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# Why the number of haze days in Shenzhen, China has reduced since 2005 : From a perspective of industrial structure

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**सार -** चीन में तेजी से विकसित हो रहे महानगर शेन्जेंन की विगत 35 वर्षों की जलवायु, पर्यावरणीय तथा आर्थिक आँकड़ों का उपयोग करते हुए शेन्जेंन शहर में औद्योगिक ढॉचों से वायुमंडलीय पर्यावरण पर पड़ने वाले प्रभाव का विश्लेषण किया गया है। इसका सरांश इस प्रकार है (*i*) धुंध वाले दिनों की संख्या तथा प्रति व्यक्ति सकल घरेलू उत्पाद के बीच का फिटिंग कर्व वितरण उल्टे यू की आकृति के समान है और सकल घरेलू उत्पाद (जी डी पी) के साथ धुंध वाले दिनों की संख्या में विभिन्ता कजनेट्स कर्व थ्योरी की तरह है (*ii*) द्वितीय चरण के उद्योगों के अनुपात में लगातार कमी आने लगी है जबकि सहायक उद्योगों में वर्ष 2005 से वृद्धि हो रही है जो कि समय के बिल्कुल अनुकूल है और इससे धुंध वाले दिनों की संख्या कम होने लगी है (*iii*) द्वितीय चरण के उद्योगों में हाई-टेक उद्योगों के विकास का धुंध वाले दिनों की संख्या के बदलाव में महत्वपूर्ण भूमिका रही है (*iv*) शेन्जेम मुनिसिपल सरकार द्वारा उद्योगों को अपग्रेड करने के लिए प्रोत्साहित करने के लिए अनेक नीतियॉ बनाई गई है जिसका औद्योगिक ढॉचे के समायोजन, ऊर्जा दक्षता में विकास और धुंध वाले दिनों की संख्या में कमी लाने में महत्वपूर्ण रूप से सकारात्मक भूमिका रही है।

**ABSTRACT.** The impacts of the industrial structure on the atmospheric environment in Shenzhen are analyzed by utilizing climate, environmental and economic data over the past 35 years of Shenzhen, a rapid developing megacity in China. The main conclusions are as follows : (*i*) The fitting curve between the number of haze days and GDP per capita had an "inverted U-shaped" distribution and the variation of the haze days along with the GDP is a new evidence for the Environmental Kuznets Curve theory (*ii*) The proportion of the Second Industry began to continually reduce, while that of the Tertiary Industry significantly kept rising since 2005, which is quite accordant to the time when the number of haze days began to reduce (*iii*) The development of the high-tech industry in the Secondary Industry plays an important role in the variation of the number of haze days (*iv*) A series of policies on promoting the industry upgrading had been issued by Shenzhen Municipal Government, which are believed to have played a positive role in adjusting the industrial structure, promoting the energy efficiency and consequently reducing the number of haze days.

**Key words** – Haze, Atmospheric environment, Industrial structure, Kuznets curve.

## 1. Introduction

Since the economic reform in 1978, various big cities in China have grown rapidly and atmospheric environmental problems appeared along with economic development in the cities. Based on current literatures, atmospheric environmental problems of different levels have appeared in almost all big cities in China during the past 35 years. Regional atmospheric environment pollutions have been observed in the city clusters in the Beijing-Tianjin-Hebei area, the Yangtze River Delta and the Pearl River Delta (Tang *et al*., 2016; An *et al*., 2013; Xie *et al*., 2016). However, while the air quality in other Chinese cities is still poor, Shenzhen, one of the four megacities in China, has experienced an improvement in air quality for more than ten years, which is quite different from most other cities in China.

Shenzhen is an especially notable city in China, which is known as the first special economic zone (SEZ) in China. Shenzhen is famous for its drastically rapid development after the foundation of SEZ in 1980. Over the last 30 odd years, Shenzhen had transformed from a small town to a megacity with its population having increased by more than 30 times and its gross domestic product (GDP) by more than 1000 times (Li *et al*., 2015). The latest official data tell that the year-end permanent population is around 10.78 million and the GDP is around 1600 billion Chinese Yuan (around 240 billion U. S. Dollars).

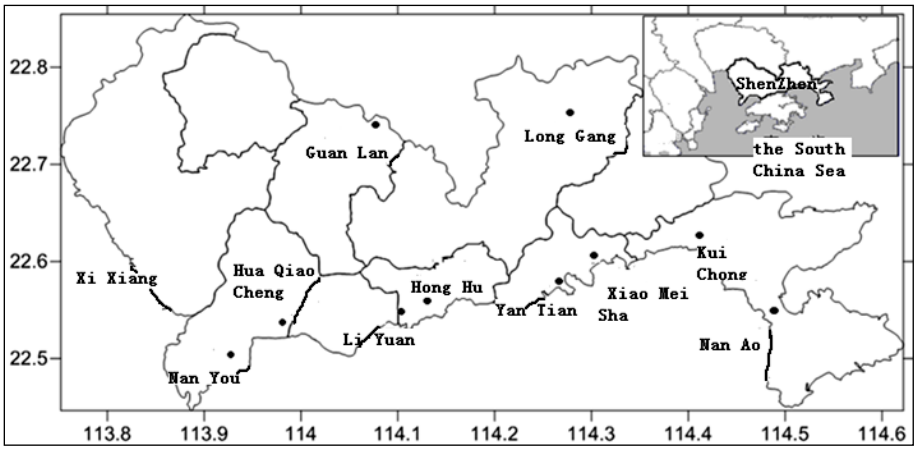
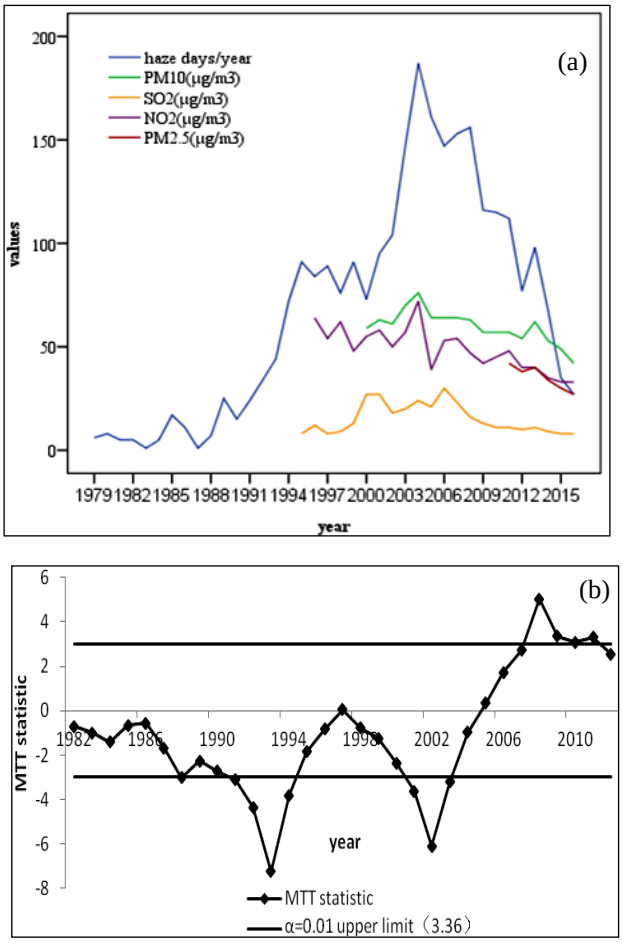



**Fig. 1.** Eleven state-controlled atmospheric environment monitoring sites in Shenzhen

Just like many other cities in China, Shenzhen has experienced a continuous deterioration of the atmospheric environment in the first 20 years of the rapid development. During this period, more and more haze cases were observed. However, according to Shenzhen Environment Bulletins, the air quality of Shenzhen has been continuously improving in recent 10 years and is currently among the best ones when compared with 74 other major cities in China. Besides the traditional air quality elements measured by environment monitoring agencies, the number of haze days measured by meteorological bureau can also be taken as another indicator to the atmospheric environment. The number of haze days is more consistent with the public perception on the atmosphere environment and has a much longer data series than traditional air quality elements. In the light of the observation record from the municipal meteorological bureau of Shenzhen, the number of haze days in Shenzhen has significantly decreased since 2005 after a drastic increase since 1980s. It can be said that Shenzhen is the first among Chinese megacities to achieve the economic growth and improve its environment quality at the same time.

Kuznets Curve is an economic theory first put forward by the economist Simon Kuznets in 1950s to analyze the relationship between per capita income levels and the equitableness of distribution. In 1991, Grossman and Krueger creatively introduced the Kuznets Curve into the research of the relationship between environmental pollution and economic growth and found that the relationship between $SO_2$ emissions and economic growth conformed to the Kuznets hypothesis; that is : with the increase of per capita income of a certain country, its environmental deterioration will aggravate with economic growth; however, after a certain critical point is reached, the further increase of per capita income will gradually mitigate its environmental deterioration. This phenomenon is called as Environmental Kuznets Curve (EKC). Many scholars have confirmed the relationships between pollutant emissions and per capita incomes of multiple countries by using the EKC hypothesis. (Galeottia and Alessandrolar, 2015; Rafindadi, 2016; Boluk and Mert, 2015; Sinha and Bhattacharya, 2016; Kang, *et al*., 2016; Li *et al*., 2016). They point out that the shape of EKC curves are related to the levels of economic development. The higher the level of economic development is, the more obvious the EKC will be. It is generally believed that the pollutant emissions and the economic growths of economically developed cities conform to the Environmental Kuznets Curve hypothesis. The levels of economic development of some cities in Europe, East Asia and the Pacific, South Asia and the America are relatively high and there are obvious inverted U-shaped curves exist between their industrial pollutant emissions and GDP per capita (Saboori *et al*., 2016; Al-Mulali *et al*., 2016). Besides the air quality issues, the EKC theory are also used to analyze the relationship between the economy and the green-house gas emission/ energy consumption (Dogan and Turkekul, 2016; Pablo-Romero and Jesus, 2016).

However, there are not yet detailed studies on Shenzhen, which has continuously improved its atmospheric environment quality for over ten years. As the first Chinese megacity to achieve the economic growth and improve its environment quality at the same time, Shenzhen is expected to set up a successful sample for cities in China or even in other developing countries on how to protect environment when developing economy. Therefore, it is worth to carry an in-depth research on Shenzhen. Starting with the relationship between the number of haze days & the industrial structure by utilizing the Kuznets Curve, this paper tried to analyze the possible connections of economic restructuring and the changes of the atmospheric environment in Shenzhen during the past




**Figs. 2(a&b).** The variation of the atmospheric environment in Shenzhen from 1979 to 2015 (a) The numbers of haze days and pollutant concentrations (b) The Moving T-Test (MTT) for the number of haze days ($n_1$= $n_2$= 4).

35 years, thus to provide references to other cities for possible optimization of the economical structure and the improvement of the atmospheric environment.

## 2. Data sources and methods

There are three types of data used in this study: (*i*) traditional air quality elements data (including : annual average concentrations of $PM_{2.5}$, $SO_2$ and $NO_2$) from the annual Environment Monitoring Bulletins of Shenzhen Habitat and Environment Committee since 1996; (*ii*) the number of haze days during the period of 1979 to 2015; (*iii*) economic data during the period of 1979 to 2015.

There are totally 11 state-controlled atmospheric environment monitoring sites in Shenzhen (Fig. 1) and the air quality data in the Bulletins are the average values of the observed data from the 11 sites. Due to the limitation of the air quality data source, which can not cover the whole range of the study period, "the number of haze days" is chosen as the major indicator of the atmospheric environment quality in the current study and these data are retrieved from the observational data of haze and the annual haze monitoring bulletins of Shenzhen national basic weather station during the period of 1979 to 2013. The determination of haze days is based on relevant operational regulations of Guangdong Provincial Meteorological Service, in the light of which a natural day with a daily average visibility less than 10 km and relative humidity no greater than 90% is defined as a haze day. This method can well reflect the historical trend of the atmospheric environment of Shenzhen. The economic data are collected from the Yearly Statistical Books of Shenzhen.

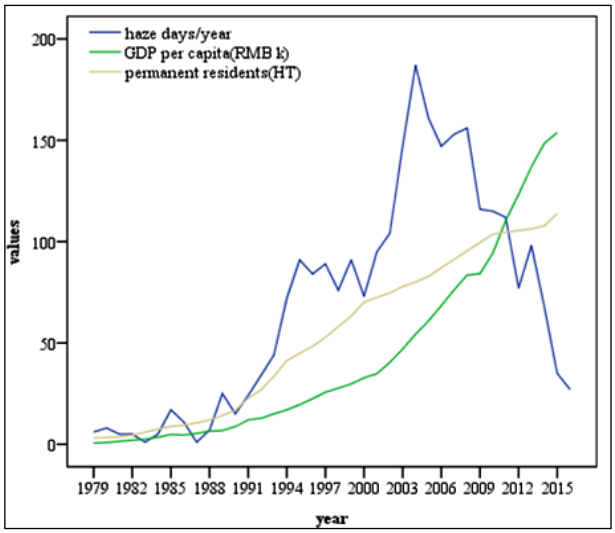



**Fig. 3.** GDP per capita, year-end permanent residents and number of haze days from 1979 to 2015

For research methods, the EKC theory is used to analyze the relationships between the number of haze days and economic growth to establish an environmental Kuznets curve model in Shenzhen. The equations are as follows :

$$Y=\alpha+\beta_1 X+\beta_2 X^2+\varepsilon \quad (1)$$

$$Y=\alpha+\beta_1 X+\beta_2 X^2+\beta_3 X^3+\varepsilon \quad (2)$$

$$Y=\alpha e^{\beta X} \quad (3)$$

where, $Y$ denotes the number of haze days (atmospheric environment quality indicator), $X$ denotes economic indicator, $\alpha$, $\beta$ are coefficients and $\varepsilon$ is the error.

Besides the inter-comparison between the number of haze days and the economic data analysis, the policies driving the industrial restructuring and their impact on the local economy and energy consumption are reviewed.

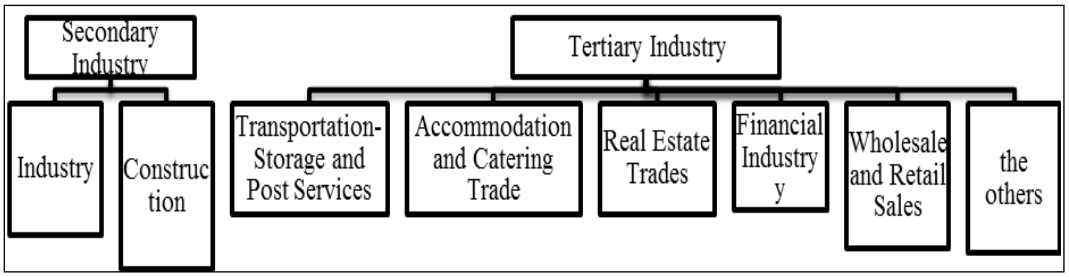



**Fig. 4.** Sectors of primary industry, secondary industry and tertiary industry

## 3. Data analysis

### 3.1. *The variations of the atmospheric environment and the economy*

Many previous studies pointed out that the haze problems in the Pearl River Delta area, where Shenzhen is situated in, are closely related to the atmospheric pollution in this area (Wu *et al*., 2005; Deng *et al*., 2008). Fig. 2(a) shows the trend of the number of haze days from 1979 to 2013 and the pollutant concentrations from 1996 to 2013 in Shenzhen. It can be seen from the figure that the atmospheric environment quality of Shenzhen has first deteriorated and then improved with the turning point appearing in 2005. Fig. 2(b) using Moving T-Test (MTT) to find the change trends of the number of haze days. The number of haze days has kept a rising trend from 1979 to 2004 (MTT statistic Value < 0), growing from an average of less than 10 days in 1980s to 187 days in 2004, then started to drop after 2005 (MTT statistic Value > 0). It can also be found that the major pollutant concentrations also first rose and started to decrease with the same turning point. The independently observed data from the environmental protection agency and the meteorological bureau show that the year 2005 is indeed a turning point in the quality of atmospheric environment in Shenzhen.

From the comparative analysis between atmospheric environment indicators and economic ones (Fig. 3), it can be seen that before 2005, the number of haze days and the GDP per capita/ the number of permanent residents have similar trends, in which pollutant concentrations and the number of haze days kept rising while economy and population grew. However, after 2005, the number of haze days showed a divergent trend with economic and population data. In 2005, the GDP per capita in Shenzhen was RMB 54236 and the number of permanent residents reached 8.2775 million (Fig. 3). The reasons for the appearance of such trends are worth further discussions.

According to the official statistic method used by the Shenzhen Statistical Yearbooks, the economy consists of three industries. The Primary Industry is agriculture and the Secondary Industry includes industry and construction. While the Tertiary Industry includes transportation-storage-post services, accommodation-catering trade, wholesale-retail sales, financial industry, real estate trades and the others (Fig. 4).

Since 1979, the industrial structure in GDP has changed dramatically as the economy rapidly developed. In general, the proportion of the Primary Industry Outputs in GDP continued to decrease, from 37% in 1979 to almost disappear in 2013, which is currently completely insignificant in the GDP structure. The proportions of the Secondary and the Tertiary Industries continued to rise and the proportion of the Secondary Industry has increased from 20% in 1979 to 43% in 2013, while that of Tertiary Industry has risen from 43% in 1979 to 57% in 2013. It is especially notable that the Tertiary Industry began to steadily grow from 2005 and finally exceed the Secondary Industry with larger and larger gaps (Fig. 5).

### 3.2. *The relationship between the climate elements and the number of haze days*

In order to determine whether the decreasing of the number of haze days is caused by climate change or not, the correlation tests between the climate elements and the number of haze days are performed. The climate elements chosen here include annual precipitation (which can remove the pollutants in the air), yearly average wind speed (which can blow away the pollutants) and yearly number of weak cold air activities (which tend to bring stable atmospheric stratification and lead to the occurrence of haze). All the 3 climate elements chosen here are closely related to the atmospheric self purification capability and will have impacts on the number of haze days. However, the results of the Pearson tests suggest that the correlation coefficients between these climate elements and the number of haze days cannot pass the significance test at the level of 0.01 (Table 1). Thus, it can be concluded that the climate change is quite possibly not to be the reason leading to the variation of the atmospheric environment in Shenzhen.

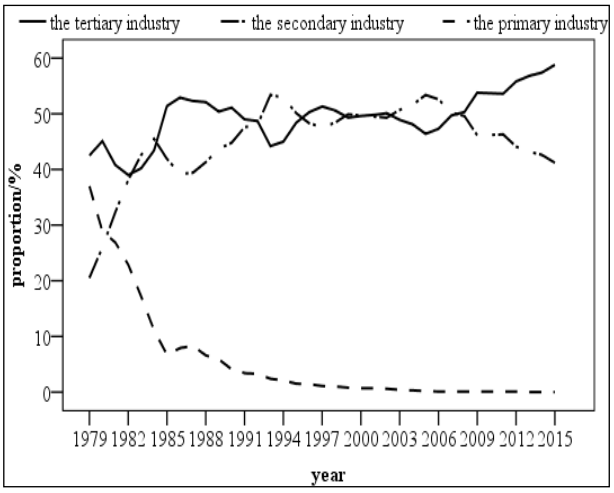



**Fig. 5**.Proportions of the primary, secondary and tertiary industries in GDP from 1979 to 2015

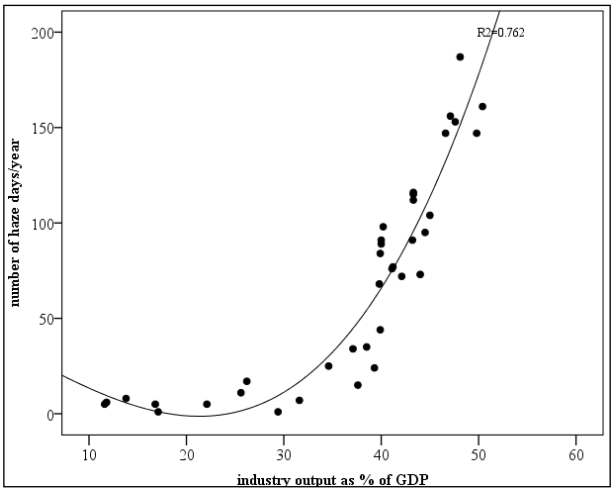



**Fig. 7**. Fitted curve between the number of haze days and proportions of manufacturing outputs in GDP from 1979 to 2015

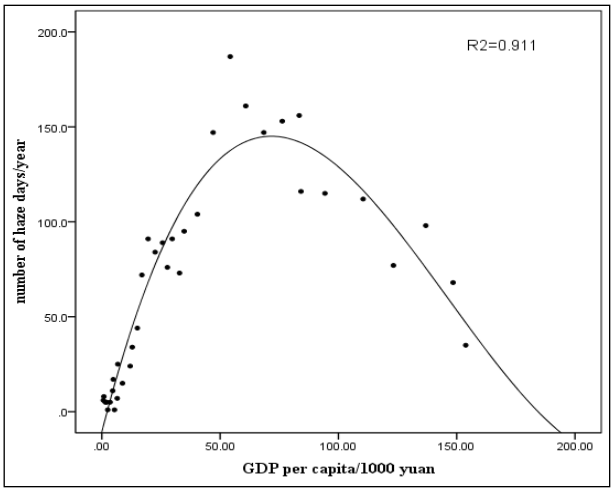



**Fig. 6**. Fitted curves of GDP per capita and the number of haze days from 1979 to 2015

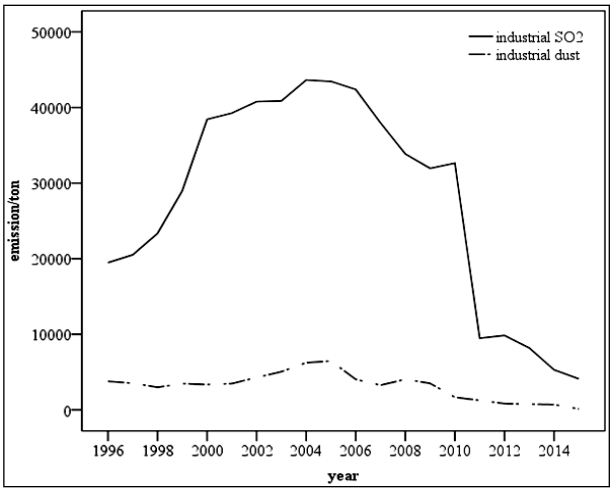



**Fig. 8**. Pollutant emissions from 1996 to 2015

### 3.3. *The relationship between the number of haze days and the economy structure*

#### 3.3.1. *The number of haze days and the GDP per capita*

From the coupling analysis results between number of haze days and GDP per capita, the fitting quadratic equation had the highest correlation, with the degree of coefficient $R^2$ of 0.91 (Fig. 6), whereas the fitted curve had an "inverted U-shaped" form. From the fitted curve, it can be seen that the number of haze days had the trend of first rising and then decreasing with the growth of GDP per capita. This trend can be explained as follows: Initially, the GDP growth was mainly relied on high energy consumption industrial sectors in the Secondary Industry, which will lead to the large quantities of pollutant emissions, therefore, the number of haze days also rose with GDP growth. However, the further GDP growth relied more on the increases of the high-tech industrial sectors or low energy consumption sectors in the secondary and the tertiary industries, whereas emission reduction technologies and pollution control measures are implemented to reduce the pollutant emissions. The cumulative effects of the above the industrial structure variation gradually act as an driving force to improve the atmospheric environment and reduce the number of the haze days.

#### 3.3.2. *The number of haze days and the industry*

The fitting curve between number of haze days and the proportion of manufacturing output in the GDP according to equation (2) had a coefficient of correlation as high as 0.8986 (Fig. 7). The curve form and the high correlation coefficient indicated that the pollutants of the industry emissions might be one of the major reasons of

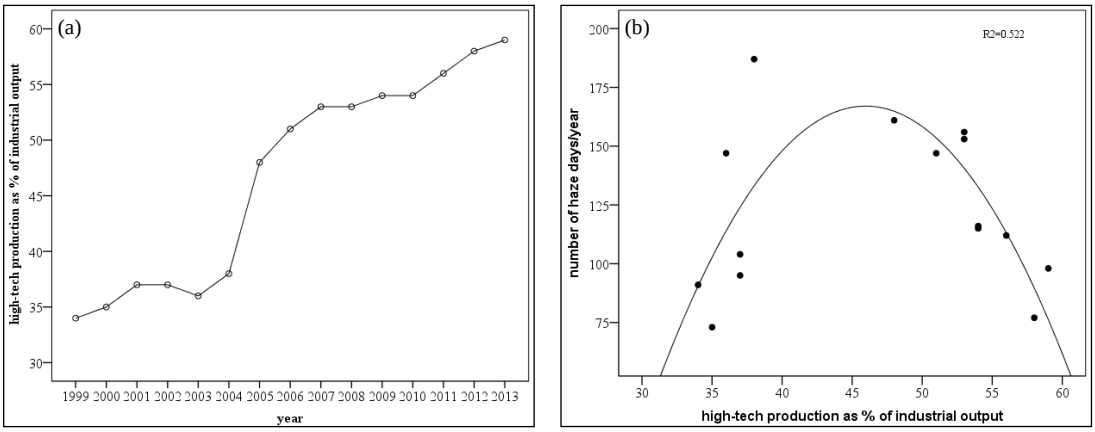



**Fig. 9(a&b)**. (a) The proportion of high-tech products in industrial output from 1999 to 2013 (b) Fitting curve of high-tech product outputs with the number of haze days

**TABLE 1**

**Pearson correlation test between meteorological elements and the number of haze days**

| Item | wind speed ($m \cdot s^{-1}$) | Number of week cold air activities (days) | Annually rain (mm) |
|---|---|---|---|
| Correlation coefficient | -0.307 | -0.25 | 0.004 |

**TABLE 2**

**Pearson correlation test between the numbers of haze days and proportion of Tertiary Industry Sectors in GDP (%)**

| | Real estate trades | Transportation-storage and post services | Accommodation and catering trade | Financial industry | Wholesale and retail sales |
|---|---|---|---|---|---|
| correlation r | 0.839** | -0.727** | -0.557* | -0.122 | -0.592* |

* significant at the 0.01 level, * significant at the 0.05 level.

air quality deterioration in Shenzhen. From 1979 to 2004, the proportion of manufacturing output kept rising with continuous increase of pollutant emissions and rapid growth of the number of haze days. The proportion of the industry reached the highest point at 49.8% in 2006 and then began to drop.

The variation of the industry proportion had been well reflected in the pollutant emissions, which reach their peaks around 2005 (Fig. 8). This peak is almost accordant with that of the industry proportion in the GDP. In recent years, the total pollutant emissions have been reduced substantially, whereas conventional atmospheric pollutants like sulfur dioxide, nitrous oxides, particulate matter ($PM_{10}$) had shown a decreasing trend and steadily satisfied the latest national ambient air quality standard of China.

3.3.3. *The number of haze days and the high-tech industry*

The proportion of the high-tech industry output in the Secondary Industry is a major indicator of the industrial transformation and upgrading in Shenzhen. When analyzing the proportion of the high-tech industry (including the internet, information technology and electronics industries), it can be found that there is a sudden "jump" in 2005 [Fig. 9(a)], which is accordant to the time of the turning point of the number of haze days. The high-tech products have reached a new level since 2005 and the proportion of their output in the total output of the industry has increased from 38% in 2004 to 48% in 2005, with the proportion grew by 10% year over year. The correlation analysis with the number of haze days indicates that the relationship between the proportion of the high-tech industry output in the total output of industry and the number of haze days also conformed to the inverted "U-shaped" form of Environmental Kuznets Curve equation (1) with a coefficient of correlation of 0.65 [Fig. 9(b)]. The number of haze days decreases as the proportion of high-tech industry output increases. In 2005, the proportion of high - tech industry output in industrial output of Shenzhen jumped to as high as around 50% and the number of haze days began to drop since then.

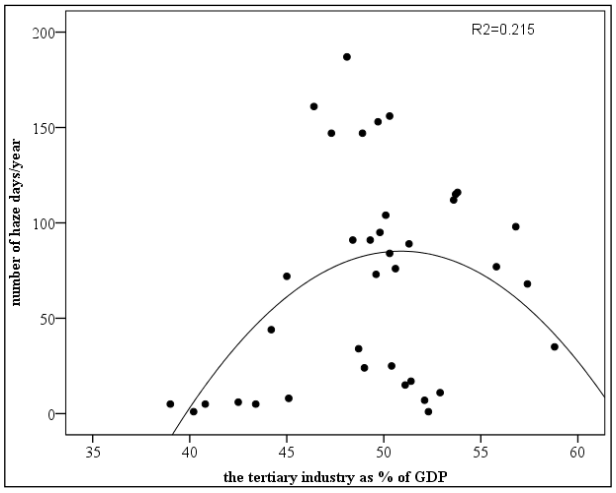



**Fig. 10**. The fitting curve between the proportion of the tertiary industry in the whole GDP and the number of haze days from 1979 to 2015

High-tech industries include information technology, biotechnology and new materials technology. These industries may don't take direct intervention on atmospheric pollution and haze days, but through its own development, the industrial structure optimization is realized, which consequently reduces energy consumption including coal and oil, so as to achieve the goal of improving air quality. Furthermore, some enterprises in high-tech industry are related to pollutant emission monitoring and reduction techniques and the application of these techniques has directly positive impact on local atmospheric environment.

#### 3.3.4. *The number of haze days & the tertiary industry*

In general, the impacts on the environment of the Tertiary Industry are less insignificant than those of the Secondary Industry. Since 1985, the Tertiary Industry of Shenzhen was always fluctuating around 50% and was keeping as the largest industry. Since 2006, the Tertiary Industry showed a growing trend and reached 57% of the whole GDP in 2013. The fitting relationship between the Tertiary Industry proportion and the number of haze days also exhibited the inverted U-shaped distribution with a relatively low fitting coefficient $R^2$ of 0.2157 (Fig. 10). The relatively low coefficient of correlation indicated that the Tertiary Industry may only have less significant impacts on the atmospheric environment over the past 35 years.

The reason why the correlation coefficient between the number of haze days and the Tertiary Industry is low can be attributed to the complexity of the Tertiary Industry. The correlations between the number of haze days and different sectors of the Tertiary Industry are illustrated in Table 2. It can be found in Table 2 that the "transportation-storage and post services" and "the accommodation-catering services" have significantly negative correlation with the number of haze days, while the real estate trades has significant positive correlation with the number of haze days. Apart from the above sectors significantly related to the number of haze days, there are still some other sectors with low correlation coefficients to the number of haze days. Thus, the complexity of the Tertiary Industry sectors is the major reason leading to the low correlation coefficient between the number of haze days and the total output of the whole Industry.

## 4. Policies review

### 4.1. *A brief history on industrial policies in Shenzhen*

In the first ten years after the establishment of the SEZ, Shenzhen's economic development depends mainly on commercial trade and industrial development is in its very initial stage. During that period, any industry which can bring economic benefits are encouraged to develop, so there were quite a lot of manufacturing enterprises with high energy consumption and high pollutant emission appeared in Shenzhen.

In 1990, a new development strategy was formulated by local government, which is "Taking high technology as the forerunner, taking advanced Second Industry as the base, taking the Tertiary Industry as the pillar". This is possibly the first strategy on promoting the High-tech industry in Shenzhen's history. With the instruction of this strategy, related policies are made to guide more capital and social resources into high-tech enterprises.

Starting from 1994, after realizing the negative environment effects brought by low level industrial enterprises, the local municipal government issued a series of new policies on restricting the development of the low level industries. New enterprises on primary production and processing are no longer able to obtain license after 1994 and the existing ones are allowed to continue to exist but encouraged to upgrade their production lines or even their development modes. However, though there are the ups and downs of the Second Industry's share of GDP in this period, the overall size of the Second Industry is still growing. At the same time, the number of the motor vehicles in Shenzhen increased rapidly in the same period. In 2004, there are totally 0.605 million vehicles in Shenzhen, which is of a territory with around 1990 $km^2$. As an impact of the above two factors, the atmospheric

**TABLE 3**

**The policies on the industrial restructuring of Shenzhen from 2004 to 2015**

| No. | Document | Document number | Date |
|---|---|---|---|
| 1 | Decision on Improving the Regional Innovation System to Promote the Continuous and Rapid Development of High-tech Industries | No. 1 of SF ( 2004) | January 16, 2004 |
| 2 | Decision on the Implementation of the Independent Innovation Strategy to Build a National Innovative City | No. 1 of SF ( 2006) | January 4, 2006 |
| 3 | Document of Four Supporting Policies on the Implementation of Decision of the CPC Shenzhen Municipal Committee & Shenzhen Municipal Government on the Implementation of the Independent Innovation Strategy to Build a National Innovative City | No. 8 of SBF ( 2006) | April 19, 2006 |
| 4 | Opinions on Accelerating the Construction of National Innovative City | No. 8 of SF ( 2008) | September 19, 2008 |
| 5 | Policy Measures on Enhancing Independent Innovation to Promote the Development of High-tech Industries | No. 200 of SG ( 2008) | September 21, 2008 |
| 6 | Decision on Accelerating Transformation of Economic Development Mode | No. 12 of SF ( 2010) | October 12, 2010 |
| 7 | Guidance on Accelerating Industrial Transformation and Upgrading | No. 165 of SG ( 2011) | October 28, 2011 |
| 8 | Shenzhen New Generation of Information Technology Industry Revitalization and Development Policy | No. 210 of SG ( 2011) | December 29, 2011 |
| 9 | Measures on Deepening the reform of Science and Technology System to Promote the Science and Technology Innovation Capability | No. 123 of SG ( 2012) | November 2, 2012 |
| 10 | Decisions on Efforts to Build a National Independent Innovation Demonstration Zone to Realize Innovation-driven Development | No. 14 of SF ( 2012) | November 4, 2012 |
| 11 | Notification of Shenzhen Municipal People's Government on the Issuance of Future Industry Development Policy | No. 122 of SG ( 2013) | December 31, 2013 |
| 12 | Shenzhen National Independent Innovation Demonstration Zone Construction Plan | No. 54 of SG ( 2015) | July 22, 2015 |

environment in Shenzhen did not improve after 1994. On the contrary, the number of hazy days reached its peak point in 2004 and a lot of criticism on the atmospheric environment in Shenzhen appeared on the local media.

Starting from 2004, the Shenzhen Municipal Government has vigorously carried out industrial restructuring strategies, economic transformation and upgrading initiatives and a series of relevant policies are issued since then (Table 3). During this period, the development strategy of Shenzhen had been adjusted from the “Shenzhen speed” to “Shenzhen quality” and the issued industrial policies in this period has a clear goal, that is the development mode should be changed from speed oriented to quality oriented. The core of this development mode is to promote the optimization of industrial structure and industrial upgrading and promote more social resources into industries with active innovation, high added-value and low energy consumption. With this strategy, the most stringent industry access standards are issued to promote green production, green manufacturing and green consumption. Since 2009, Shenzhen has introduced 6 major industry strategic planning, which are the internet industry, biomedicine industry, new energy industry, new materials industry, cultural industry and new information technology industry.

### 4.2. *The implementation of the policies and their effects*

Due to the strict implementation of these policies, Shenzhen has made significant achievements in the elimination and transformation of low level enterprises. Statistics data show that more than 10 thousand low level enterprises were eliminated or upgraded and a typical example is the furniture enterprise. Some scientific studies reported that the furniture production and the use of paint is an important source of volatile organic compounds (VOC) and $PM_{2.5}$. In order to eliminate these pollutant sources, Shenzhen moved more than 500 large and medium-sized furniture enterprises out of the city and shut down 112 coating production lines, though they can bring a GDP of 85 billion Chinese Yuan. With these efforts, many outdated production facilities and polluting enterprises were closed down for less competitiveness and worse market environment. Apart from the furniture enterprises, the iron and steel, the cement, the electrolytic aluminum, the coal and the other sixteen heavy polluting industries basically disappeared from Shenzhen and the local media proudly reported that it was difficult to see a smoking chimney in the city.

In 2010, Shenzhen completed "oil to gas" transformation projects for all 11 fuel power plants. In July 2011, the municipal government set the whole region

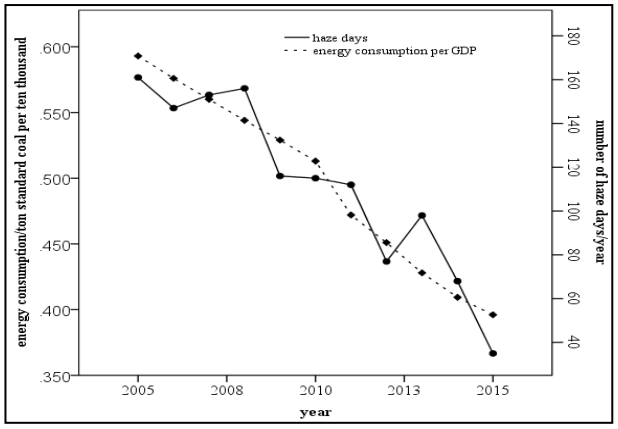



**Fig. 11**. Energy consumption per GDP and the number of haze days from 2005 to 2015

of Shenzhen as a ban zone for high pollution fuel burning and more than 1 thousand high pollution boilers are eliminated or reformed into low pollution ones.

In 2013, economic development in Shenzhen achieve a historic breakthrough : the growth rate of the strategic new emerging industries reached 20.5% and the total amount reached more than 500 billion Chinese Yuan, whose proportion in the GDP is more than 1/3. In that year, the contribution of the strategic new emerging industries to the whole GDP growth rate for the first time exceeded 50%, which has become to be the main engine of economic development.

Apart from the industry upgrading, the policies also attracted more investment on the environmental protection in Shenzhen, which has increased year by year, from RMB 7.95 billion in 2004 to 29.865 billion in 2011. In recent years, the number of haze days are steadily decreasing, while the proportion of environmental protection fund in the GDP is keeping above 2.4%.

The industrial restructuring policies also lead an increase of the energy efficiency in Shenzhen. According to the Shenzhen Statistical Yearbook in 2013, the major energy sources of Shenzhen included raw coal, raw petroleum and natural gas and their percentages were 91%, 3% and 6% respectively. The raw coal was still the largest energy consumption source in Shenzhen. The raw coal and the natural gas are mainly consumed in the production and supply of the electric power, the gas and the water. For improving the air quality, the industrial restructuring direction should be geared towards technology-intensive industries with low energy consumption and high added value. Based on the energy consumption data since 2005, the industrial restructuring of Shenzhen has led to a decreasing trend of the energy consumption per GDP year by year and the correlation of the energy consumption per GDP and the number of haze days is 0.946, which can pass the significance test at the level of 0.01. Thus it is easy to conclude that with the improvement of the energy efficiency, the air quality of Shenzhen is ameliorating and the number of haze days keeps dropping in a fluctuating way (Fig. 11).

## 5. Conclusion and policy implications

The atmospheric environment quality of Shenzhen has experienced a trend of "first deteriorating and then improving" over the last 35 years. As the economy in Shenzhen develops, the number of haze days first increased and then decreased with the turning point appearing in around 2005. The current study focuses on the possible reasons leading to such turnaround from the perspective of industrial structure. The major conclusions are as the following :

(*i*) The correlation coefficients between the major climate elements (yearly average wind speed, the annual total precipitation and the yearly number of weak cold air activities) and the number of haze days cannot pass the significance test at the level of 0.01. The poor correlation between the climate elements and the number of haze days suggests that the temporal variation of the number of haze days in Shenzhen over the last 35 years may not be caused by the local climate change, though the local climate in Shenzhen does have a significant change over the last 35 years under the impact of global climate change and local rapid urbanization.

(*ii*) The correlation coefficient between the number of haze days and the GDP per capita can pass the significance test at the level of 0.01 with the fitting curve between them distributed in an "inverted U-shaped" form. When the GDP per capita was small, the number of haze days grew with the increase of the GDP per capita. After GDP per capita has reached a certain level, the number of haze days began to drop with the increase of GDP per capita. The turning point was at around 2005, with GDP per capita of that year was RMB 54,236. The variation of the haze days along with the GDP is a new evidence for the Environmental Kuznets Curve Theory.

(*iii*) In Shenzhen, the proportions of the Secondary Industry and the Tertiary Industry in the whole GDP had significant changes since 2005. The proportion of the Secondary Industry began to continually reduce and the proportion of the Tertiary Industry significantly kept rising since 2005, which is quite accordant to the time when the number of haze days began to reduce. The above facts hint that the adjustment of the industrial structure is quite possibly the major reason leading to the significant reduction of the number of haze days in Shenzhen.

(*iv*) From the point of specific industry sector, the high-tech industry is especially notable. The proportion of the high-tech industry in the Secondary Industry has been keeping rising since 1999 and had a sudden jump in 2005. The fitting curve between the high-tech industry and the number of haze days is also in a typical "inverted U-shaped" distribution and the correlation coefficient can pass the significance test at the level of 0.01, which means that the development of high-tech industry in the Secondary Industry may play an important role in the variation of the atmospheric environment in Shenzhen. Along with the increase of the high-tech industry, the number of haze days in Shenzhen is expected to continually reduce in the future.

(*v*) Since 2004, a series of policies on promoting the industry upgrading were issued by Shenzhen Municipal Government. Due to the implementation of these policies, Shenzhen has made significant achievements in the elimination and transformation of low level enterprises. Statistics data show that more than 10 thousand low level enterprises were eliminated or upgraded, many outdated production facilities and polluting enterprises were closed down for less competitiveness and worse market environment. The policies have played a positive and important role in adjusting the industrial structure, promoting the energy efficiency and consequently reducing the number of haze days.

The experiences in Shenzhen show that though the market should be taken as the basic tool to determine the allocation of the social and capital resources, the scientific industry policies are still essential to achieve a reasonable industry structure avoid negative environmental effects brought by disorder development. The experiences in Shenzhen also hint that in developing countries it is possible to avoid taking a too long time to cope with polluted atmospheric environment, the government in the developing countries should realize that atmospheric environmental problems are not only "environmental" problems and they could play more important roles in managing the environment by making and carrying out scientific industrial policies.

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