The relationship between growth and the environment in Beijing, using PM2.5 concentrations.

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Abstract
This study examines the relationship between income and the environment in Beijing from 2008 to 2017 using quarterly data. The indicator for environmental quality is concentrations of Particular Matter (PM) 2.5, from the Mission China Air Quality Monitoring Programme (MCAQMP), whose observation site is in the US embassy in Chaoyang District, Beijing. By adding cubic GDP and other variables consistent with the Urban Environmental Kuznets Curve Hypothesis, such as green space and the length of the road network, the result suggests an N-shaped pattern rather than the conventional inverted U shape. The per capita GDP for Beijing is currently slightly lower than the second turning point, suggesting that the degradation would become more severe as income grows, if no new development strategies are implemented in the city.

Keywords: Environmental Kuznets Curve; PM 2.5; Beijing.

JEL Classification: O18, Q53, Q56.

Acknowledgements: We wish to thank Riccardo Scarpa, seminar participants at Durham University, two anonymous referees and an associate editor for valuable comments that greatly improved this paper. The first author is also grateful to the China Scholarship Council for financial support while undertaking this research.

1.Introduction

The environmental Kuznets curve (EKC) hypothesis states that economic growth leads to degradation and pollution but, beyond some level of income per capita, it is conducive to an improvement in environmental quality (inverted U-shaped relationship). The EKC hypothesis has become a powerful tool in analysing the empirical relationship between growth and the environment. The literature on the EKC has relentlessly proliferated since the seminal contribution of Grossman and Krueger in 1991, to take into account different pollutants and control variables.[1]

A recently published paper by Stern and Zha (2016) highlights two very recent developments in the extensive literature on EKC hypothesis, namely the importance of ambient pollution concentrations and the opportunity offered by newly recorded particular matter (PM2.5) at urban level.

The need to consider ambient pollution within the EKC framework is embedded in the concept of Urban EKC. The urban dimension is generally captured by including variables shedding light on the relationship between ambient pollution and economic growth, such as emissions from urban transport, suspended particular matter in urban areas, municipal solid waste, population density, characteristics of transport network etc. Examples of studies within the Urban EKC literature are Hilton and Levinson (1998) for 47 countries, Day and Grafton (2003) for Canada, Orubu and Omotor (2011) for African countries, Asahi and Yakita (2012) and Hossain and Miyata (2012) for the urban areas of Yokkaichi and Toyohashi, Japan, Kim et al., (2016) for South Korea and Sinha and Bhattacharya (2016) for India.

Nevertheless, to our knowledge, most of the research on the Urban EKC is based on China either at province or city level, as China is experiencing a remarkable urbanisation growth, coupled with consistently high energy consumption and pollution (Dhakal, 2009).[2] Since the early 2000s, studies on the urban EKC in China have been undertaken with regularity and include a wide range of environmental and urban indicators. Results also support a variety of estimated EKC, from the standard inverted U-shape to the more unusual U-shape and N-shape.

As data for PM2.5 concentrations have only recently become available with sufficient frequency[3], EKC studies using PM2.5 as an indicator of ambient pollution are scarce (Stern and Zha, 2016; Hao and Liu 2016). Yet PM2.5 concentrations have been proven to be extremely harmful to human health[4] by affecting respiratory and cardiovascular functions and causing cancer, and to ecological systems

In this paper, we examine the relationship between income and the environment in Beijing using PM2.5 concentrations as our chosen environmental indicator. In addition to being

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1 See for example, the country level studies by Grossman and Krueger (1995), Shafik and Bandyopadhyay (1992), Panayotou (1992, 1993 and 1995), Cropper and Griffiths (1994), Bhattarai and Hamming (2001), Markandya et al. (2006), Plassmann and Khanna (2006).

2 The percentage of population living in urban areas has increased in China from 40% in 2005, to 57.3% in 2016, with 790 million residents in urban areas (see https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS).

3 Only recently, concentrations of PM2.5 have been regulated and regularly recorded. Although some measurement of PM2.5 concentration was undertaken in the US already in the late 1990s, the US implemented daily standards in 2007, followed by Japan in 2009, Russia in 2010 and more recently by the EU and South Korea in 2015.

4 See Sørensen et al. (2003), Cohen et al. (2005), US EPA (2009), Janssen et al. (2011).

the national capital of China, Beijing is identified in the latest Chinese national plan[5] as one of 35 major cities in terms of size and economic significance. These cities, with less than 20% of the national population, account for 40% of total energy consumption and are characterized by high pollution levels. As PM 2.5 is considered an ambient pollutant, we include relevant local variables such as green space, and length of road network as controls. By using a recently available dataset for PM2.5 from the Mission China Air Quality Monitoring Programme (MCAQMP) which possesses high reliability[6], we are able to provide the first EKC analysis of a Chinese city for the medium run. Contrary to most of the existing literature, our analysis supports an N-shaped EKC relationship[7]. The first turning point is about 60,000 CNY per year while the second turning point is about 132,000 CNY per year. The income at the second turning point is just above the current average income of Beijing residents. The improved environment quality in the last several years can mainly be attributed to the implementation of stringent government environmental policy while the latest spur in pollution may be a consequence of the stimulus growth policies implemented since late 2014[8]. These results suggest that in the next decades, it may be extremely challenging to achieve stable growth rates and high air quality in China.

The paper proceeds as follow: Section 2 surveys the existing literature on Urban EKC hypothesis for China; Section 3 describes the data used in this paper; Section 4 focuses on the empirical model and the econometric methodology; Section 5 presents the results from our empirical analysis; Section 6 includes some policy implications for Beijing and section 7 concludes and offers suggestions for future research on the Urban EKC.

2. A Survey of the Existing Literature on the Urban EKC in China

To our knowledge, the first study that addresses the existence of EKC in China is De Groot et al., (2004). They use data from 30 provinces from 1982 to 1997 and include waste water, water gas, and solid waste, as environmental indicators and a regional specific intercept. Their results support a typical EKC for water gas, an N-shaped relationship for solid waste, and a monotonically decreasing relationship for waste water.

Shen (2006) examines the EKC hypothesis for 31 Chinese provinces. It includes five pollutants, Sulphur Dioxide (SO2) and Fall Dust for air, Organic Pollutants, Arsenic, and Cadmium for water, with population density, industrial share and abatement expense as control variables. The results suggest an EKC relationship for water pollutants and for SO_2, but no relationship for Fall Dust.

Liu et al., (2007) test the EKC hypothesis in Shenzhen, based on data from 1989 to 2003. They include a large number of pollutants for several environmental media, including major

[5] See http://www.mlr.gov.cn/tdsc/djxx/djjc/201004/t20100401_143692.htm. Beijing has been listed as one of the main observation cities since 2008, by the Ministry of Housing and Urban-Rural Development

[6] Official data from China has been found not to be reliable as air quality measurements are related to the career progression opportunities of officials and therefore may be prone to manipulation (See Chen et al., 2012 and Ghanem and Zhang, 2014).

[7] Other EKC studies that find an N-shaped EKC, although in a different setting, are Shafik and Bandayopadhyay (1992), Grossman and Krueger (1993), Selden and Song (1994) Panayotou (1997).

[8] See Bloomberg 2015 *China Stimulus Kicks in to Help Keep 2014 Growth Near Target*, https://www.bloomberg.com/news/articles/2015-01-19/china-gdp-beats-estimates-leaving-2014-expansion-close-to-target

rivers and near-shore water. The results show that production induced pollution support the canonical EKC hypothesis, while consumption related pollutants do not.

Brajer et al. (2008) test the relationship between SO_2 and per capita income based on city level data in China from 1990 to 2004, with population density as control. Using different econometric methods, both the inverted U-shaped and N-shaped EKC are supported.

Based on Chinese provincial data from 1985 to 2005, Song et al. (2008) investigate the EKC hypothesis between GDP per capita and three environmental indicators: waste water, waste gas, and solid waste, without adding control variables. Their results assert that all these three environmental indicators follow an inverted U-shape EKC relationship and the turning point for waste gas is lower than the other two indicators

Diao et al., (2009) analyse the relationship between GDP per capita and a number of industrial pollutants, with environmental policies, investment strategies, and contribution to GDP as control variables, for Jiaxing city. An inverted U-shape relationship is observed for industrial waste water, industrial waste gas, SO2, and industrial dust. The turning points for the pollutant are generally lower than previous studies in China and lower than the turning points in developed countries and can be explained by the early local government policies against industrial pollution.

Shaw et al. (2010) examine the EKC hypothesis for 99 cities in China from 1992 to 2004. Air pollution includes SO_2, Nitrogen Oxide (NOx) and particle deposition, and control variables include population density, contribution of secondary industry to GDP, and a policy variable. The conclusion shows only SO_2 supports an inverted U shape, while NO_X increases as income grows.

He and Wang (2012) analysis the impact of economic structure, development strategy and environmental regulation on the shape of the EKC, using city level data from 1990 to 2001. The relationship between environmental indicators, SO2, NOx, total suspended particles (TSP) and GDP per capita are examined, with openness, regulation, population density, area, and capital/labour ratio as control variables. Openness, measured by FDI, always increases the level of the three pollutants, and capital abundance increase the concentration of TSP but decrease the concentration of NOx.

Luo et al., (2014) support a negative linear relationship between Gross Regional Product per capita and particulate matter 10 (PM10) concentrations in all province capitals for the last decade. However, only the PM10 concentration in the central parts of China are significantly related to GRP,

Sun and Yuan (2015) examine the relationship between GDP per capita and three indicators for environment, including industrial SO2, industrial soot, and industrial sewage discharged, based on data for 287 cities in China from 2003 to 2008. Besides, population density, area, variables standing for agglomeration are used as control variables. Their results show an N-shaped EKC for all three pollutants with industrial agglomeration having a significant influence on regional environmental quality.

Zhang et al., (2016) analyse the relationship between a comprehensive air quality index (API) and wealth based on data for 26 capital cities and 4 municipalities in China from 2002 to 2010. As control they include population size, urbanization level, industrialization level, green coverage level, and pollution control investment. Economic level shows an inverted U shape EKC and the turning point is about 63,000 CNY.

Wang and Ye (2017) illustrate the monotonic increasing relationship between Carbon Dioxide (CO2) emission and GDP per capita using city-level data and employing a spatial lag model and a spatial error model. As a novelty from the previous literature, Wang and Ye include dummy variables for coastal and central cities.

Finally, the latest developments in the literature include the use of particulate matters 2.5 data. Stern and Zha (2016) use PM 10 and PM 2.5 data from the years 2013 and 2014 for 50 Chinese cities to regress pollution growth on GDP growth. They find U-shaped relationship which however results to be statistically insignificant. Similarly, based on data for 73 Chinese cities in 2013, Hao and Liu (2016) examine the influence of GDP per capita, population density, transport, and industry on air quality. All estimation models, OLS, spatial lag model (SLM) and spatial error model (SEL) support a U-shaped EKC.

Given the fast-paced developments in connection to the Urban EKC hypothesis and the growing interest for China, as a key player in the global economy, we expect this literature to expand considerably in the next few years. Our paper intends to contribute to this literature by focusing on the case of Beijing.

3. Data

In this paper, the urban unit of reference is the city of Beijing and the pollutant used for the analysis is PM2.5 concentrations, whose source is local. Controls are also local level variables such as population, green space and length of road network. In the proceedings of this chapter we exactly define the urban area, the data and all issues surrounding their measurements.

The reason why the paper focuses on Beijing rather than other cities can be explained from several perspectives. Firstly, Beijing, as the capital of China, has all the hallmarks of an ideal unit of investigation for the EKC Hypothesis. Indeed, the city attracts large amounts of labour, capital, and intelligence resources which contribute to the rapid urban development, but also the degradation of the city's air quality. Secondly, Beijing is due to undergo an ambitious urban restructuring plan as highlighted in the city development plan for the year 2035[9]. Beijing will raise its profile as the political centre of China by focusing on developing its tertiary sector rather than industrial production and agriculture and restricting granting permanent residency rights to highly skilled workers. Heavy industries have already been relocated to neighbourhood provinces such as Hebei and Tianjin to decrease the effects of sulphur dioxide and particulate matter[10]. Therefore, the findings of this paper may inform the city planners of the likely environmental impact of further development projects in the city. Thirdly, the availability of data for Beijing is higher than for other cities.

3.1. Definition of Urban Area

According to the China City Statistical Yearbook, 2016, Beijing metropolitan area includes 16 districts (see map in Figure A below). Dongcheng and Xicheng Districts are the core parts of

[9] See Beijing government (2017*): Beijing General Urban Plan 2020-2035.* http://zhengwu.beijing.gov.cn/gh/dt/t1494703.htm

[10] One example is the Shougang Group, one of the largest steel companies located in Beijing that started moving to Hebei since 2005 in the preparation for the Olympic Games of 2008.

Beijing, historically dating back to the Qing Dynasty[11]. Together with the four surrounding districts of Haidian, Chaoyang, Fengtai and Shijingshan, they are referred to as the Urban Six District. In 1949, six more districts were added to the Beijing metropolitan administrative area: Shunyi, Changqing, Mentougou, Fangshan, Daxing, and Tongzhou. As the 2035 city plan indicates, these districts are becoming increasingly important, with the city administrative offices being gradually moved to this suburban area. In 2000, four more districts in the north of Beijing were included in the Beijing metropolitan area.

Recently, the newly-published city planning encourages residents to move away from the Urban Six Districts to other districts, in order to enjoy better living conditions and lower house prices. Therefore, nowadays, many workers still need to commute daily to the Urban Six Districts for work. As one of the major sources for local PM2.5 concentrations is transport (Zíková et al., 2016), it makes sense to include all 16 districts of Beijing into our investigation area.

According to the statistic Yearbook of China, the acreage of Beijing does not change from April 2008 to June 2017, despite the implementation of a few changes affecting the districts borders[12]. Therefore, acreage is not considered as a variable in this paper. Also, as acreage is fixed we only use population and not population density to capture the effects of urbanisation.

Figure A: Beijing Metropolitan Area

Source: http://www.dsac.cn/file/attached/image/20150720/20150720164446_6118.jpg

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[11] In 2010, the districts of Dongcheng (1 in the map in Figure A) and Chongwen (3 in the map) were merged into the Dongcheng district, and the districts of Xuanwu (2 in the map) and Xicheng (4 in the map) were merged into the Xicheng district.

[12] One is the consolidation of the four central districts into two, Dongcheng and Xicheng, in 2008; another is the establishment of a new district, Xiong'an, in 2017.

3.2 Data Description

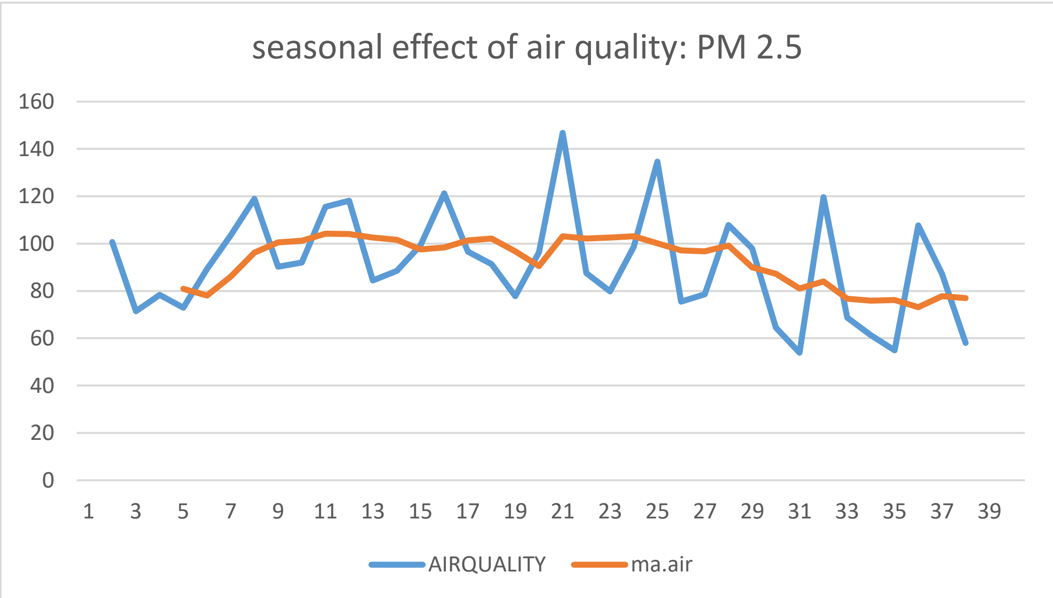
Data for environmental quality PM PM2.5 concentrations are from the Mission China Air Quality Monitoring Programme (MCAQMP) available online at http://www.stateair.net/web/historical/1/1.html, which started as a means to provide reliable information about air quality in China for US expats. The observation site is in the US Embassy, which is located in the Chaoyang District, one of the busiest downtown areas in Beijing. Air quality recordings from the embassy site are less frequents than recordings from official national sites, nevertheless, they are the longest publicly available recorded data for PM2.5 in Beijing having started in April 2008. In addition, a new study (Zhang and Mu, 2017) finds that the data for PM2.5 from the Chinese Ministry of Environmental Protection are correlated with the data from the US Embassy, hence we expect our results not to be biased.

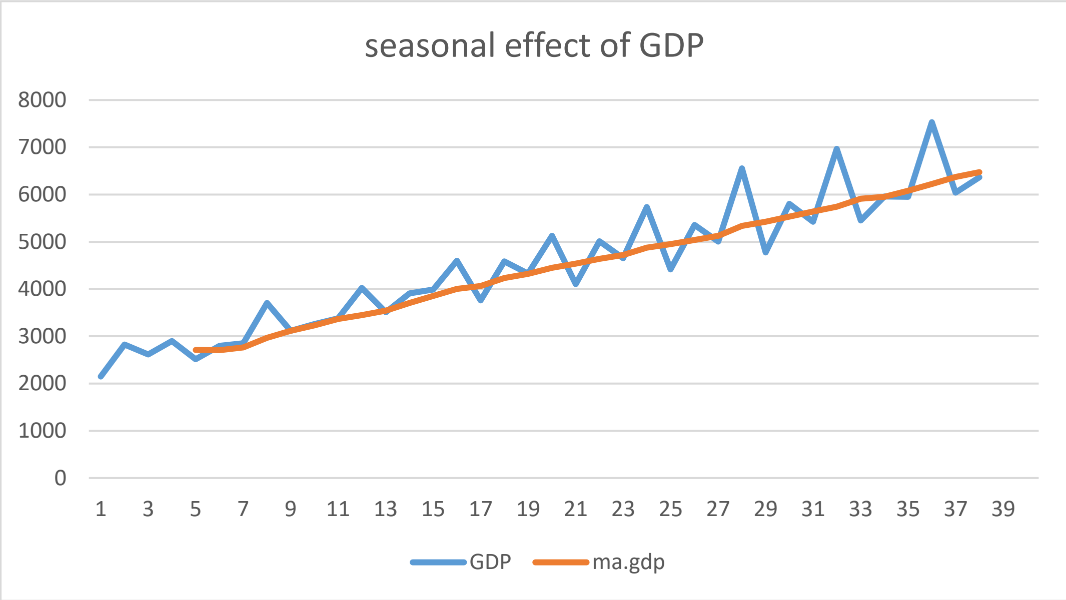
Our dataset contains data from April 2008 to May 2017, typically with one observation per hour. Tables A and B below gives a brief summary of the data and their descriptive statistics. Our indicator for pollution is the quarterly average of PM 2.5 concentrations from the second quarter of 2008 to the second quarter of 2017 (the longest interval we have data for). There are 37 observations in total.

The data for population and GDP are from the Statistic Yearbook of Beijing. Quarterly data for GDP are available, while for population defined as the number of residents in Beijing metropolitan area, observations are annual. By calculating the growth rate of population each year, interpolation is used for population. For other variables, including length of road network and green space, we use the same interpolation method to generate more data points for our regression analysis.

As both the data for PM2.5 and GDP present the problem of seasonality (see graphs below) we smooth the series by applying the moving average method.

Figure B: Seasonal effects





Source: Own elaboration from relevant data.

Other variables of interest are green space (Zhang et al. 2016) and length of roads as those have been identified in the literature as having an impact on urban pollution. Green space, or parks, play an essential role in ameliorating air quality in a city. Yin et al., (2011) estimate that vegetation in Shanghai contributes to 9.1% of TSP removal. Tallis et al., (2011) estimate that the removal of PM 10 by urban trees in the Greater London Authority is between 0.7% and 1.4%. Longer road length is supposed to serve more vehicles. Vehicles and dust from the road are a major source of PM 2.5 in urban areas (Cassady et al., 2004); furthermore, increasing highways capacity is found to be positively related to the vehicle mileages, suggesting a positive correlation with emissions as well (Noland, 2000).

Table A: Data Description

Data	Source	Website	Frequency	Time span
PM 2.5	US Embassy	http://www.stateair.net/web/historical/1/1.html	hourly	Since April 2008
Populat.	Beijing Macroeconomics Database	http://www.bjhgk.gov.cn/	yearly	1949 - 2016
GDP	Beijing Bureau of Statistics	http://www.bjstats.gov.cn/tjsj/yjdsj/GDP/2018/	quarterly	Since Q1 2005
Green Space	Beijing Macroeconomics Database	http://www.bjhgk.gov.cn/	yearly	Since 1975
Length of road network	Beijing Macroeconomics Database	http://www.bjhgk.gov.cn/	yearly	2003 - 2016
T	Time trend: T= year-2007			
Quarter1	Dummy Variable; =1 when the data is in the 1st quarter; =0 in 2,3,4 quarter			
Quarter2	Dummy Variable: =1 when the data is in the 2nd quarter; =0 in 1,3,4 quarter			
Quarter3	Dummy Variable: :=1 when the data is in the 3rd quarter; =0 in 1,2,4 quarter			

Table B: Descriptive Statistics

Variable	Mean	Std. Dev	Min	Max	No. of observation
Air quality	91.6	21.5	53.9	146.8	37
Population	2029.2	141.0	1732.6	2174.1	37
GDP	4564.6	1301.1	2511.9	7531.5	37
GDP per capita	2.2	0.5	1.4	3.5	37
Green space	15.3	0.9	13.2	16.4	37
Length of road network	14.0	0.6	13.3	15.2	37

4. Model and Methodology

The empirical model used in this paper is based on Grossman and Kruger (1995) and can be expressed as:

$$\text{ma.airquality} = \beta_0 + \beta_1(ma.gdp/population) + \beta_2(ma.gdp/population)^2 + \beta_3(ma.gdp/population)^3 + \beta_4 Z + \varepsilon$$

where, ma.airquality is measured by PM 2.5 concentrations; $ma.gdp\ /population$ is Beijing per capita GDP. For completeness we both include the squared and cubic values of $ma.gdp\ /population$. As control variables, we use: Greenspace (including public parks); Length of the road network (the length of road per capita, an indicator for transport activities); Year, a linear time trend; 3 dummy variables, one per quarter to capture the seasonal effects of pollution (with Q4 being our omitted dummy). We perform OLS estimations.

In the EKC literature, the most common shape for the relationship between income and pollution is an inverted u-shape pattern, that means β_3 should be insignificant, while β_1, β_2 should be both significant with $\beta_1 > 0$ and $\beta_2 < 0$. For other patterns the coefficients take on the signs reported in the Table C below (Song et al., 2008):

Table C: Different EKC Patterns

Pattern	β1	β2	β3
N shape	>0	<0	>0
Inverted N shaped	<0	>0	<0
Inverted U shape	>0	<0	Insignificant
U shape	<0	>0	Insignificant
Monotonously increasing	>0	Insignificant	Insignificant
Monotonously decreasing	<0	Insignificant	Insignificant

5. Results

Table D below presents the results of 4 OLS regressions. Regressions 3 and 4 use logs of all variables, regressions 2 and 4 do not include green space and length of road as those are found to be highly correlated with GDP (see Table E below).

Table D: OLS Regression Results for PM 2.5 Concentrations

	1	2	3	4
	ma.airquality	ma.airquality	log(ma.airquality)	log(ma.airquality)
Intercept	-503.07	-540.84***	5.75	2.45***
	(707.62)	(113.17)	(12.00)	(0.46)
ma.gdp/population	856.87	921.88***	8.574	8.16***
	(679.09)	(168.75)	(6.96)	(2.04)
(ma.gdp/population)^2	-406.99	-439.26***	-11.39	-11.01***
	(313.36)	(87.31)	(9.38)	(3.22)
(ma.gdp/population)^3	55.26	60.54***	3.34	3.52**
	(43.72)	(13.24)	(3.51)	(1.35)
T	17.9	17.58**	0.22	0.16*
	(18.25)	(7.49)	(0.20)	(0.08)
Quarter1	-12.88	-12.71**	-0.16	-0.11*
	(14.43)	(5.90)	(0.16)	(0.06)
Quarter2	-10.51	-9.77**	-0.13	-0.08*
	(9.97)	(4.51)	(0.11)	(0.05)
Quarter3	-6.89	-6.69**	-0.08	-0.06
	(5.92)	(3.24)	(0.06)	(0.04)
Greenspace	-0.02	----	-0.56	
	(23.36)		(3.82)	
Lengthofroadnetwork	629.32	----	0.41	
	(31330)		(2.49)	

- Standard error in parenthesis;
- One, two, or three asterisks indicate significance levels at 10%, 5%, or 1% respectively.

All four regressions (although the coefficients in regression 1 and 3 are not statistically significant) show an N-shaped relationship between air quality and income, with positive coefficient for per capita GDP and GDP cubic and negative for GDP square.

In regression 2, all coefficients are significant, and the goodness of fit is high (R^2=0.86), indicating that regression 2 is a good description of the EKC relationship in Beijing. The first turning point is reached at 15,272 CNY (2009 Q4) per quarter or 60,000 CNY per year and the second turning point will be reached at 33,500 CNY per quarter or 132,000 CNY per year. When income is in the interval of the first and second turning point, PM 2.5 decreases as income grows. From the second turning point onwards, pollution starts increasing again as income increases. Per capita income in Beijing in 2017 Q2, the last quarter in our dataset was 29,280 CNY a little lower than the income associated with the second turning point. It suggests that Beijing will shortly reach the second turning point and it is possible that the environment will worsen as income grows, if tailored structural policies or stricter environmental policies are not implemented.

The negative coefficients of the seasonal variables Q1-Q3 suggests that air quality is worse (higher PM2.5 concentrations) in Q4, which may be explained by the start of the winter season in Beijing and therefore higher use of fossil fuels (including coal) for central heating. This effect is also well highlighted in the previous literature (see He et al. 2002; Duan et al. 2006 and Zhao et al. 2009).

The time trend in all four regressions are positive, indicating that the pollution will rise as time goes. The reason for may be due to low-energy efficiency of the Beijing economy (China energy development report 2008) which calls for urgent energy efficiency reforms.

The coefficients for green space and length of road network, although insignificant, present the expected sign (see regressions 1 and 3). The concentration of PM 2.5 is positively related to length of road network, suggesting that longer roads lead to more vehicles and therefore higher air pollution. The coefficient of green space is negative and suggests a small reduction in pollution by a unitary increase in green space. One potential explanation for these variables being insignificant is that they are highly correlated to GDP per capita, and GDP per capita is positively related to air pollution. As shown in Table E below, Variance Inflation Factors (VIF) of green space and length of the road network are greater than 30, suggesting multicollinearity. We therefore proceeded to eliminate those two variables from regressions 2 and 4 in which most of the coefficients are significant and of the correct sign.

Table E: VIF; All Regressions

	regression 1		regression 2		regression 3		regression 4	
	Uncentred	Centred	Uncentred	Centred	Uncentred	Centred	Uncentred	Centred
C	782956	NA	22381	NA	1882737	NA	2877.4	NA
MA_GDP /POPULATION	3535771	129066	249800	9563	387370	25224	35555	2367
MA_GDP /POPULATION)^2	4218520	526737	385991	50319	531688	100334	69254	13304
MA_GDP /POPULATION)^3	508581	117572	56837	13644	63205	19401	10634	3313
T	19497	2960	3854	595	20349	3089	3433	530
Q1	89	65	16	11.8	92	67	14	11
Q2	38	29	9	7	39	30	8	6
Q3	13	10	4	3	13	10	4	3
GREEN SPACE	203792	370			1426623	358		
LENGTH OF ROAD	72262	691			2019113	728		

6. Discussion and Policy Implications

In Panayotou (1997) some intuitions are given for the occurrence of the first turning point. When income reaches a relatively high level, consumers' demand for environmental goods, such as energy efficient housing and cars increases. Furthermore, more resources can be devoted by the government towards environmental protection further decreasing degradation[13].

The Beijing government has placed air pollution control as a priority since 1998, and a

[13] Panayotou (1997) found that improvements in the quality of institutions (policies) by 10% will lead to a 15% reduction in SO_2 emissions. Bhattarai and Hammig (2001) found that the quality of official policies is negatively related to deforestation.

variety of measures has been significantly implemented ever since. These measures include clean energy promotion, on-road vehicle constraints, industrial construction upgrading, air quality monitoring and forecasting system, and education aiming at public awareness of air quality. Examples of pollution control policies are: The 'Green Olympic' implemented for the 2008 Beijing Olympics Games[14], and the 'Beijing Clean Air Action Plan 2013-2017' which includes reduction of PM 2.5 emissions.

Furthermore, the dependency of the city on coal has been lessen by restructuring the power generation process and by phasing out coal-based boilers for domestic heating (UNEP 2016). For power generation, coal was the major source until 2005, when natural gas was introduced in the production process. Consequently, the total thermal coal consumption in Beijing has decreased from 9 million tonnes in 2005 to 6.4 million tonnes in 2013. By 2013, natural gas accounted for 35% of the total energy consumption for the thermal power sector. This coupled with the promotion of end-of-pipe control technologies has led to a substantial decline in PM 2.5 emissions in 2013 compared with 1998 levels (UNEP 2016). The process of removing coal-based boilers in Beijing started with small boilers (in 1998), boilers under 14MW capacity (2003-2008), and finally with all other coal-based boiler types (2009-2013) in the urban six areas. In the more suburban areas, small size boilers were replaced or connected to large size boilers (2006-2009). Besides, boiler operators are given incentives incentive to innovate. In 2013, the reduction of PM 2.5 emissions from removing coal-based boilers was about 20 thousand tonnes with respect to 1998 levels.

The control of transport emissions includes emission control on new and in-use vehicles, fuel quality improvement, promotion of clean and new energy sources, and better traffic management.

Perhaps the most interesting result of this paper is that Beijing is fast approaching a second turning point. This is often explained in the literature by the so-called scale effect of further increasing economic growth. In recent years the Chinese government has continuously implemented mini-stimulus policies to boost decreasing GDP growth rates[15]. One of the sectors benefitting from these policies has been the housing industry. The People's Bank of China eased lending requirement and cut interest rates in 2016. In addition, to help estate developers raise money for their new projects, the China Securities Regulatory Commission also lifted restrictions on bond and stock sale since 2016 (Bloomberg 2016[16], Bloomberg 2018[17]). As a result, investment in real estate has increased since 2016. In Beijing and Shanghai, more than 50% of investment comes from real estate. The housing stimulus woes also to boost the related industries, including upstream steel and cement, and downstream furniture and textile. Although the growth rate of GDP from 2014 to 2016 was still lower than in previous years, the growth rate stopped decreasing in 2016 and started to increase at a rate

[14] Our dataset starts in 2008, therefore we do not have a sufficient data span to test the so-called Olympic Games effect on air pollution.

[15] See Independent UK 2016: *China's economic growth remains strong but increasing risks revealed:* https://www.independent.co.uk/news/business/news/china-economic-growth-gdp-global-economy-slowdown-stimulus-brexit-a7138111.html

[16] See Bloomberg 2016 *China Banking Official Urges Cut to Required Reserve Ratio:* https://www.bloomberg.com/news/articles/2016-12-28/china-banking-official-says-required-reserve-ratio-should-be-cut

[17] See Bloomberg 2018 *China to Ease Bad-Loan Provision Rules to Support Growth:* https://www.bloomberg.com/news/articles/2018-03-06/china-is-said-to-ease-bad-loan-provision-rules-to-support-growth

of 6.7% in 2016, and 6.9% in the first and second quarter of 2017. One can therefore speculate that the second turning point in Beijing can be generated by the scale effect associated with an increase in GDP growth in the last couple of years. This has profound implications for policymakers in Beijing and suggests that environmental degradation may become serious if growth is further enhanced and more stringent environmental protection is not implemented.

7. Conclusion

This study contributes to the literature on the Urban EKC by examining the relationship between growth and air degradation for Beijing. We focus on the relationship between per capita GDP and PM2.5 concentrations using quarterly data from 2008 to 2017 and including local variables of interest as controls. The data for PM2.5 concentrations are publicly available courtesy of the US embassy, which is deemed to be reliable and provide the earliest continuous records of PM 2.5 concentrations.

Our estimation results support an N-shaped pattern for environment and per capita income in Beijing. Determining the shape of the EKC is important for policy making. Our analysis suggests that after a period of economic growth coupled with improved air quality, Beijing may now be on the verge of a reverse path, where a stimulus to growth causes environmental degradation.

Our analysis has concentrated only on the effect of a few control variables. Further research at city level can include, among others, the share of the manufacturing sector to capture the effect of structural policies towards the protection of the environment (Shen 2006; Diao et al., 2009; Shaw et al., 2016; Kim et al., 2016), the intensity of local resident's campaigns as a proxy for residents' environmental sensitiveness (Asahi and Yakita, 2012), public environmental investment (Diao et al., 2009; Shen 2006; Zhang et al., 2016) and other environmental policies (Diao et al., 2009; He and Wang, 2012; Shaw et al., 2010).

Finally, the major constraint for our analysis has been the availability of city level data for pollution. We expect more research to emerge for Chinese cities as official data quality keep improving.

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