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Identifying the main contributors of air pollution in Beijing

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A B S T R A C T

Air pollution has become an emerging environmental issue in developing countries like China in the last two decades. Sulphur dioxide (SO_2) is one of the major air pollutants that poses significant risks in many areas undergoing a process of industrialization such as Beijing. Realizing the main factor causing environmental quality changes is the key to solving this problem. By using an extended version of IPAT model, this paper aims to identify the main contributors of air pollution in Beijing from 1989 to 2012. The result shows that the most influential factors affecting air pollution in Beijing are affluence and emission intensity. From analyzing the historical background, we conclude that the air pollution change in Beijing is heavily policy-driven.

1. Introduction

Air pollution is one of the most serious environmental issues in many developing countries (Kanada et al., 2013). Indoor air pollution produced by the combustion of biomass fuels as well as coal in poorly ventilated heating and cooking environments causes significant mortality and morbidity from respiratory diseases, particularly among children. Globally, urban air pollution is responsible for significant mortality every year, mostly as a result of heart and lung diseases (Bolund and Hunhammar, 1999). Another effect of urban air pollution is that it might induce biodiversity loss which may be irreversible (Bolund and Hunhammar, 1999). For example, it has been discovered long ago that air pollution has an influence on forest ecosystems throughout the temperate regions of the world. If the effect of air pollution exposure on some components of the ecosystem biota is inimical then a Class II relationship[1] is established (Smith, 1974). Although most recent attentions have been focused on reducing carbon dioxide (CO_2) emissions, due to concerns on global climate change, local air pollution is still a critical issue that poses an acute threat to both public health and natural ecosystems (BP, 2012; Chen et al., 2012; Chung et al., 2011; Kan et al., 2012; Lu et al., 2010; Smith et al., 2011; Streets and Waldhoff, 2000; Tang et al., 2010). Sulfur dioxide (SO_2) is one of the major air pollutants that poses significant risks in many developing countries undergoing a process of industrialization. Many studies have found that SO_2 pollution causes severe respiratory problems and significant ecosystem degradation due to acid rain formation (Guttikunda et al., 2003; Su et al., 2011).

Currently, air quality in China is becoming a world-concerning issue. Not only has it contributed to regional environment degradation, but also severely affected local residents' living quality. Especially, the air quality in Beijing and other megacities has become an urgent challenge to the Chinese government. The Chinese Ministry of Environmental Protection Data Center reports that out of the thirty one provinces and municipalities, Beijing is among the worst air quality provinces, ranked second to last (Liu, 2013). Realizing the main factor causing air quality changes is the key to solve this problem. Hao et al.'s study showed the high SO_2 emission induced a significant impact on the urban area (Hao et al., 2007). SO_2 reduction plays an increasingly significant role in improvement of air pollution in China due to its popular appearances in pollution abatement methods (Liu and Wang, 2013). To improve air quality, Beijing government has formulated plans to reform air-related administrative management systems and increase administrative efficiency. Beijing's twelfth five-year plan set the goal to have 80% of days achieving national Grade II or better air quality in Beijing (Jiang, 2014). The goal is to reduce major pollutant SO_2 by 8% by

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[1] “When exposed to intermediate dosage, individual tree species or individual members of a given species may be adversely and subtly affected by nutrient stress, reduced photosynthetic or reproductive rate, predisposition to entomological or microbial stress, or direct disease induction” (Smith, W.H., 1974. Air pollution—effects on the structure and function of the temperate forest ecosystem. Environmental Pollution (1970) 6, 111–129.).

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2015 (KPMG, 2011). Control measures such as fuel substitution, flue gas desulfurization, dust control improvement and flue gas denitration has greatly mitigated the SO_2 and PM10 pollution, especially alleviating the pressure on the urban area to reach the National Ambient Air Quality Standard (Hao et al., 2007).

Air quality is closely associated with human activities (Pehoiu, 2008). Up to now there have been many different approaches to measure the effects of human activities to the environment. Some researchers used both CO_2 and SO_2 as indicators of climate change and air pollution in Britain to measure environmental quality changes using a temperature matrix to perform a number of parallel analyses (Balling and Idso, 1992), others use IPAT (I = Impact, P = Population, A = Affluence, and T = Technology) model to analyze how different drivers (including economic development, income levels, urbanization and other socio-economic drivers) contribute to the growth of CO_2 emissions in China (Feng et al., 2009). Furthermore, Wang et al. (2013) has examined the impact factors of population, economic level, technology level, urbanization level, industrialization level, service level, energy consumption structure and foreign trade degree on the energy-related CO_2 emissions in Guangdong Province, China from 1980 to 2010 using an extended STIRPAT model which is a stochastic model of IPAT using regression on population, Affluence and Technology. Amongst the current approaches utilized by researchers, IPAT has become a popular tool to identify drivers of air pollution impacts due to its simplicity, transparency, and demand of less data.

Through applying an extended IPAT model, this paper aims to identify the main contributors of environmental quality changes in Beijing. In this research, sulphur dioxide (SO_2) is used as the indicator of air pollution.

2. Data and method

Population, Gross Domestic Product (GDP), GDP by industries and energy consumption data are collected from Beijing Statistical Yearbooks, and SO_2 emission data are obtained from Beijing Municipal Environmental Protection Bureau.

The IPAT identity is a widely recognized formula for analyzing the effects of human activities on the environment (York et al., 2003). The *IPAT* equation could be used to determine which single variable is the most damaging to the environment, as well as recognizing that increases in population and affluence could, in many cases, be balanced by improvements to the environment offered by technological systems (Chertow, 2001).

The limitation of using the original *IPAT* model is that it only includes three aggregate factors; population, affluence, and technology, respectively. However, it has been broadly discussed that economic structure is also a key driver for air pollution (Brizga et al., 2013). In addition, technology could be further disaggregated into energy intensity (energy consumption per unit of economic output) and emissions intensity (emissions per unit of energy consumption) (York et al., 2003). In this research, we develop an extended version of *IPAT* model to analyze the contributing factors to environmental quality changes: population, affluence, economic structure, energy intensity and emission intensity.

In this study, the quantitative analysis is focused on how different variables contribute to SO_2 emissions I, impact on Beijing's air pollution:

This extended *IPAT* method can reveal the main driving factors have contributed to the environment pollution and it is expressed as:

$$I = P \times A \times S \times IEn \times IEm \tag{1}$$

here, I is SO_2 emissions; P refers to the size of the resident population in Beijing; A is per capita GDP; S presents economic structure/industrialization (share of industrial GDP); IEn is energy intensity which shows how much energy is put into one unit of industrial GDP; and IEm is emission intensity which represents how much the SO_2 emissions result from one unit of energy consumption.

To facilitate understanding and analysis, converting all variables to logarithmic form allows seeing the respective contributions as a share of the total impacts. These modifications yield the following models (Feng et al., 2009):

$$\log I = log\ P + \log A + \log S + \log IEn + \log IEm \tag{2}$$

$$\Delta\log I = \Delta log\ P + \Delta\log A + \Delta\log S + \Delta\log IEn + \Delta\log IEm \tag{3}$$

$$\log\frac{I_t}{I_1} = log\frac{P_t}{P_1} + \log\frac{A_t}{A_1} + \log\frac{S_t}{S_1} + \log\frac{IEn_t}{IEn_1} + \log\frac{IEm_t}{IEm_1} \tag{4}$$

Where script t is a time in the future and script *1* is the original time being compared with. This final equation comprised of addition can show how much impact is contributed by each sector.

In this study, the timeframe is set from 1989 to 2012 to see the progression of population, GDP, emission of SO_2 and how has it affected air quality in Beijing.

3. Results/interpretation

The results of this research are classified into six time frames: 1989–1995 (the relaxed immigration policy after Open-Door Policy), 1995–1999 (Asia economic crisis), 1999–2003 (after the economic crisis and closing of small factories), 2005–2008 (pre-Olympics), 2009–2012 (post Olympics). There are three visual representations. One is the variation in percentage in relation to its previous year (Fig. 1). Another is the trend of each variable and how it changes overtime (Fig. 2a–f). The third one is the percentage contribution of each variable for the six time periods (Fig. 3 and Table 1).

3.1. Relaxed immigration policy after open-door policy 1989–1995

From 1989 to 1995 population and affluence contributed the most to air pollution, being 264% and 367%, while the economic structure and emission intensity had ameliorated this by 284% and 219%. Thus, the overall impact in this period decreased by 9%.

The economic openness of China began in the provinces of the South-East. The creation of “Special Economic Zones” and of “Open Economic Zones” was the master piece of the open-door policy. During 1989 to 1995, migrants tended to concentrate in three main regions: the Pearl River Delta,[2] the Yangtse Delta,[3] and the area around the Bohai Gulf,[4]including Beijing (Renard et al., 2011). In 1995, to stimulate the economy and development of the city, Beijing released “Urban household registration management

[2] A low-lying area surrounding the Pearl River estuary where the Pearl River flows into the South China Sea. This paper refers to the part within the Guangdong Province.

[3] Triangular shaped river delta area that drains into the East China Sea. This paper refers to the part within Shanghai, Jiangsu Province.

[4] The innermost gulf of the Yellow Sea on the coast of Northeastern and North China and has close proximity to Beijing.

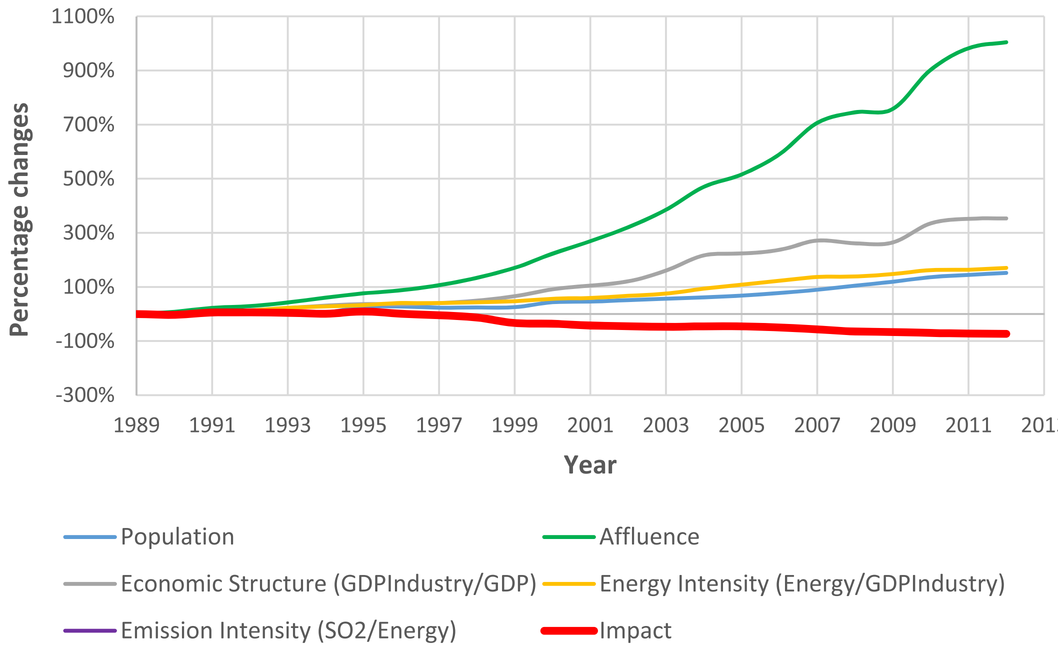

Fig. 1. Gradual development 1989–2012. Note: Emission intensity is blocked by Impact in this two dimensional graph.

implementation for small town on the outskirts of Beijing" policy. This policy has profound and far-reaching influence on population migration since Beijing was one of the few big cities (Beijing, Shanghai and Guangzhou) before 2000. Unlike most of the other countries, China has been using Hukou system (household registration) to distinguish rural and urban residency status and regulate populations in big cities such as Beijing (Perry and Selden, 2003; Wing Chan and Buckingham, 2008). As the Capital, Beijing is not only the political and economic center, but also the cultural and educational center of China. There are more than 50 universities or colleges in Beijing, around 20 of them are among the top 100 universities in China, including two of the most renowned universities in China: Tsinghua and Peking University. Besides, the residents of Beijing also have many privileges including the rights to permanently settle in Beijing as well as lower entry standard on college admission exams. Therefore, having Beijing residency is very attractive. The population of Beijing increased remarkably from 11.3 million in 1994 to 12.5 million in 1995, a net increase of more than 1 million within a year (Fig. 2a), which was largely due to a new residency policy: "residents outside of Beijing could buy a home with two or more bedroom for Beijing residency registration up to four family members" (Beijing Municipal People's Government Office, 1995). Due to this large increase in population, the affluence, which is measured by GDP per capita, has dropped in 1995 (Fig. 2b). However, the overall affluence is still an increasing trend in this time period.

The emission intensity and economic structure contributed to the changes in emissions by 284% and 219%. There are two major sources of SO_2 emission in Beijing: industrial and life-related activities. Before 1991, coal-fired heating system was the major warming method in Beijing. Usage of low-quality high-sulphur coal due to economic reasons and lack of proper regulation resulted in the high concentrations of primary gaseous pollutants in Beijing during the winter (Zhang et al., 2006). The official heating season in Beijing is from November 15th to March 15th, during which huge portion of SO_2 emission is generated through coal-fueled boilers for central heating systems or smaller residential heating units. However, after 1991, Beijing started transforming small city boilers with a capacity of less than 20 tons into gas or electricity-powered units. Further comparing the evolution of China's economic structure and that of SO_2 emission since 1991, the rate of decrease of SO_2 emission intensity is about the same as economic structure. Meaning, there is a shift in the economic structure from industrialized to more service-based since there is less GDP from industrial section and less SO_2 produced. Clearly, in China's industrialization process, environmental cost for one unit of product decreases consistently during the time. China actually made obvious progress in its pollution control activities and this improvement tendency still continues (He, 2006).

3.2. The East Asian financial crisis 1995–1999

During this period, although affluence was the only factor that contributed to air pollution impact, the rate has slowed down significantly by 279%. Therefore, emission intensity became dominant factor (120% of the change in SO_2 emissions) for the change in SO_2 emissions which overwhelmed the effects of affluence and led to a net decrease in emissions by 39% over this time frame.

While the economy in Beijing kept increasing overall in this time period, the growth rate has dropped sharply. Meanwhile, others factors having noticeable improvements which resulted in affluence being only factor contributing to the increase in SO_2 emissions. The East Asian financial crisis that happened in 1997 was the sharpest financial crisis to hit the developing world and it is remarkable in ways that it hit the most rapidly growing economies in the world, and prompted the largest financial bailouts in history (Radelet and Sachs, 1998). A combination of the international investment community, policy mistakes at the onset of the crisis by Asian governments, and poorly designed international rescue programs turned the withdrawal of foreign capital into a full-fledged final panic, and deepened the crisis more than was either necessary or inevitable (Radelet and Sachs, 1998). The economic depression that resulted from the East Asian financial crisis caused

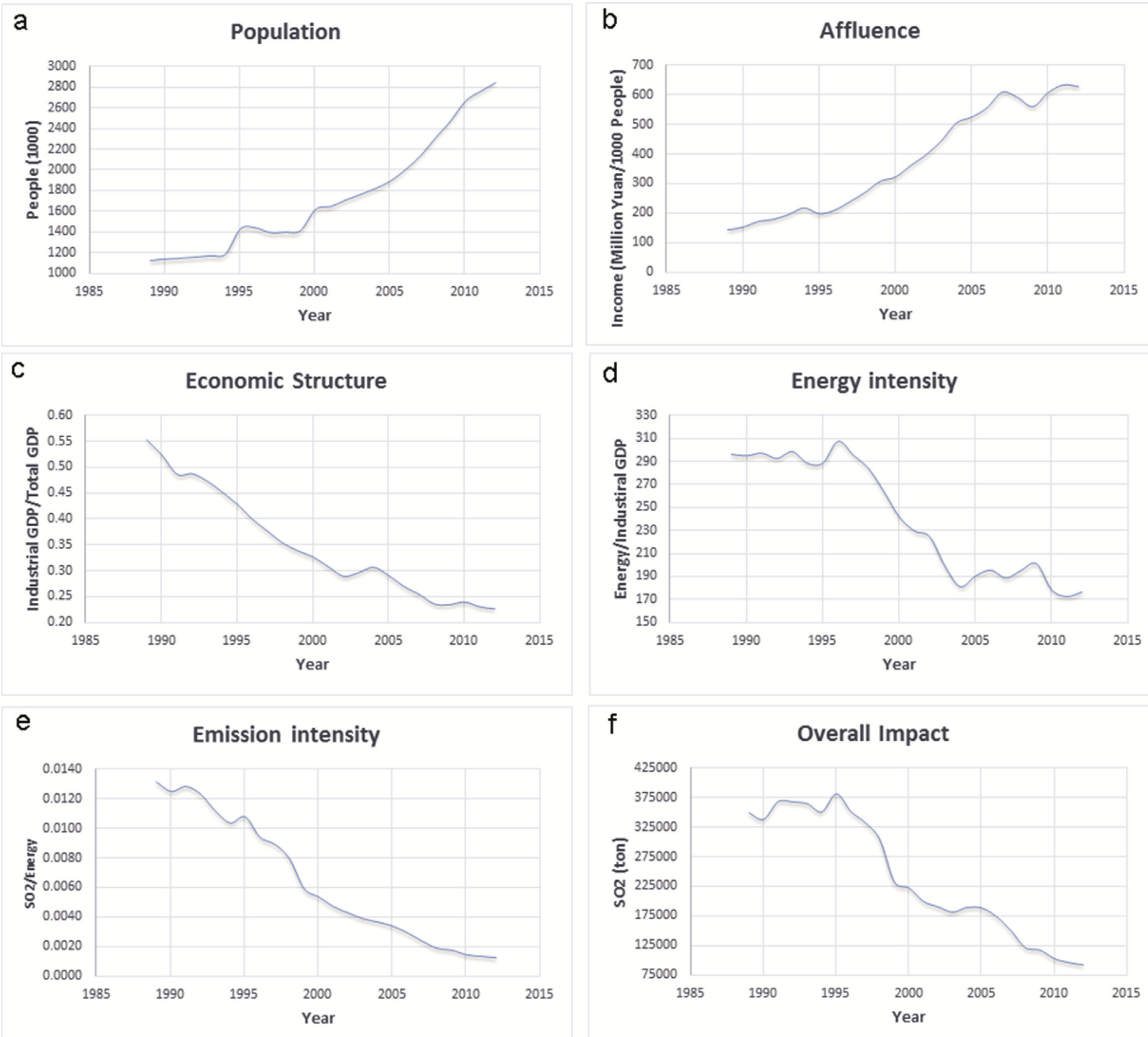

Fig. 2. Changing trend of population, affluence, economic structure, energy intensity, emission intensity and overall impact in Beijing from 1989 to 2012.

numerous large and medium sized state-owned enterprises to suffer heavy losses, which set off a chain reaction of production stagnation and declining energy demand (Gao et al., 2009).

The pollution control was doing very well to reduce impact. There were plans to control pollution and to improve air quality which resulted in greatly reduced emission intensity. Emissions related to energy consumption by industry, power plants, domestic heating, and vehicle are the major sources of SO_2 and other pollutants in Beijing (Hao et al., 2005). The Chinese government implemented the policy of industrial structure adjustment and Air Pollution Prevention and Control Law (APPCL), and introduced many regulatory measures (Gao et al., 2009). First, a campaign to close polluting enterprises was launched in 1996. By April 1997, the state had forced the closure of more than 62,000 small factories cited for environmental pollution. Second, the Chinese government shut down small coal-fired generating units to improve energy efficiency. Third, most cities introduced and improved a variety of environmental protection practices, especially those that promoted the utilization of cleaner energy, such as shifting coal to electricity and natural gas for cooking and water heating. In 2000, a report on Beijing's environmental situation was published, commenting on the severity of pollution. It indicated that the air pollution is comparatively severe to other surrounding areas, there has been more effort and enforcement to control air pollution (Beijing Municipal Environmental Protection Bureau, 2000). By the end of 1998, there had been three major pollution control regulations: to control air pollutants from smoke emissions,[5] to control pollution by advancing motor vehicles' emission filters, and prevention of dust by planting more than 24 million acres of forested area. One of these three regulations especially worth mentioning is “Emission

[5] Smoke emission refers to the gases resulted from combustion being channeled into the atmosphere or into a collection receptacle (ex. Power plants).

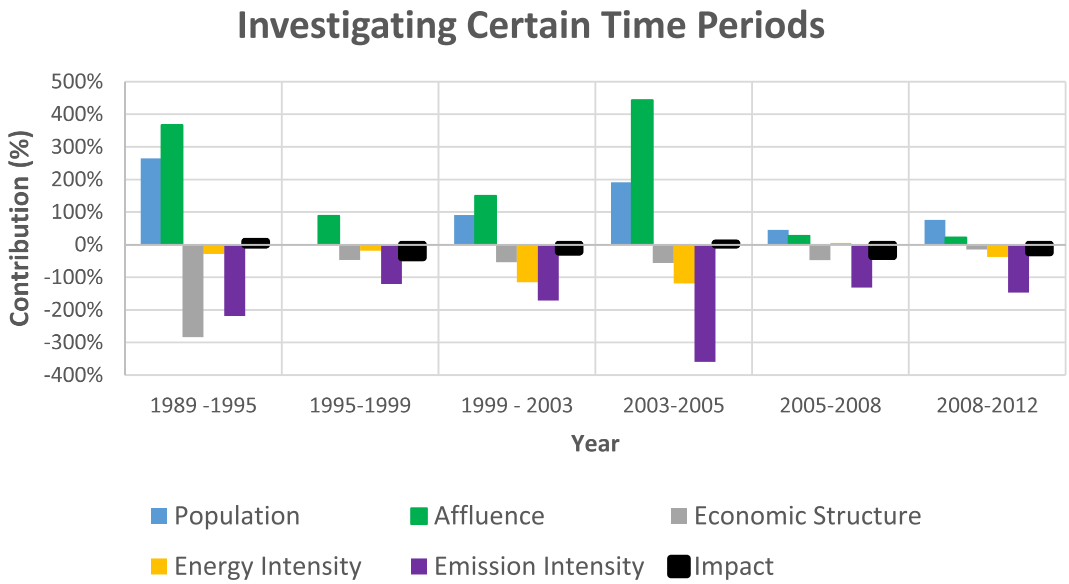

Fig. 3. Contribution of five driving forces to the change in SO_2 emissions in Beijing for the six different time periods.

Table 1
Percentage change of the six time periods of each variable. Negative percentage means reduced impact and positive percentage means increased impact.

	Time period	Population	Affluence	Economic structure	Energy intensity	Emission intensity	Impact
Relaxed Immigration Policy after Open-Door Policy	1989–1995	264%	367%	−284%	−28%	−219%	9%
The East Asian financial crisis	1995–1999	−2%	88%	−47%	−18%	−120%	−39%
After Economic Crisis and Closing Small Factories	1999–2003	91%	150%	−54%	−115%	−171%	−22%
Reopening Small Factories	2003–2005	191%	443%	−57%	−119%	−359%	4%
Pre-Olympics	2005–2008	46%	27%	−48%	6%	−131%	−35%
Post Olympics	2008–2012	76%	22%	−15%	−37%	−147%	−24%

Population (P)	Population of Beijing
Affluence (A) = GDP/Population	Per capita GDP (gross domestic product) how much money per one thousand people made
Economic Structure (S) = $GDP_{Industry}$/GDP	Industrial GDP over aggregated GDP
Energy Intensity (IEn) = Energy/$GDP_{Industry}$	energy consumption per unit of industrial production
Emission Intensity (IEm) = SO_2/Energy	SO_2 emissions per unit of energy consumption

standard for exhaust pollutants from light-duty vehicle" drafted in 1997. This is important because while other industrial output units remained relatively constant in their emission such as power plants, the vehicle population in Beijing increased at an average annual rate of 14.4% since 1990 and became even faster as more and more citizens could afford owning private cars. During its process, new vehicles had been modified to fulfil the "green standard". More than 80,000 vehicles produced before 1995 were forced to install the vacuum delay valve. 120,000 vehicles produced after 1995 had been modified to fit the new emission standards. More than 30,000 vehicles were discarded and a third of vehicles from others provinces were rejected the entrance to Beijing (Ministry of Environmental Protection of the People's Republic of China, 1998). As the graph on emission intensity shows, there is an accelerated reduction in emission intensity during this time period (Fig. 2e).

3.3. After economic crisis and closing small factories 1999–2003

During this time, there was an overall reduction in pollution which resulted in a 22% decrease in air pollution impact. Affluence had impacted the environment by 150% but this was balanced by energy intensity and emission intensity which contributed −115% and −171% to the change in SO_2 emissions.

During this period, the environment kept on improving. One of the causes was that the Capital Steel Corp[6] initiated relocation project to move its factory out of Beijing since 2005 (Xie et al., 2008). The other cause was that 1999 was the 50th anniversary of China's foundation. As a major political event, Beijing made a great effort to prepare for the celebration on the National Day, including enforced air pollution control even if it sacrificed the rapid growth of the economy. For example, 25 of Beijing's largest soot-spewing factories were shut down from September 21st through the October 1st anniversary (Kuhn, 1999). This short-term shut down of heavy industries, to some extent, may also contribute to the overall emissions reduction in Beijing. As a result of relocation of energy and pollution intensive factories and other policy events, there was a sharp decrease of emission intensity in 1999 (Fig. 2e). This type of fluctuation of impact, which results primarily from technology

[6] The Capital Steel Corp and Yanshan Petrochemical Corp are the two main industrial pollutant sources in Beijing.

change, is not an indication of industrial restructuring that changes SO_2 emission rate, but rather a politic consequence. Overall, even though the economy grew faster than before, the emission still decreased due to the investments in cleaner technology and strict regulations.

3.4. Reopening small factories 2003–2005

During this period, emission intensity continued to contribute to the improvement of environmental quality but was overwhelmed by affluence which degraded the environment by 443%.

At the beginning of the 10th Five-Year Plan, SO_2 emissions were declining. Though successful in general, the rate of improvement had slowed in these years (Figure c, d, e). In the latter part of the 10th Five-Year Plan, energy efficiency was seriously underfunded, and the Chinese government emphasized economic growth over improving energy efficiency and environmental protection (Lin, 2007; Sinton et al., 2005). Some small factories were allowed to move back in. China's dependence on coal has created great pressure on environment. In 2004, total primary energy consumption reached a new high, discharging massive tons of SO_2 and suspended particulate wastes (China Council for International Cooperation on Environment and Development, 2005). The rapid increase of energy consumption is accompanied by low efficiency in energy use. Around the same time, the overall energy use efficiency was around 33%, 10 percentage points lower than that in the developed countries; energy consumption for manufacturing major industrial products was 20%–100% higher than that of the developed countries, at an average of 40% (China Council for International Cooperation on Environment and Development, 2005). In short, during these three years, the emission intensity has decreased with a much slower rate.

Affluence increased during this time. Between 2002 and 2003, as people were becoming wealthier, the number of motor vehicles increased by 153% from 1,500,000 to 2,300,000. The use of motor vehicles also became more frequent as an indication of consumers moving away from inferior goods to higher quality goods with their increased income.

3.5. Pre-Olympics 2005–2008

During this period, there was a significant reduce in pollution of 35%. Population, affluence and energy intensity had contributed to the increase in pollution but they have small magnitudes. The most significant one is population. The contributing factor to environmental quality improvement was emission intensity being 131%.

The most dramatic reduction in pollution was from 2007 to 2008. This was due to the Olympics game held in 2008. To prepare for the 2008 Olympic Games, China adopted a number of radical measures to improve air quality such as closing facilities producing construction materials which reduced the sector's SO_2 emissions by 85% (Wang et al., 2010).

Policies introduced during this period focusing on controlling pollution contributing units to reduce emission had worked very effectively. Domestic coal combustion, building material manufacturing, metallurgy, industrial boilers, and power plants were the largest contributors to SO_2 emissions, which respectively accounted for 25%, 23%, 16%, 16%, and 11% of total SO_2 emissions in Beijing (Wang et al., 2010). Emissions during the Olympic Games were further decreased by 30% (Wang et al., 2010). About 50% of the industrial boilers were closed, and all operating boilers met with the Emission Standard of Air Pollutants for Boilers in Beijing (DB11/139–2007). SO_2 emission reductions attributable to temporary air pollution control measures and has declined from 103.9 t/d in June 2008 to 61.6 t/d during the Olympic Games. SO_2 emissions from building material manufacturing decreased 85% due to the temporary closure of most sources. This reduction represents a majority of the total SO_2 emission reductions during the Olympic Games (Wang et al., 2010). This is also reflected in Fig. 2e where there is a steeper decrease in emission intensity pre-Olympics.

Population's rate of increase was slower during the pre-Olympics period than previous years and years after. Based on Chinese government reports and statements relating to construction and urban redevelopment leading up to the Olympics game, Geneva-based Centre on Housing Rights and Evictions (COHRE) estimated that roughly 1.5 million were displaced during preparations for the Olympics (Yuan, 2008).

3.6. Post Olympics 2009–2012

Although population and affluence had contributed to the increase in SO_2 emissions, emission intensity's further decline by 147% had brought down the overall emissions to −24%. However, the rate dropped from −35% to −24%, showing a noticeable reduction in rate of improvement. The emission standard had relaxed but the changes in population and affluence was very little as well.

After stringent removal of industrial companies and harsh regulations to reduce pollution, the economy had paid the price. The growth rate of investment decreased 11.9% since 2007 and losing tens of billions of yuan[7] (Kang, 2006; Sekiyama, 2008). To alleviate the pain, some factories were allowed to move back in thus increasing the emission and bringing back the impact for 2009. In 2010, policy makers realized that they cut back too much and need to reinforce some regulations again. In May of 2010, State Council of China issued a regulation named “Joint Prevention and Control of Air Pollution” (Zhang et al., 2015). It was the first comprehensive policy document aiming to improve regional and urban air quality in China focusing on the three “key regions” especially Beijing (Zhang et al., 2015). Therefore decreasing air pollution for 2010 again.

According to officially reported air pollution index (API) from 2000 to 2009, although Beijing's API had improved during and a little after the Olympics Games, a significant proportion of the effect faded away by October 2009 (Chen et al., 2013). While some policies removed, the rest were kept in their places and worked to reduce pollution.

4. Discussion and conclusion

To identify the major driver that contributed to air quality changes in Beijing during its rapid growth, our study examined the impact of population, affluence, economic structure, energy intensity and emission intensity over the most recent two decades (1989–2012) using an extended IPAT approach. Emission intensity was the most influential factor to impact on improvement of air pollution in Beijing out of all five factors. Results indicate although that the population and affluence increase 250% and 439% from 1989 to 2012, economic structure, energy intensity and emission intensity decreased 60%, 40% and 90%. Total SO_2 emission decreased from 340,000 ton in 1989 to 93,849 ton in 2012. Based on this analysis, it is clear that the government regulations and strategies played a key role in the long-term SO_2 emission decline, including modifying economic structure, changing to cleaner energy sources, limiting population growth (after 1995), and regulating the number and emission of vehicle.

[7] Chinese currency.

One may also notice that major political events had significant impact on air quality change in Beijing. But the impact was also transient and unsustainable, usually rebounding after the event. For instance, the 50th anniversary of China's foundation in 1999, the 2008 Olympic Games, and most recently, the APEC China 2014.

The government regulations and strategies play a major role in the long-term and more permanent SO_2 emission decline, including modifying industrial structure, changing to cleaner energy source, limiting population growth, regulating the number and emission of vehicles.

As Beijing keeps reforming its economic structure to decrease the ratio of secondary industry, it is clear that the policies made by the government will continue be the major driver to improve air quality. As proof, by 2020, Beijing will completely forbid coal usage, which will greatly improve air quality.

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