, all of the three specifications show that the average value of API in the preparation period of Beijing is significantly higher than that in the Game period. This may demonstrate that the measures implemented during the Game period played a part in the air quality improvement. The coefficients for the post-Game period of Beijing are all positive, which may indicate that although the measures improved the air quality in the Game period, the effect did not last long. In other words, the air quality bounded back after the Olympic Game. However, the positive coefficients are not statistically significant at any level, suggesting that the bound back is not statistically significant. Therefore, it may imply that the measures imposed during the Olympic Games do lead to relatively long term effects on the air quality improvement. Meanwhile, by examining the coefficients for Shijiazhuang, we can find that most of the coefficients are not significant, which may indicate that air quality for Shijiazhuang in the Game period is not significantly different from that in the other periods. In other words, there was no significant improvement of air quality in Shijiazhuang during the Game period.

To further examine the conclusions we obtained above, DID test is conducted and the results are presented in Table 8. Columns 1 and 2 shows the coefficients for Beijing and Shijiazhuang, respectively; and column 3 demonstrates the DID estimates. The DID estimates reflect the variations of API in both time dimension and city dimension. By examining the DID estimates, we can test if the changes in API between each period compared and the Game period for the two cities are significantly different. For example, the results for testing the DID estimates comparing the pre-preparation and post-Game period with the Game period are not significant at any statistical levels, while the results comparing preparation period with the Game period are significant for all the three specifications. Thus, it is implied that the improvement of air quality in the Game period compared to the preparation period for Beijing is significantly greater than that for Shijiazhuang. Table 8 shows that the DID estimates for each period in the three specifications are all positive, which indicates that the improvement of air quality in

Beijing for the Game period compared with each of the other periods is greater than that for Shijiazhuang. Therefore, the above discussion suggests that the measures imposed to improve air quality in Beijing during the Game period are effective in improving air quality measured by API.

The estimation results presented in Table 7 also show that other explanatory variables such as month, weather and socioeconomic variables may explain the API variation as well. First, the positive coefficients of month dummies, most of which are statistically significant, suggest that API in August is lower (better air quality) compared with other months. In north China, spring and autumn are the two seasons with high occurrence of dust storms, which partly explains why the months of these two seasons have worse air quality than August. And in winter, the heating system increases the emission of air pollutants. Furthermore, summer has larger amount of precipitation compared with other seasons. The insignificance of July and September, which are the months before and after August, may due to the similarity in weather conditions and other factors. Second, the results for the meteorological variables show that the occurrence of snow, rain, and rain in the day before can significantly improve the air quality. Keeping the other variables constant, the higher the maximum or the minimum temperature is, the higher the API is, which represents a worse air quality. Also, the more precipitation there is, the better the air quality would be. However, high humidity is not helpful for improving the air quality. Third, the results of the socioeconomic variables show that, on one hand, along with the economy development, which is inferred from the increase of GDP, the air quality is getting worse. This result is consistent with previous literature which suggests that air quality would deteriorate along with the economy development (Cai and Xie, 2007). On the other hand, if the openness of economy, GDP growth rate, or the industry energy consumption increases, the air quality is getting better. For the structure variables, we set the percentage of state owned enterprises (SOE) as a base. The results indicate that a larger proportion of SOE helps to improve the air quality. This may be due to a better availability of financial resources and pollution treatment equipment owned by SOE. Other possibility may be that SOE takes a larger proportion in the ownership structure in the previous years when the air quality is relatively better.

6.2. Empirical Analysis on Public Health

6.2.1 Summary Statistics of the Hospital Inpatient Data

Figure 3 shows the percentage of inpatients for the surgical and respiratory departments over the four periods by city and disease type (chronic vs. acute). The percentage of respiratory inpatients is significantly higher in the post-Game period than other periods in Shijiazhuang for both acute and chronic diseases. In comparison, the percentage of inpatient in the post-Game period in Beijing does not demonstrate an obvious difference than other periods. The above results suggest that there might be a major bound back in air quality after the Olympic Games for Shijiazhuang, while might not for Beijing. For surgical department, on the other hand, there is no obvious pattern shown in the figure for both cities and disease types.

6.2.2 Logistic model analysis for inpatient record model

In our analysis, two logistic models for the inpatient record data are estimated to capture the effects of the Olympic Games as well as air quality on different types of diseases. Table 9 shows the model estimation results and marginal effects of the logistic models for inpatient records. In logistic models, the coefficients and marginal effect gives similar information. Therefore, we mainly focus on the marginal effects in the following discussion since it is more intuitional for us in this analysis. The marginal effects for API indicate that the increase of API, which means a worse air quality, would lower the risk of acute diseases when keeping all the other variables the same, although the value of the marginal effect is trivial. It also indicates that the increase of API has no significant effect on chronic diseases. The marginal effects for the year dummies show that the risk of acute disease is significantly lower in the years 2003, 2004, and 2009 compared with the year 2008, and the risk of chronic disease is significantly lower in the years 2003, 2004, and 2006 while significantly higher in the years 2009 and 2011. The marginal effects for the month dummies show that the risk of acute disease is significantly lower in March and October compared to August, while significantly higher in June and September. For the risk of chronic disease, it is significantly lower in July while significantly higher in March, May, October and November, ceteris paribus.

The DID estimation results calculated from the model estimation and marginal effects analysis are shown in Table 10. In the table, the two columns under “Mean test between periods” label reflect the difference of marginal effects, corresponding to both cities, for each period compared to the Game period given each disease type and department. First, we can examine the results for acute disease. In the table, for the respiratory department, we can see that the values of the marginal effect difference for Beijing in preparation period and post-Game period are both negative, meaning that the risk of acute respiratory disease in Beijing in these two periods is lower than that in the Game period, yet such difference is not significant according to the test results. Also, the results for Shijiazhuang reflect similar trends for acute respiratory disease that the risk for Shijiazhuang in both preparation and post-Game periods is lower than that in the Game period, but not significant. However, if we compare the difference of marginal effects between the two cities, which is indicated by the DID estimates in the last column in Table 10, it is found that the increase of the risk of acute respiratory disease during the Game period for Beijing is actually statistically significantly lower than that for Shijiazhuang. At the same time, similar comparison for the surgical department results can be done. As shown in Table 10, the values of the marginal effect difference in preparation and post-Game periods compared to the Game period for both cities are positive, which suggests that the risk of acute surgical disease decreased during the Game period for both the two cities, and such decrease is statistically significant. But if we look at the DID estimates, the difference of the risk decrease between the two cities is not significant for acute surgical disease. Therefore, we can infer from the above discussion that the risk increase of acute respiratory disease for Beijing during the Game period is statistically significantly lower than that for Shijiazhuang. Also, in the analysis of API model, we already observed that the air quality during the Game period is improved. Therefore, we may conclude that the lower risk increase of acute respiratory disease in Beijing during the Olympic Games is related to the improvement of air quality.

Meanwhile, we can also examine the results for chronic disease. For the respiratory department, we can see the risk of chronic respiratory disease is decreased during the Game period for both cities. However, the DID estimates indicate that the difference of the risk decrease between the two cities is not significant. While for the surgical department, the risk of chronic surgical disease has different changes for different cities and period, but only the change between preparation period and Game period in Shijiazhuang is significant. However, in the last column, the DID estimates results shows that the difference of the risk changes between the two cities is not significant for all the periods. Therefore, it is suggested in the results that the risk of chronic disease might not be closely related to the Olympic Games.

Moreover, based on the DID estimates results above, we further computed the Triple-Difference estimates, which are summarized in Table 11. As we can see in the table, the four Triple-Difference estimates for both acute and chronic diseases and for both preparation and post-Game periods are all positive, which suggest that relative to either preparation period or post-Game period, the improvement of the risk in the Game period in Beijing compared to that in Shijiazhuang in respiratory department is greater than the improvement in surgical department. This result is consistent with our intuitive expectation that the improved air quality may lead to decreased risk of respiratory diseases. Therefore, based on the above results, we may conclude that the improvement in air quality in Beijing due to the Olympic Games also have positive effects on the occurrence of respiratory diseases.

CHAPTER 7: CONCLUSION

This thesis employs a difference-in-difference (DID) approach to examine the Olympic effects on air quality and public health. Two particular data sets are used to achieve the purpose, air quality data measured by daily air pollution index (API) and hospital inpatient records (HIR) before and after the Olympic Games for the Olympic city (Beijing) and non-Olympic city (Shijiazhuang, the capital city of Hebei province). The HIR are collected from both surgical and respiratory departments in one main hospital of each city. The major conclusions of this study are presented below.

First, based on the analysis of the daily API data, the air quality in Beijing was improved compared to Shijiazhuang during the Game period relative to the other time periods. The air quality improvement also lasted to the post-Game period but in a small magnitude. The DID analysis also suggests that the improvement of API in the Game period compared to each of the other periods in Beijing is greater than that in Shijiazhuang. The improvement in air quality implies that the air pollutant control policies implemented during the Beijing Olympic Games are effective.

Second, the analysis of the inpatient record data finds that although the risk of acute respiratory diseases increases for both Beijing and Shijiazhuang during the Game period, the increase of risk in Beijing is significantly lower than that in Shijiazhuang. The Triple-Difference estimates also suggest that the improvement of the risk in respiratory department is higher than that for surgical department. Therefore, it can be considered that given all other factors consistent for both cities, the lower risk of respiratory diseases in Beijing might be related to the improvement of air quality during the Olympic Games due to the implementation of the air pollutant control measures.

In addition, from the policy making perspective, the findings suggest that the air pollution control measures implemented in Beijing during the Olympic Games, such as traffic control, construction reduction, and industrial plant restrictions and closures, did improve air quality and to some degree reduced the risk of acute respiratory diseases. But it is unclear how long the reduced positive effect can last, which could be one of the future research directions.

Although this study focuses on the city of Beijing, the conclusions and findings may also be helpful for other cities with similar situation. And we know, major polluted cities, such as Beijing in China and New Delhi in India, are mainly in developing countries and usually have large populations. The source of air pollution are similar in these cities, including traffic, construction, and industrial emissions. Therefore, this study may provide some useful clues or suggestions to better understand similar air quality and public health problems in other cities, and to improve air quality as well as urban environment using similar strategies.

In terms of the possible directions for the future study, I have the following suggestions. First, since the control city (Shijiazhuang) is the capital city of Hebei. Hebei is a neighboring province of Beijing and some pollution control policies were also implemented in Hebei to prepare for the Olympic Games, the Olympic effect is partly confounded. The future research may require a "real" control city that has similar geographic and climate conditions as Beijing but did not implement pollution control for the Games to control for the confounding effect. For the same reason, the results in this thesis need to be interpreted with caution. Second, in this work, we could not conduct complete and systematic model analysis since the inpatient record data is very preliminary which only include one hospital in each city. In the future, if we can obtain more hospital data from the two cities, more thorough analysis can be done to investigate the correlations between Olympic Games and public health.

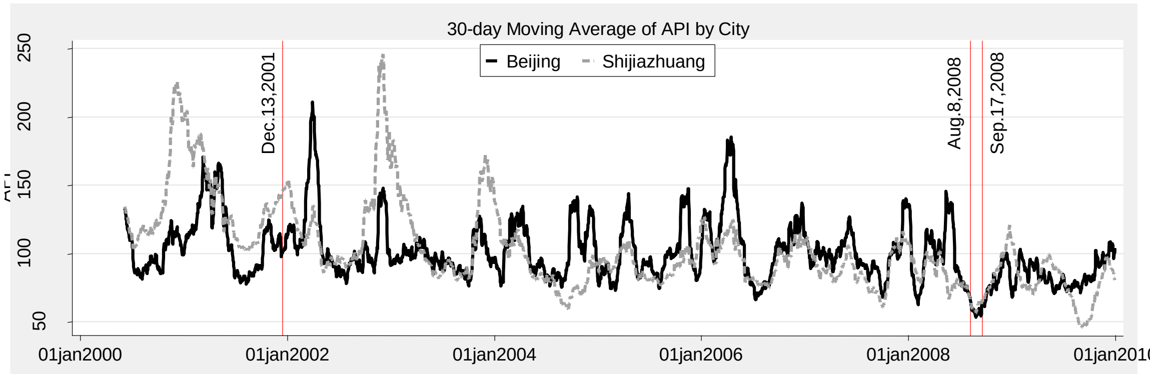

Figure 1. 30-day moving average of API by city

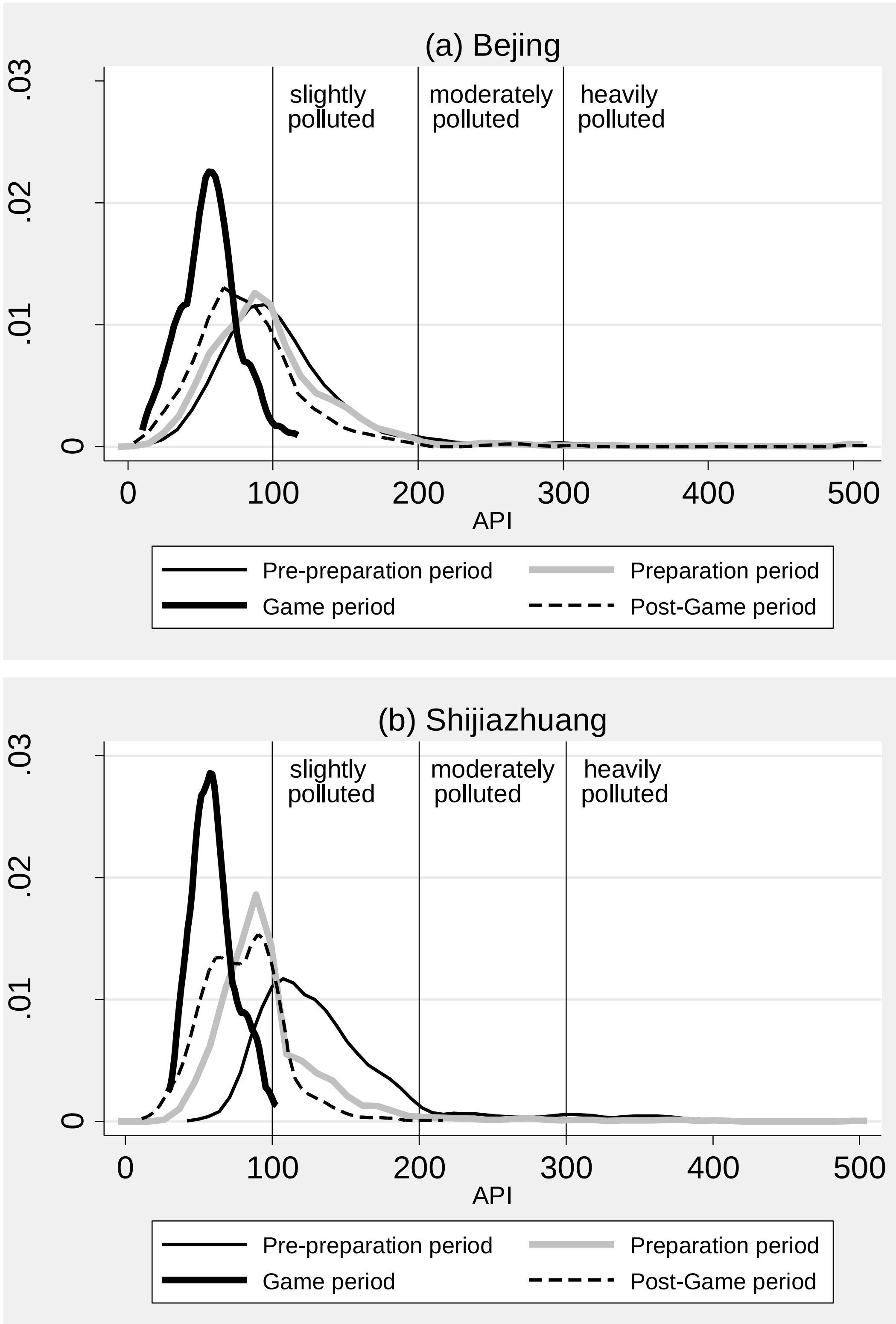

Figure 2. Kernel density of API by city and period

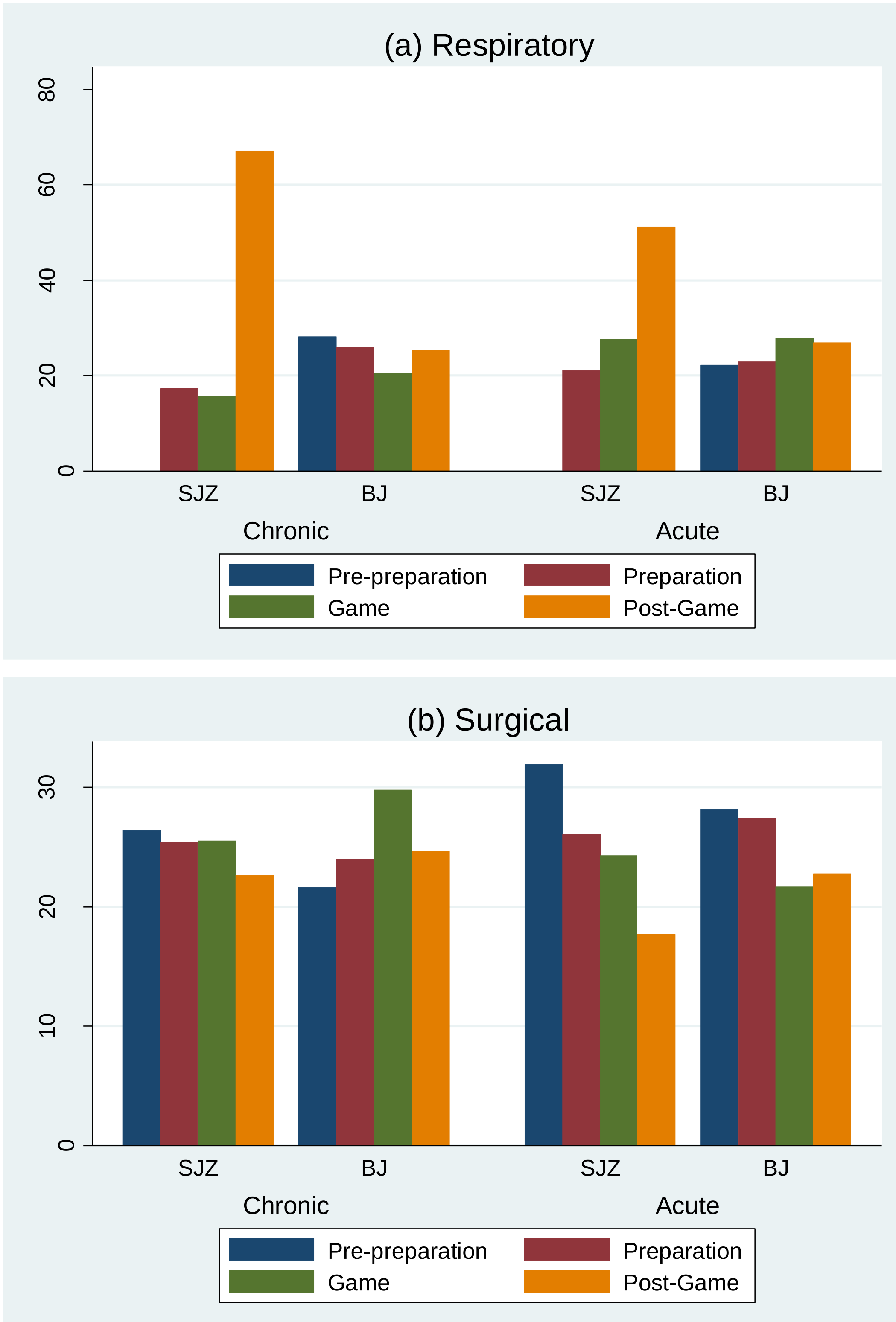

Figure 3. Percentage of inpatients by disease type, period and city

Table 1. API and Its Health Impacts

API	**Level**	**Condition**	**Impact to health of human beings**
0～50	I	Excellent	Good for normal activities
51～100	II	Good	Moderate for normal activities
101～150	III1	Slightly Polluted	Symptoms may occur among sensitive groups after long-term exposure
151～200	III2	Lightly polluted	Symptoms may occur among healthy groups after long-term exposure
201～250	IV1	Moderately polluted	Symptoms may occur among healthy groups after certain-time exposure
251～300	IV2	Heavily Pollution	Symptoms of cardiopath or pulmonary disease patient significantly exacerbated after certain exposure
>300	V	Severely Polluted	Strong symptoms apparently occur among healthy groups, diseases appear earlier

Source: Ministry of Environmental Protection of the People's Republic of China

Table 2. Inpatient record data: Dec. 25, 1999 to Oct. 9, 2011

	Beijing		**Shijiazhuang**	
	Respiratory	**Surgical**	**Respiratory**	**Surgical**
Acute	2,357	2,231	4,698	12,733
Chronic	4,382	3,770	2,392	34,400
Indeterminate	163	1,446	1,397	17,702
Sub-total	6,902	7,447	8,387	64,835
Total	14,349		73,322	

Source: Major hospital in Beijing and Shijiazhuang

Table 3. Summary Statistics of Control Variables: Meteorological and Economic Variables (June 5th, 2000 to December 31st, 2009)

Variable	Shijiazhuang		Beijing	
	Mean	Standard Deviation	Mean	Standard Deviation
Meteorological Variables				
Mean Temperature (° C)	14.94	10.79	13.21	11.16
Maximum Temperature (° C)	19.67	11.27	18.83	11.51
Minimum Temperature (° C)	9.75	10.35	7.38	11.18
Mean humidity (%)	55.16	20.45	53.94	21.79
Precipitation amount (mm)	1.64	7.00	1.46	5.74
Mean visibility (Km)	11.71	4.75	9.60	3.80
Mean wind speed (Km/h)	5.57	2.32	9.68	4.67
Maximum sustained wind speed (Km/h)	10.03	4.32	20.97	9.90
Indicator for occurrence of: Rain or Drizzle	0.20	0.40	0.24	0.43
Indicator for occurrence of: Rain or Drizzle	0.20	0.40	0.24	0.43
Indicator for occurrence of: Snow or Ice Pellets	0.03	0.17	0.04	0.19
Indicator for occurrence of: Thunder	0.04	0.20	0.09	0.28
Indicator for occurrence of: Fog	0.03	0.19	0.07	0.25

Socioeconomic Variables				
GDP (100,000,000 CNY)	1835.65	665.70	7215.62	2959.19
GDP growth rate	0.13	0.04	0.16	0.03
Openness of trade: (Import+Export)/total GDP	0.66	0.17	1.33	0.21
Percentage of state owned enterprises (SOE) in ownership structure	17.35	6.65	12.33	6.80
Percentage of collectively owned enterprises (COE) in ownership structure	11.93	5.99	2.23	1.54
Percentage of private enterprises in ownership structure	28.98	16.20	4.66	1.20
Percentage of Hong Kong, Macao, Taiwan and foreign funded enterprises in ownership structure	8.31	2.45	43.02	2.18
Industry energy consumption (10,000 standard coal equivalent (SCE))	3588.97	980.36	2472.68	139.54
Emission of SO2 per gross value of industry	102.30	48.08	20.34	13.54
Emission of smoke per gross value of industry	54.58	36.21	5.47	4.49
Emission of dust per gross value of industry	85.21	70.43	7.26	6.44

Note: Numbers in parentheses are units.

Table 4. Summary of daily average API by treatment periods and cities (June 5th, 2000 to December 31st, 2009)

Period	Beijing	Percentage of days with API above 100 for Beijing	Shijiazhuang	Percentage of days with API above 100 for Shijiazhuang
Pre-preparation	109.01	47.30	139.93	76.62
	(56.03)	(0.50)	(57.28)	(0.42)
Preparation	102.89	36.50	100.08	29.55
	(58.88)	(0.48)	(47.53)	(0.46)
Game	56.37	2.44	59.98	0.00
	(19.72)	(0.16)	(14.91)	(0.00)
Post-Game	84.09	22.77	79.81	15.32
	(42.75)	(0.42)	(26.76)	(0.36)
Total	100.79	35.97	103.22	34.77
	(56.85)	(0.48)	(50.06)	(0.48)

Note: Numbers in parentheses are standard deviation.

Table 5. Mean tests of API by treatment period and city

Period	Mean test between periods (Base = the Game period)		Mean test between two cities for each period (Base=Shijiazhuang)	Difference in Difference
	Beijing	Shijiazhuang		
	(1)	(2)	(3)	(4)
Pre-preparation	52.64	79.96	-30.92	-27.31
	(0.00)	(0.00)	(0.00)	(0.00)
Preparation	46.53	40.10	2.82	6.42
	(0.00)	(0.00)	(0.01)	(0.06)
Game	.	.	-3.61	.
	.	.	(0.13)	.
Post-Game	27.73	19.83	4.29	7.89
	(0.00)	(0.00)	(0.02)	(0.20)

Note: Numbers in parentheses are P-value for the mean test.

Table 6. Mean tests of "bad-day" by treatment period and city

Period	Mean test between periods (Base = the Game period)		Mean test between two cities for each period (Base=SJZ)	Difference in Difference
	BJ	SJZ		
	(1)	(2)	(3)	(4)
Pre-preparation	0.45	0.77	-0.29	-.0.02
	(0.00)	(0.00)	(0.00)	(0.00)
Preparation	0.34	0.30	0.07	0.05
	(0.00)	(0.00)	(0.00)	(0.00)
Game	.	.	0.02	.
	.	.	(0.32)	.
Post-Game	0.20	0.15	0.07	0.05
	(0.00)	(0.01)	(0.00)	(0.01)

Note: Numbers in parentheses are P-value for the mean test.

Table 7. Estimation results of API models

Explanatory variables	1	2	3
Date fixed effect			
Tbj	-0.00	-0.00***	-0.03*
	(0.00)	(0.00)	(0.02)
Tsjz	-0.02***	-0.02***	-0.03
	(0.00)	(0.00)	(0.02)
Interaction terms between cities and periods (base=Game period)			
Beijing*pre-preparation period	30.26***	23.59***	19.03
	(8.98)	(8.51)	(12.24)
Beijing*preparation period	24.36***	21.60***	21.60***
	(8.10)	(7.70)	(8.15)
Beijing*post-Game period	7.22	10.83	9.51
	(8.18)	(7.77)	(8.43)
Shijiazhuang*pre-preparation period	18.28**	11.32	9.85
	(8.98)	(8.32)	(10.37)
Shijiazhuang *preparation period	0.14	-2.13	1.97
	(8.10)	(7.51)	(7.93)
Shijiazhuang *post-Game period	3.01	1.97	-2.21
	(8.18)	(7.58)	(8.21)
Months dummies (base=August)			
January	33.44***	132.62***	127.66***
	(4.13)	(6.20)	(7.23)
February	24.38***	112.68***	108.30***
	(4.18)	(5.77)	(6.61)
March	33.62***	109.21***	105.96***
	(3.24)	(4.62)	(5.34)
April	34.58***	85.91***	83.88***
	(2.95)	(3.67)	(4.25)
May	21.57***	50.57***	49.06***
	(2.92)	(3.04)	(3.43)
June	12.39***	24.28***	22.26***
	(2.88)	(2.73)	(2.96)
July	3.05	1.37	1.12
	(2.84)	(2.65)	(2.77)
September	4.56	23.96***	24.83***
	(2.83)	(2.83)	(2.92)
October	17.08***	63.85***	65.89***

	(2.85)	(3.64)	(3.81)
November	36.68***	108.79***	110.02***
	(3.26)	(4.93)	(5.17)
December	44.54***	134.75***	136.35***
	(4.07)	(5.97)	(6.31)
Heating (Nov 15th-Mar 15th)	-2.29	8.70***	9.97***
	(2.91)	(2.84)	(2.88)
Meteorological variables			
Mean temperature		-1.85**	-2.16***
		(0.73)	(0.74)
Maximum temperature		2.97***	3.04***
		(0.45)	(0.46)
Minimum temperature		2.55***	2.82***
		(0.42)	(0.43)
Mean humidity		0.74***	0.72***
		(0.05)	(0.05)
Precipitation amount		-0.29***	-0.28***
		(0.10)	(0.10)
Mean wind speed		1.53***	1.49***
		(0.19)	(0.20)
Rain or drizzle		-4.51**	-4.73***
		(1.80)	(1.84)
Rain or drizzle for the day before		-17.44***	-17.17***
		(1.51)	(1.54)
Snow or ice pellets		-12.40***	-12.23***
		(3.31)	(3.38)
Thunder		0.83	0.93
		(2.65)	(2.71)
Fog		36.05***	38.12***
		(2.63)	(2.72)
Socioeconomic variables			
GDP			0.01*
			(0.00)
GDP growth rate			-30.86
			(38.22)
Industry energy consumption			-0.01
			(0.01)
Openness of trade: (import+export)/GDP			-1.52
			(7.33)

Structure (base=percentage of collectively owned enterprises)			
Percentage of state owned enterprises			3.08
			(2.51)
Percentage of private enterprises			2.12**
			(0.99)
Percentage of Hong Kong, Macao, Taiwan and foreign funded enterprises			2.01***
			(0.57)
Percentage of other enterprises			0.53
			(0.58)
Emission			
Emission of SO2 per gross value of industry			0.38**
			(0.19)
Emission of smoke per gross value of industry			-1.06
			(0.79)
Emission of dust per gross value of industry			0.30
			(0.19)
Constant	83.95***	-63.52***	-159.93**
	(6.35)	(9.27)	(65.11)
No. of observations	6994	6810	6609
Within R^2	0.15	0.28	0.29
Between R^2	1.00	1.00	1.00
Overall R^2	0.06	0.17	0.13
AIC	74433.33	71250.53	69152.79
BIC	74577.24	71468.97	69445.02
** p<0.10, ** p<0.05,*** p<0.01			

Note: Numbers in parentheses are standard error (SE).

Table 8. DID estimates for the Olympic effect on API

Specification	Period	Mean test between periods (Base = the Game period)		DID (BJ-SJZ)
		BJ	SJZ	
		(1)	(2)	(3)
1	Before-Game	30.26***	18.28**	11.98
		(0.00)	(0.04)	(0.34)
	Preparation-Game	24.36***	0.14	24.22**
		(0.00)	(0.99)	(0.03)
	Post-Game	7.22	3.01	4.22
		(0.38)	(0.71)	(0.71)
2	Before-Game	23.59***	11.32	12.28
		(0.01)	(0.17)	(0.30)
	Preparation-Game	21.6***	-2.13	23.74**
		(0.01)	(0.78)	(0.03)
	Post-Game	10.83	1.97	8.86
		(0.16)	(0.79)	(0.41)
3	Before-Game	19.03	9.85	9.19
		(0.12)	(0.34)	(0.60)
	Preparation-Game	21.60***	1.97	19.63*
		(0.01)	(0.80)	(0.08)
	Post-Game	9.51	-2.21	11.72
		(0.26)	(0.79)	(0.29)

Note: Numbers in parentheses are P-value.

Table 9. Estimation results of the logistic models for inpatient record data

	Acute		Chronic	
Explanatory Variables	**Coefficients**	**Marginal Effect**	**Coefficients**	**Marginal Effect**
Interaction terms among city, period and department (base=Beijing*Game period*Respiratory department)				
Beijing*Pre-preparation period*Respiratory department	-0.05	-0.01	0.03	0.01
	(0.37)	(0.06)	(0.36)	(0.09)
Beijing*Preparation period*Respiratory department	-0.3	-0.05	0.44**	0.11**
	(0.22)	(0.04)	(0.22)	(0.05)
Beijing*Post-Game period*Respiratory department	-0.07	-0.01	0.02	0.00
	(0.23)	(0.04)	(0.22)	(0.05)
Beijing*Pre-preparation period*Surgical department	0.15	0.03	-0.77**	-0.19**
	(0.37)	(0.06)	(0.36)	(0.09)
Beijing*Preparation period*Surgical department	-0.44**	-0.08**	-0.21	-0.05
	(0.22)	(0.04)	(0.22)	(0.05)
Beijing*Game period*Surgical department	-0.84***	-0.15***	0.33	0.08
	(0.32)	(0.06)	(0.30)	(0.07)
Beijing*Post-Game period*Surgical department	-0.53**	-0.09**	-0.25	-0.06
	(0.23)	(0.04)	(0.22)	(0.05)
Shijiazhuang*Preparation period*Respiratory department	0.49**	0.09**	-1.47***	-0.35***
	(0.22)	(0.04)	(0.22)	(0.05)
Shijiazhuang*Game period*Respiratory department	1.47***	0.26***	-1.60***	-0.39***
	(0.31)	(0.05)	(0.31)	(0.08)
Shijiazhuang*Post-Game period*Respiratory department	0.90***	0.16***	-1.20***	-0.29***
	(0.22)	(0.04)	(0.22)	(0.05)
Shijiazhuang*Pre-preparation period* Surgical department	-1.41	-0.25	0.70	0.17
	(1.14)	(0.20)	(0.91)	(0.22)
Shijiazhuang*Preparation period*	-0.93***	-0.16***	-0.13	-0.03

Surgical department				
	(0.22)	(0.04)	(0.22)	(0.05)
Shijiazhuang*Game period* Surgical department	-1.07***	-0.19***	-0.29	-0.07
	(0.23)	(0.04)	(0.22)	(0.05)
Shijiazhuang*Post-Game period*Surgical department	-0.94***	-0.16***	-0.31	-0.08
	(0.22)	(0.04)	(0.22)	(0.05)
API	-0.00*	-0.00*	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Year dummies (base= Admission year_2008)				
Admission year_2000	0.25	0.04	-0.27	-0.07
	(0.30)	(0.05)	(0.29)	(0.07)
Admission year_2001	0.04	0.01	-0.11	-0.03
	(0.28)	(0.05)	(0.27)	(0.07)
Admission year_2002	-0.05	-0.01	-0.19***	-0.05***
	(0.04)	(0.01)	(0.03)	(0.01)
Admission year_2003	-0.07*	-0.01*	-0.20***	-0.05***
	(0.04)	(0.01)	(0.03)	(0.01)
Admission year_2004	-0.20***	-0.04***	-0.11***	-0.03***
	(0.04)	(0.01)	(0.03)	(0.01)
Admission year_2005	0	0.00	-0.06*	-0.01*
	(0.04)	(0.00)	(0.03)	(0.01)
Admission year_2006	0.05	0.01	-0.08**	-0.02**
	(0.04)	(0.01)	(0.03)	(0.01)
Admission year_2007	0.01	0.00	0.01	0.00
	(0.04)	(0.01)	(0.03)	(0.01)
Admission year_2009	-0.17***	-0.03***	0.23***	0.06***
	(0.05)	(0.01)	(0.04)	(0.01)
Admission year_2010	0.06	0.01	0.08**	0.02**
	(0.05)	(0.01)	(0.04)	(0.01)
Admission year_2011	-0.04	-0.01	0.28***	0.07***
	(0.08)	(0.01)	(0.07)	(0.02)
Month dummies (base= Admission month_Aug)				
Admission month_Jan	-0.03	-0.01	-0.02	-0.00
	(0.04)	(0.01)	(0.03)	(0.01)
Admission month_Feb	-0.02	-0.00	-0.03	-0.01
	(0.04)	(0.01)	(0.04)	(0.01)
Admission month_Mar	-0.13***	-0.02***	0.08**	0.02**
	(0.04)	(0.01)	(0.03)	(0.01)
Admission month_Apr	0	0.00	0.04	0.01

	(0.04)	(0.01)	(0.03)	(0.01)
Admission month_May	-0.05	-0.01	0.06*	0.01*
	(0.04)	(0.01)	(0.03)	(0.01)
Admission month_Jun	0.09**	0.02**	-0.04	-0.01
	(0.04)	(0.01)	(0.03)	(0.01)
Admission month_Jul	-0.02	-0.00	-0.06*	-0.01*
	(0.04)	(0.01)	(0.03)	(0.01)
Admission month_Sep	0.14***	0.02***	0.02	0.00
	(0.04)	(0.01)	(0.04)	(0.01)
Admission month_Oct	-0.07*	-0.01*	0.06*	0.01*
	(0.04)	(0.01)	(0.04)	(0.01)
Admission month_Nov	-0.05	-0.01	0.09**	0.02**
	(0.04)	(0.01)	(0.04)	(0.01)
Admission month_Dec	0.06	0.01	-0.00	-0.00
	(0.04)	(0.01)	(0.04)	(0.01)
Constant	-0.42*		0.30	
	(0.22)		(0.22)	
Number of observations	87106		87106	
Pseudo R^2	0.05		0.02	
* p<0.10, ** p<0.05,*** p<0.01				

Note: Numbers in parentheses are standard error (SE).

Table 10. DID estimates of the logistic models for inpatient records data

Disease Type	Department	Period	Mean test between periods (Base = the Game period) BJ	SJZ	DID (BJ-SJZ)
Acute	Respiratory Department	Before-Game	-0.01		
			(0.89)		
		Preparation-Game	-0.05	-0.17	0.12**
			(0.17)	(1.00)	(0.02)
		Post-Game	-0.01	-0.10	0.09**
			(0.76)	(0.99)	(0.05)
	Surgical Department	Before-Game	0.17***	-0.06	0.23
			(0.00)	(0.62)	(0.11)
		Preparation-Game	0.07**	0.02**	0.05
			(0.05)	(0.03)	(0.14)
		Post-Game	0.05*	0.02*	0.03
			(0.10)	(0.06)	(0.23)
Chronic	Respiratory Department	Before-Game	0.01		
			(0.93)		
		Preparation-Game	0.11**	0.03	0.07
			(0.05)	(0.28)	(0.17)
		Post-Game	0.00	0.10**	-0.09
			(0.94)	(0.04)	(0.89)
	Surgical Department	Before-Game	-0.27	0.24	-0.51
			(1.00)	(0.13)	(0.99)
		Preparation-Game	-0.13	0.04***	-0.17
			(1.00)	(0.00)	(1.00)
		Post-Game	-0.14	-0.01	-0.13
			(1.00)	(0.65)	(0.99)

Note: Numbers in parentheses are P-value.

Table 11. Triple-Difference of the logistic models for inpatient records data

Disease Type	Period	DID (BJ-SJZ)		Triple-Difference (Respiratory-Surgical)
		Respiratory	Surgical	
Acute	Before-Game		0.23	
			(0.11)	
	Preparation-Game	0.12**	0.05	0.07
		(0.02)	(0.14)	(0.15)
	Post-Game	0.09**	0.03	0.06
		(0.05)	(0.23)	(0.33)
Chronic	Before-Game		-0.51	
			(0.99)	
	Preparation-Game	0.07	-0.17	0.24
		(0.17)	(1.00)	(0.00)
	Post-Game	-0.09	-0.13	0.04
		(0.89)	(0.99)	(0.33)

Note: Numbers in parentheses are P-value.

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